U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES OFFICE

Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances (2015 Update)

W. Goetzler, M. Guernsey, K. Foley, J. Young, G. Chung

June 2016

(This page intentionally left blank)

Preface

The Department of Energy's (DOE) Building Technology Office (BTO), a part of the Office of Energy Efficiency and Renewable Energy (EERE) engaged Navigant Consulting, Inc., (Navigant) to develop this report on commercial appliances. This report is an update to a 2009 report of the same name by including newly available information from the Energy Information Agency's (EIA) 2012 Commercial Buildings Energy Consumption Survey (CBECS) and other industry resources.

The research and development activities identified in this report are Navigant's recommendations to BTO for pursuing in an effort to achieve DOE's energy efficiency goals. Inclusion in this report does not guarantee funding; each technology or research activity must be evaluated in the context of all potential activities that BTO could undertake to achieve their goals.

Prepared for:
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Office
www.eere.energy.gov/buildings

Prepared by:
Navigant Consulting, Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803

William Goetzler
Matt Guernsey
Kevin Foley
Jim Young
Greg Chung

List of Acronyms

ACEEE	American Council for an Energy-Efficient Economy
ADL	Arthur D. Little
AEC	Annual Energy Consumption
AEO	EIA’s Annual Energy Outlook Report
AHLA	American Hotel & Lodging Association
AHRI	Air Conditioning, Heating, and Refrigeration Institute
APSP	Association of Pool & Spa Professionals
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Automated Teller Machine
BEDB	Buildings Energy Data Book
BIL	Basic Impulse Insulation Level
BTO	Building Technologies Office
CARB	California Air Resources Board
CASE	Codes and Standards Enhancement Initiative
CAT	Computed Axial Tomography
CBECS	EIA’s Commercial Building Energy Consumption Survey
CCW	Commercial Clothes Washer
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CHP	Combined Heat and Power
CMELS	Commercial Miscellaneous Electric Loads
COP	Coefficient of Performance
CRT	Cathode Ray Tube
CT	Computed Tomography
CUWCC	California Urban Water Conservation Council
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Agency
EPA	Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
FDD	Fault Detection and Diagnostic
FEMP	Federal Energy Management Program
FSTC	Food Service Technology Center
GWP	Global-Warming Potential
HPWH	Heat Pump Water Heater
HVAC	Heating, Ventilation, and Air Conditioning
HVAC&R	Heating, Ventilation, Air Conditioning, and Refrigeration
ICS	Integral Collector Storage
IOU	Investor-Owned Utility

IT	Information Technology
LBNL	Lawrence Berkeley National Laboratory
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LPG	Liquefied Petroleum Gas
MF	Multi-Family
MFD	Multifunction Devices
MRI	Magnetic Resonance Imaging
NAFEM	North American Association of Food Equipment Manufactures
NOPR	Notice of Proposed Rulemaking
NRA	National Restaurant Association
NRDC	National Resources Defense Council
NREL	National Renewable Energy Laboratory
OPL	On-Premise Laundry
PC	Personal Computer
PCE	Perchloroethylene
POS	Point-of-Service
PV	Photovoltaic
PVC	Polyvinyl chloride
Quad	Quadrillion (10^{15}) Btu
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RMC	Remaining Moisture Content
SCE	Southern California Edison
SEDAC	Smart Energy Design Assistance Center of Illinois
TE	Thermal Efficiency
TEER	Telecommunications Energy Efficiency Ratio
TSD	Technical Support Document
UEC	Unit Energy Consumption
UES	Unit Energy Savings
UPS	Uninterruptible Power Supply
USDC	U.S. Department of Commerce
UV	Ultraviolet
WLAN	Wireless Local Area Network

Executive Summary

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy's (EERE's), Building Technologies Office (BTO) 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 research, development, and demonstration (RD&D) opportunities to improve energy efficiency in each appliance category. For the purposes of this analysis, "commercial appliances" are defined as energy-consuming appliances and equipment used in commercial buildings, excluding heating, ventilation, and air conditioning (HVAC) for space conditioning, building lighting (interior or exterior), commercial refrigeration equipment, and distributed generation systems (including combined heat and power systems).

This report is an update to a 2009 report of the same name, hereafter the "2009 Commercial Appliances Report."[1] As such, this report aims to update the data where possible using newer sources and update the technology options that provide opportunities for efficiency improvements.

ES-1 Energy Consumption

Figure ES-1 provides a breakdown of commercial building primary energy consumption in the U.S. by major end-use categories.[2] According to the 2015 Annual Energy Outlook (AEO), commercial appliances consume 8.94 Quadrillion Btu (10^{15} Btu or Quad), which is nearly 50 percent of annual commercial building energy consumption in the U.S.[3]

[1] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report by Navigant Consulting, Inc., for U.S. Department of Energy. December 2009. Available: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf

[2] 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.

[3] EIA. 2015. "2015 Annual Energy Outlook." U.S. Energy Information Administration. DOE/EIA-0383(2015). April 2015. Available at: http://www.eia.gov/forecasts/aeo/

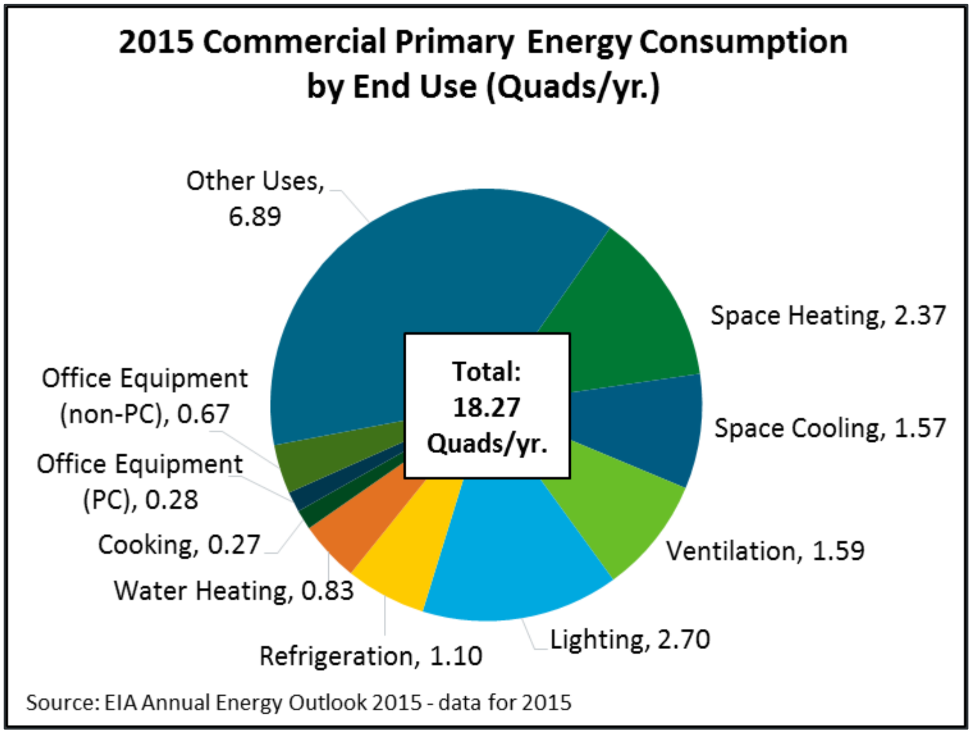
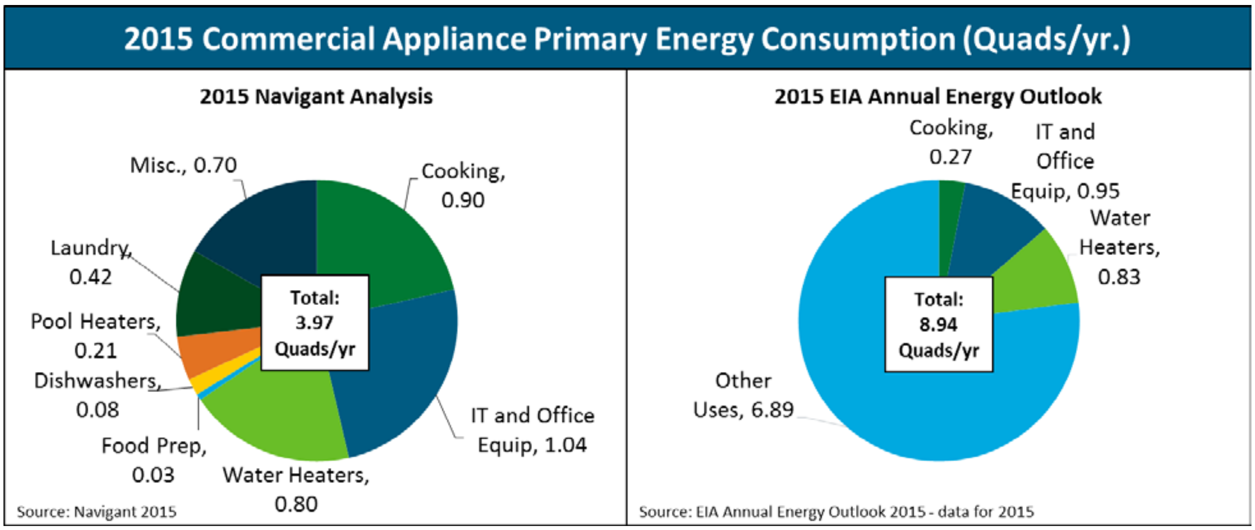


Figure ES-1: 2015 U.S. commercial sector energy consumption

This report analyzes the energy consumption and potential savings for specific end-use technologies within each appliance category, including specific breakdowns for gas-fired and electric equipment where applicable. This analysis includes eight commercial appliance categories:

- **Cooking appliances** – broilers, fryers, griddles, ovens, ranges, steamers, microwave ovens
- **Food preparation appliances** – a variety of electric appliances that aid in the preparation, storage, and serving of cooked food
- **Dishwashers** – undercounter, door-type, conveyor, flight-type
- **Information technology (IT) and office equipment** – personal computers (PCs), desktop monitors, imaging equipment, server computers, network equipment, uninterruptable power supply (UPS)
- **Water heaters** – storage water heaters, instantaneous water heaters, booster heaters, stand-alone water heaters
- **Pool heaters** – for both indoor and outdoor pools
- **Commercial laundry** – single-load, multi-load, and industrial washers and dryers, as well as dry-cleaning equipment
- **Miscellaneous appliances** – medical imaging equipment, vertical-lift technologies, coffee makers, non-refrigerated vending machines, automated teller machines (ATMs), point-of-service (POS) terminals, and distribution transformers.

Figure ES-2 (left side) shows that we estimate 3.97 quads of annual primary annual energy consumption (AEC) in the U.S. from these eight categories of commercial appliances. This value excludes any overlap of hot water energy consumption associated with water heaters, laundry, and dishwashers. Figure ES-2 (right side) shows the Energy Information Administration's (EIA) estimates in related categories in the AEO. In two of the categories characterized in both studies, including water heaters and IT and office equipment, we see good alignment of the data, with minimal variation in estimates between the two sources. Our estimate for cooking is significantly higher than the AEO estimate because of a difference in the estimated installed base of buildings that have food preparation and serving areas. The AEO estimate only includes those buildings in EIA's 2003 Commercial Building Energy Consumption Survey (CBECS) where food service is the principal building activity,[4] whereas we also include buildings in CBECS 2012 that have food preparation and serving areas, but are not primary food service buildings.



Note – 2015 Navigant analysis values for individual appliance categories do not sum due to overlap of hot water heating in both dishwasher and clothes washer operation, which is covered in the energy consumption for water heaters.

Figure ES-2: 2015 commercial appliance primary energy consumption estimates

Overall, AEO estimates a total of 8.94 Quads of primary energy consumption in commercial appliances, which is more than double the consumption documented in this report. While we do not have direct insights into the AEO's "Other Uses" category, we surmise that it includes numerous additional equipment types, such as audio/visual equipment, telecommunications equipment, water distribution equipment, security systems, and other miscellaneous building loads that this study does not address.

Table ES-1 compares the Navigant 2015 estimates and preliminary CBECS estimates for 2012.[5] Since the CBECS data are preliminary at the time of this report's publication, we do not have detailed insights on the underlying CBECS data, so the source of any differences is unclear.[6]

[4] See AEO assumptions, available: https://www.eia.gov/forecasts/aeo/assumptions/pdf/commercial.pdf

[5] During the writing of this report, EIA was analyzing the CBECS 2012 data and released preliminary energy consumption estimates in March 18, 2016.

[6] More detailed energy consumption tables and microdata tables will be available later in 2016.

This comparison provides another example for how different assumptions and end-use groupings can affect commercial appliance estimates.

Table ES-2: Source Energy Consumption by Data Source (Quads/yr.)

Building End-Use	Navigant 2015	CBECS 2012
Water Heating	0.80	0.53
Cooking	0.90	0.72
IT & Office Equipment	1.04	1.82
Other	1.23	2.52

Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

Figure ES-3 shows the estimates of primary energy consumption for cooking and food preparation equipment (0.93 Quads total) by the individual appliances types. Fryers consume the greatest amount of energy at 0.33 Quads. Of these appliances, natural gas accounts for 55% (0.51 Quads) of primary energy. Even with a large number of individual products, food preparation equipment has limited national energy consumption due to the low operating times for most appliance types.

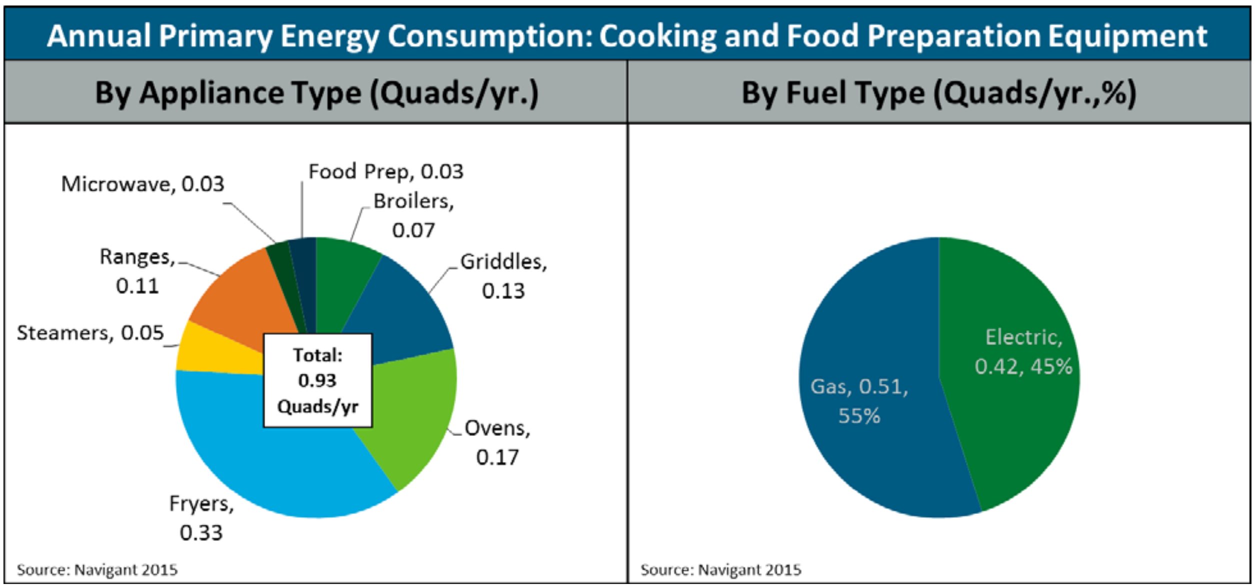


Figure ES-3: 2015 energy consumption estimates for cooking and food preparation equipment

Figure ES-4 shows the estimates of primary energy consumption for water heaters and pool heaters (1.01 Quads total). Gas-fired equipment constitutes over 60% of the primary energy consumption in this category. Gas-fired products constitute nearly 100% of the pool heater market.

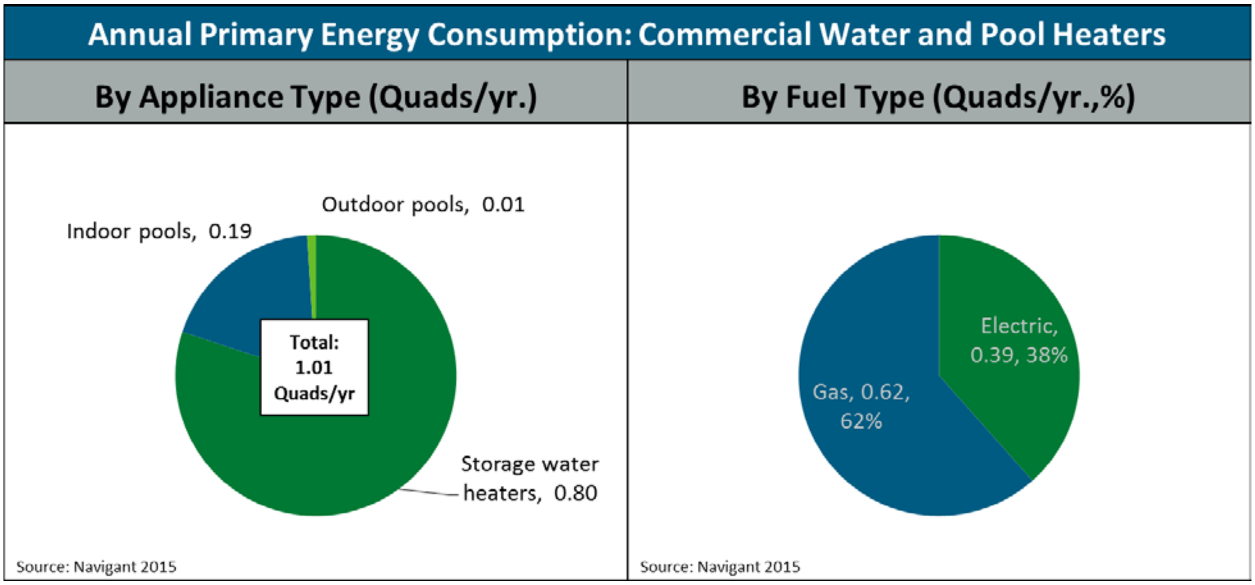


Figure ES-4: 2015 energy consumption estimates for commercial water and pool heaters

Figure ES-5 shows the estimates of primary energy consumption for the four types of common commercial dishwashers, as well as the split of this energy use associated with the building water heater versus the appliance itself (i.e., booster heater and machine energy consumption). In total, commercial dishwashers consume 0.18 Quads of primary energy annually. When excluding building water heater usage, dishwashers consume 0.08 Quads per year. More than 75% of the energy used for dishwashing is electric energy because all dishwashers require electricity to operate their controls, pumps, and motors, and because approximately 95% high-temperature dishwashers use electric booster heaters to bring the building's service water temperature up to 180°F.

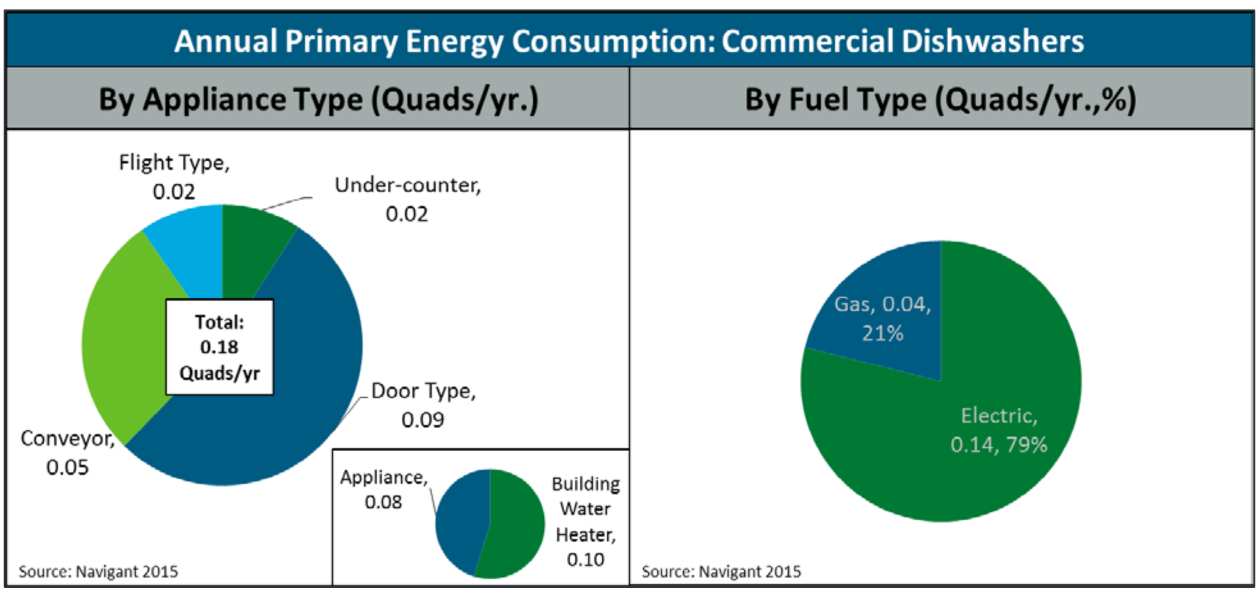


Figure ES-5: 2015 energy consumption estimates for commercial dishwashers

Figure ES-6 shows the estimates of primary energy consumption for commercial laundry equipment, including clothes washers, clothes dryers, and dry-cleaning. In total, commercial laundry equipment consumes a total of 0.42 Quads of primary energy annually. Approximately 50% of this energy is for the building water heater; therefore, the laundry equipment itself consumes 0.21 Quads per year. The largest end-use segments are multi-load washers and dryers (0.32 Quads combined, including building water heating); multi-load dryers have the largest energy consumption when excluding building water heater energy use. Natural gas accounts for approximately 88% of energy consumption in this category to supply hot water for washing, and hot air for drying.

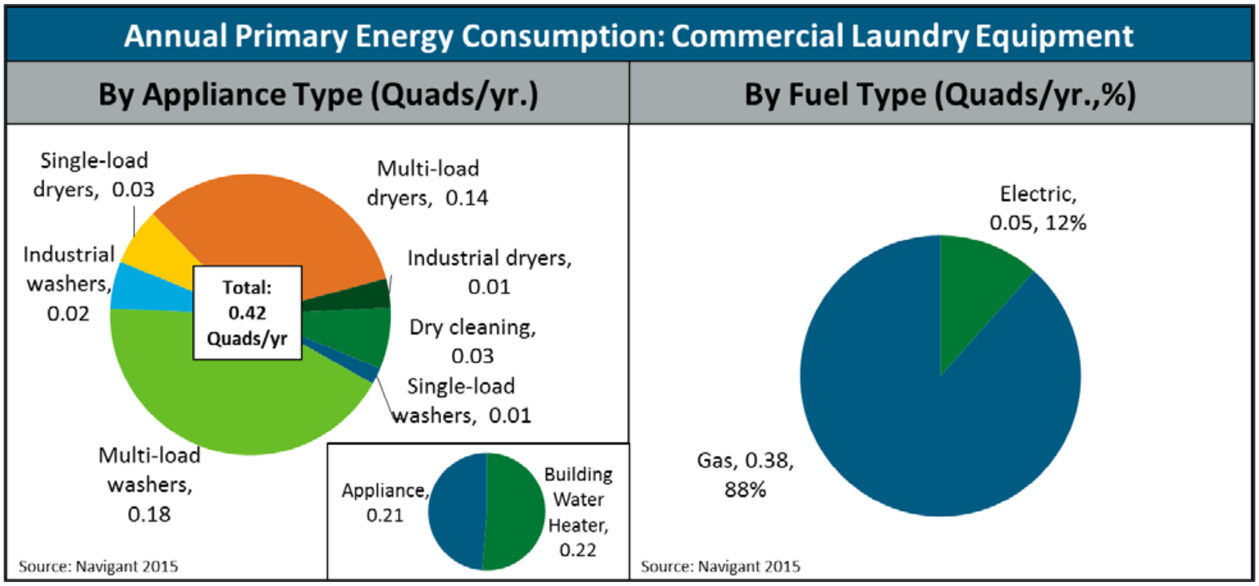


Figure ES-6: 2015 energy consumption estimates for commercial laundry equipment

Figure ES-7 shows the estimates of primary energy consumption for IT and office equipment, which together consume 1.04 Quads of primary energy annually. While computers and monitors and other equipment have become more energy efficient in recent years, the increase in installed base of server computers and network equipment has generated an increase in the total primary energy consumption for this category.

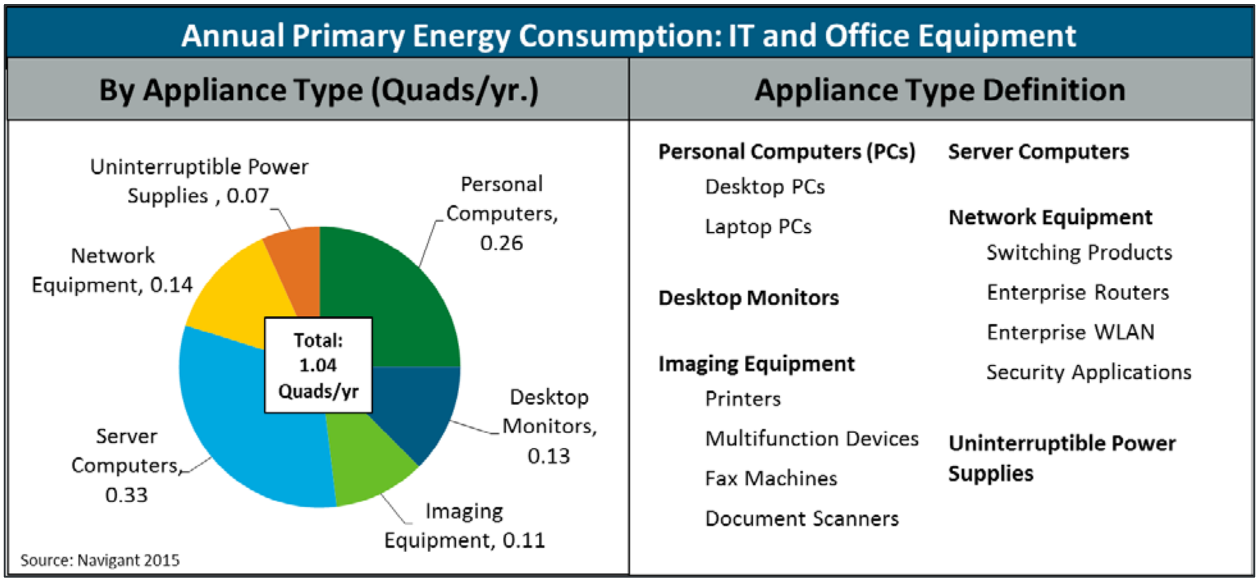


Figure ES-7: 2015 energy consumption estimates for IT and office equipment

Figure ES-8 shows the estimates of primary energy consumption for the miscellaneous commercial appliances evaluated in this report, including distribution transformers, medical imaging equipment, vertical-lift technologies and other "plug-loads." Together these appliances consume a total of 0.70 Quads of primary energy per year with distribution transformers within commercial buildings constituting over 65% (0.48 Quads) of the category total. This report documents many of the largest miscellaneous loads in commercial buildings, but does not cover all, or even all the largest, miscellaneous commercial appliances. As a comparison, our estimate makes up 23% of the miscellaneous equipment estimate from the 2008 BEDB.[7] This more-than 2 Quad difference suggests miscellaneous building loads could be one of the key differences between our total commercial appliance estimates and the AEO total estimates.

[7] DOE. 2008. "2008 Buildings Energy Data Book." U.S. Department of Energy. November 2008.

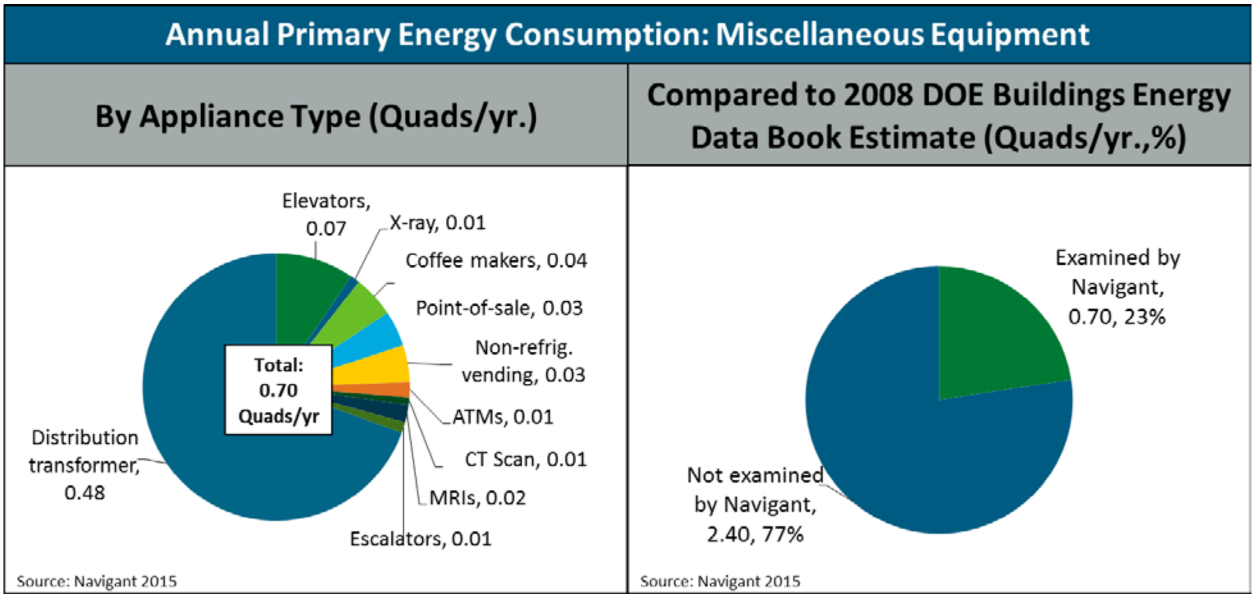


Figure ES-8: 2015 energy consumption estimates for miscellaneous commercial appliances

ES-2 Comparison to 2009 Commercial Appliances Report

Figure ES-9 compares the annual primary energy consumption estimates from this study to that of the 2009 Commercial Appliances Report, for which this report is an update. The 2009 Commercial Appliances Report documented 2.92 Quads of primary energy consumption; this report documents 3.97 Quads or 36% more, which reflects increases in consumption as well as coverage of additional end-uses. Each category, except laundry, shows an increase since 2009, with notably large increases in cooking, pool heaters, and miscellaneous loads:

- Cooking has a significant increase of 0.38 Quads (73%), due primarily to a change in calculation methodology that we believe better reflects actual consumption. As previously discussed, we expanded the installed base to include buildings with food preparation and serving areas but do not list food service as their principal building activity (e.g., a hospital with a cafeteria).
- Pool heater energy consumption nearly doubled since 2009 with a 0.11 Quad (110%) increase because newly available market data for swimming pool penetration in lodging facilities showed a significantly higher installed base.
- Laundry equipment decreased by 0.05 Quads (19%, which excludes overlap with hot water loads) based on changes in the calculation methodology to use newly available information sources.
- Miscellaneous building loads increased by 0.50 Quads (250%) primarily due to the inclusion of building distribution transformers (0.48 Quads).

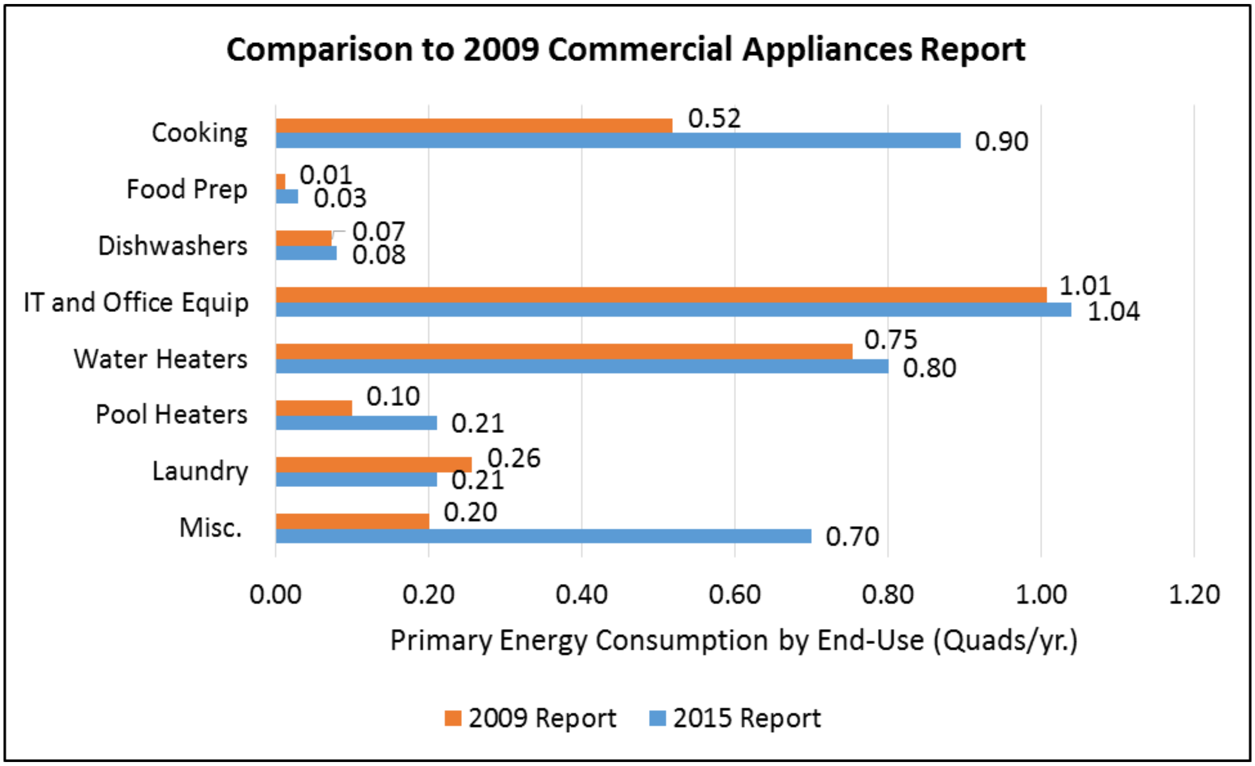


Figure ES-9: Comparison to 2009 Commercial Appliance Report

ES-3 Energy Savings Opportunities

This analysis also identified commercially available and emerging technologies that could offer energy savings for each appliance category. Figure ES-10 shows the technical potential[8] for each profiled technology, grouped by appliance category. These technologies offer energy savings over products meeting today's minimum efficiency standards or other specifications.

[8] 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 (i.e., 100% adoption). 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.

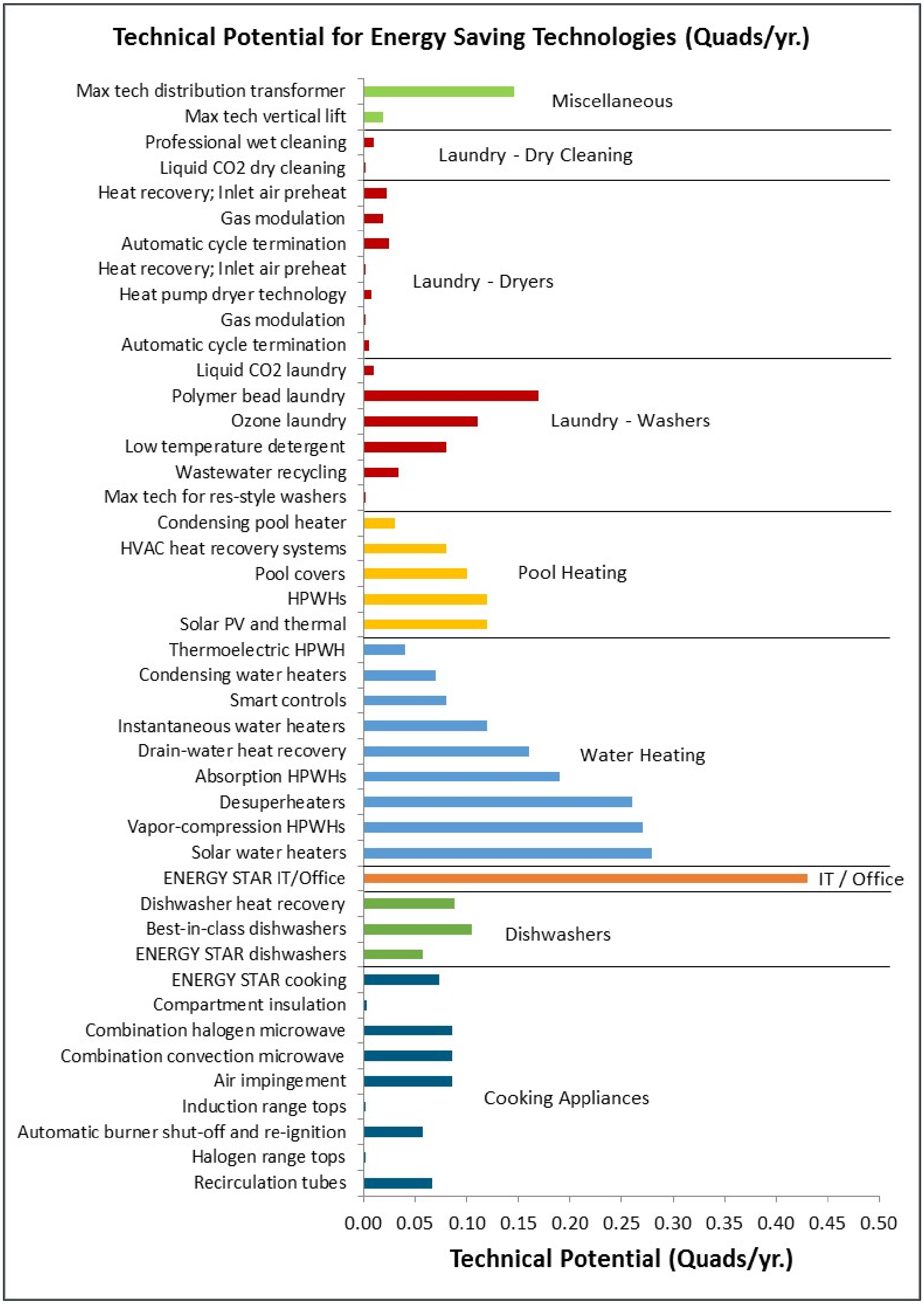
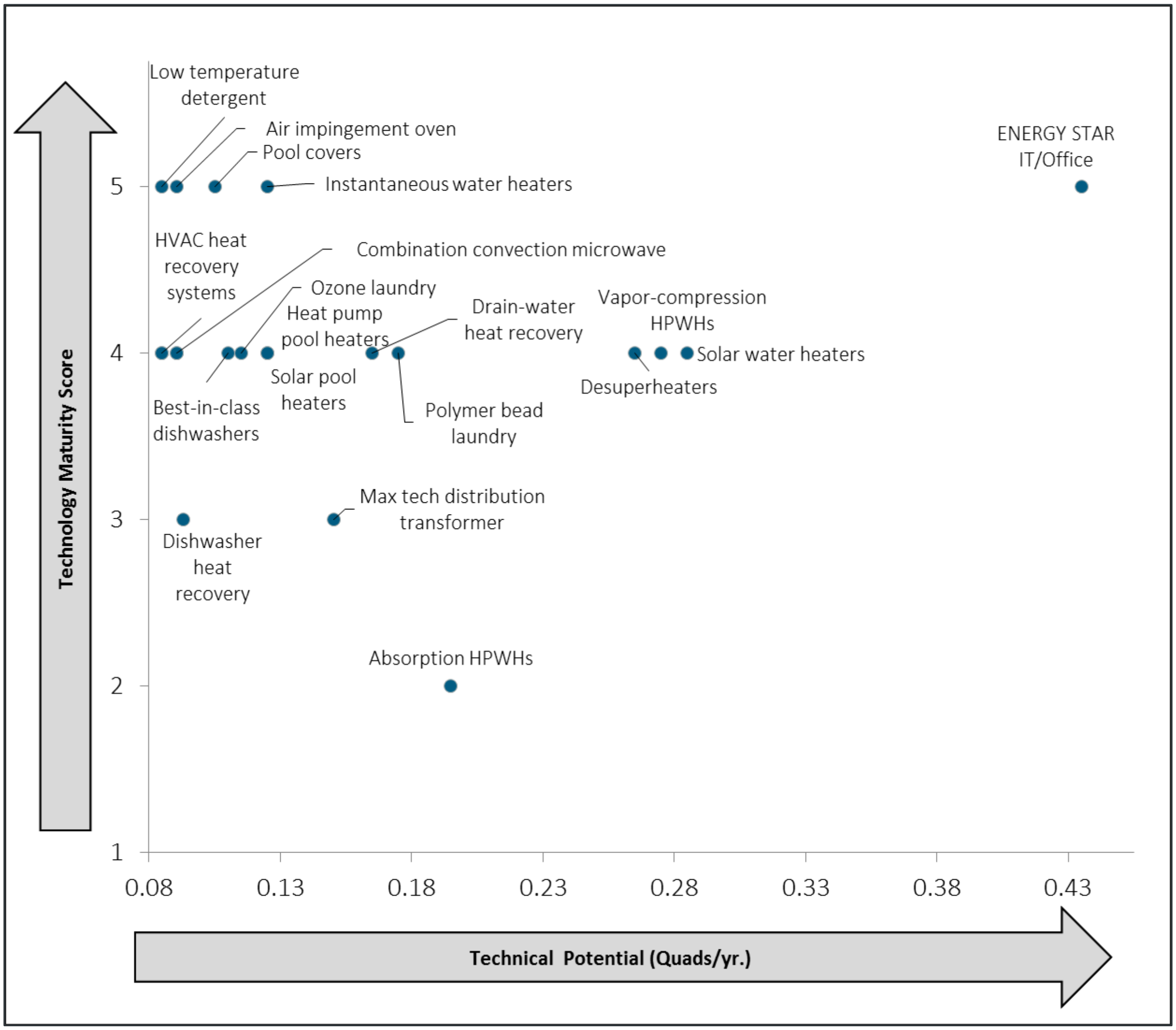


Figure ES-10: Technical potential for energy-saving technologies

Figure ES-11 plots each technology according to technology maturity and technical potential. Technology maturity ratings are based on the authors' judgement through a review of available products on the market, current RD&D efforts, and other resources.



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 in application, possibly in pilot stage or development

2 - Long Term: Proven technology though only in a lab setting or based on engineering fundamentals

1 - R&D: Unproven technology for application, energy savings is a preliminary estimate, costs are uncertain.

Note: Only selected technology labels are displayed for figure clarity.

Figure ES-11: Technology maturity and technical potential for energy-saving technologies

As Figure ES-11 shows, most of the energy savings potential resides in technologies that are already on the market today (represented by a 4 or 5 score, e.g., ENERGY STAR IT and office products, solar water heaters, instantaneous water heaters). However, in some of these cases, the technologies may not be widely used in the targeted application, and some design, demonstration, and marketing work may be needed to increase the technology's adoption. For example, low-temperature detergents for commercial laundry facilities, ENERGY STAR dishwashers for leasing agents to food service buildings, or indoor pool covers are all available energy-saving technologies, but still are underutilized in the marketplace. In these cases, RD&D activities would focus on reducing installation, operation, and maintenance complexity, performing field demonstrations at commercial buildings, and marketing the benefits to key stakeholders such as utility energy efficiency programs and regional efficiency organizations.

Emerging technologies (represented by a technological maturity score of 2 or 3) such as absorption heat pump water heaters, desuperheaters coupled with packaged HVAC equipment, and polymer bead laundry show large technical potentials, but require further RD&D before product introduction and/or wide adoption. In these cases, RD&D activities would focus on proving technical performance relative to baseline technologies, reducing technology cost to decrease cost premiums and payback times, and facilitating connections between researchers, manufacturers, retailers, and system designers for successful product launch.

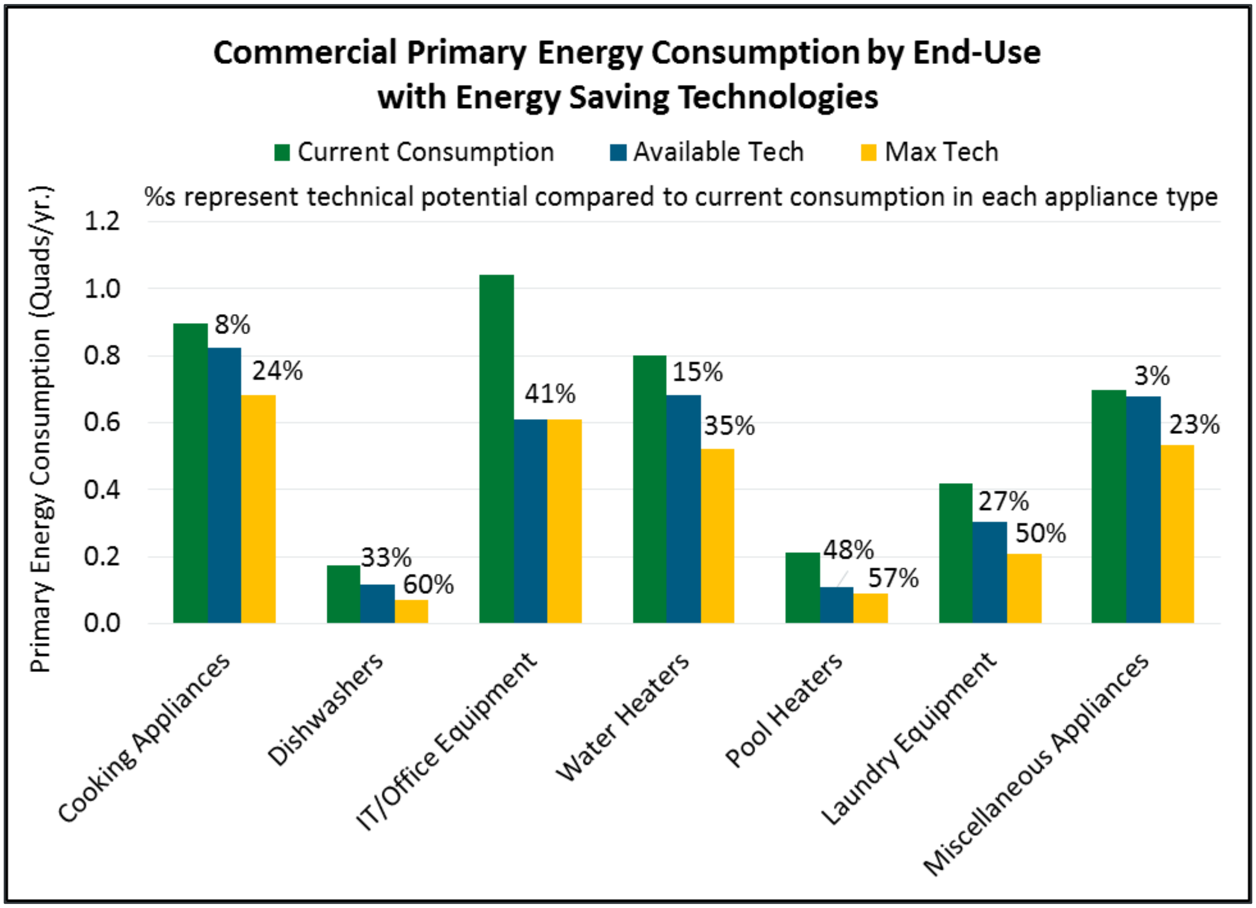
Table ES-3 and Figure ES-12 outline the technical savings potential (i.e., assuming 100% adoption) for the most promising available technologies and separately, emerging (i.e., max tech) technologies. In most commercial appliance categories, technologies exist today that can significantly improve the energy efficiency of commercial buildings. As shown in Figure ES-12, energy-saving technologies available today could reduce commercial appliance consumption by 22% overall (with a range of 3-48% among the categories) compared to technologies on the market today meeting minimum efficiency standards. Programs such as EPA's ENERGY STAR, DOE's Federal Energy Management Program (FEMP), and utility incentive programs help commercial building operators and designers identify energy-saving opportunities and reduce project cost and complexity.

Max tech technologies represent the additional energy savings that products currently in the research and development (R&D) stage or those waiting for a breakthrough could provide to commercial buildings. As shown in Figure ES-12, emerging technologies could surpass the energy saving of today's efficient products and save 36% (with a range of 23-60%) compared to baseline technologies on the market today. These opportunities require additional RD&D effort to reach the marketplace with acceptable costs, payback, and complexity.

Table ES-3: Technical Potential for Energy Savings Technologies by Commercial End-Use

End-Use	Current Consumption (Quads/yr.)	Available		Max Tech	
		Technology Name(s)	Energy Savings (Quads/yr.)	Technology Name(s)	Energy Savings (Quads/yr.)
Cooking Appliances	0.90	ENERGY STAR cooking equipment	0.07	Fryer recirculation tubes, automatic range burner control, air impingement ovens, steamer compartment insulation	0.21
Dishwashers	0.18	ENERGY STAR dishwashers	0.06	Best-in-class dishwashers	0.11
IT/Office Equipment	1.04	ENERGY STAR IT/Office equipment	0.43	ENERGY STAR IT/Office equipment	0.43
Water Heaters	0.80	Instantaneous water heaters	0.12	Solar water heaters	0.28
Pool Heaters	0.21	Pool covers	0.10	Heat pump pool heaters	0.12
Laundry Equipment	0.42	Max tech for residential washers, low-temperature detergent, automatic dryer cycle termination, gas dryer modulation, professional wet cleaning	0.11	Max tech for residential washers, polymer bead laundry, heat pump dryer, heat recovery, professional wet cleaning	0.21
Misc. Appliances	0.70	Max tech vertical-lift technologies	0.02	Max tech vertical-lift technologies, max tech distribution transformer	0.16

Note - dishwasher and clothes washer consumption and savings includes the energy associated with building's water heater



Note – energy savings estimates reflect energy efficiency improvements over today's baseline products meeting minimum efficiency standards rather than the typical installed base. Actual savings may be higher as today's standards are higher efficiency than typical installed base.

Figure ES-12: Commercial primary energy consumption by end-use with energy-saving technologies

This report provides a detailed look at each of these technology categories, including the basis for our energy consumption and installed base estimates, as well as discussion of the energy savings opportunities for each technology.

Table of Contents

Preface ii
List of Acronyms iii
Executive Summary v
ES-1 Energy Consumption v
ES-2 Comparison to 2009 Commercial Appliances Report xii
ES-3 Energy Savings Opportunities xiii
Table of Contents xix
1 Introduction 1
1.1 Report Organization 1
1.2 Background 3
1.3 Trends 4
1.4 Objectives 6
1.5 Approach 6
1.5.1 Baseline Technology 7
1.5.2 Unit Energy Consumption (UEC) 7
1.5.3 National Energy Consumption 7
1.5.4 Unit Energy Savings (UES) 7
1.5.5 Technical Potential 8
2 Commercial Cooking Appliances 9
2.1 Market Overview 9
2.1.1 Manufacturers 9
2.1.2 Major End-Users 11
2.1.3 Equipment Purchase Decision-Making 11
2.2 Annual Shipments and Installed Base 13
2.2.1 Annual Shipments 13
2.2.2 Installed Base 13
2.3 Product Cost Breakdown 18
2.4 Baseline Energy Consumption 18
2.5 Comparison of Baseline Energy Consumption to Previous Studies 21
2.6 Energy Savings Opportunities 24
2.6.1 Energy Consumption and Savings Percentage 24
2.6.2 Energy Savings Technologies 25
2.7 Regulated and Voluntary Efficiency Standards 27
3 Commercial Food Preparation 29
3.1 Market Overview 29
3.2 Annual Shipments and Installed Base 30
3.2.1 Annual Shipments 30
3.2.2 Installed Base 30
3.3 Product Cost Breakdown 31
3.4 Baseline Energy Consumption 32
3.5 Energy Savings Opportunities 34
3.6 Regulated and Voluntary Efficiency Standards 34
4 Commercial Dishwashers 36
4.1 Market Overview 37
4.2 Annual Shipments and Installed Base 38
4.2.1 Annual Shipments 38

4.2.2 Installed Base ... 39
4.3 Product Cost Breakdown ... 43
4.4 Baseline Energy Consumption ... 43
4.5 Comparison of Baseline Energy Consumption to Previous Studies ... 49
4.6 Energy Savings Opportunities ... 49
4.7 Regulated and Voluntary Efficiency Standards ... 52
5 IT and Office Equipment ... 54
5.1 Market Overview ... 56
5.1.1 Personal Computers ... 56
5.1.2 Desktop Monitors ... 57
5.1.3 Imaging Equipment ... 58
5.1.4 Network Equipment ... 59
5.1.5 Server Computers ... 62
5.1.6 Uninterruptible Power Supplies ... 62
5.2 Annual Shipments and Installed Base ... 62
5.2.1 Annual Shipments ... 62
5.2.2 Installed Base ... 63
5.3 Product Cost Breakdown ... 64
5.4 Baseline Energy Consumption ... 65
5.5 Comparison of Baseline Energy Consumption to Previous Studies ... 66
5.6 Energy Savings Opportunities ... 68
5.6.1 Energy Consumption and Savings Percentage ... 68
5.6.2 Energy Savings Technologies ... 70
5.7 Regulated and Voluntary Efficiency Standards ... 71
6 Commercial Water Heaters ... 73
6.1 Market Overview ... 73
6.2 Annual Shipments and Installed Base ... 74
6.2.1 Annual Shipments ... 74
6.2.2 Installed Base Estimates ... 76
6.3 Product Cost Breakdown ... 79
6.4 Baseline Energy Consumption ... 80
6.5 Comparison of Baseline Energy Consumption to Previous Studies ... 83
6.6 Energy Savings Opportunities ... 84
6.6.1 Smart Controls ... 85
6.6.2 Drain-Water Heat Recovery ... 86
6.6.3 Desuperheaters ... 87
6.6.4 Instantaneous Water Heaters ... 89
6.6.5 Condensing Water Heaters ... 91
6.6.6 Vapor-Compression HPWHs ... 92
6.6.7 Solar Water Heaters ... 94
6.6.8 Absorption HPWHs ... 96
6.6.9 Thermoelectric HPWHs ... 97
6.7 Regulated and Voluntary Efficiency Standards ... 99
7 Commercial Pool Heaters ... 101
7.1 Market Overview ... 101
7.2 Annual Shipments and Installed Base ... 101
7.2.1 Annual Shipments ... 101

7.2.2 Installed Base 102
7.3 Product Cost Breakdown 105
7.4 Baseline Energy Consumption 106
7.5 Comparison of Baseline Energy Consumption to Previous Studies 107
7.6 Energy Savings Opportunities 108
7.6.1 Solar Pool Heaters 109
7.6.2 Heat Pump Pool Heaters 110
7.6.3 Pool Covers 111
7.6.4 HVAC Heat Recovery Systems 112
7.6.5 Condensing Pool Heaters 113
7.6.6 Development Status for Commercial Pool Heating Technologies 113
7.7 Regulated and Voluntary Efficiency Standards 114
8 Commercial Laundry Equipment 115
8.1 Market Overview 117
8.1.1 Washers 117
8.1.2 Dryers 118
8.1.3 Dry-Cleaning Equipment 119
8.2 Annual Shipments and Installed Base 119
8.2.1 Annual Shipments 119
8.2.2 Installed Base 121
8.3 Product Cost Breakdown 122
8.4 Baseline Energy Consumption 124
8.4.1 Unit Energy Consumption 124
8.4.2 Primary Energy Consumption 126
8.5 Comparison of Baseline Energy Consumption to Previous Studies 128
8.5.1 Installed Base Comparison 128
8.5.2 Energy Consumption Comparison 129
8.6 Energy Savings Opportunities 131
8.6.1 Commercial Washer Energy Savings Opportunities 131
8.6.2 Commercial Dryer Energy Savings Opportunities 135
8.6.3 Dry-Cleaning Alternatives and Energy Savings Opportunities 138
8.7 Regulated and Voluntary Efficiency Standards 143
8.7.1 Regulated Efficiency Standards 143
8.7.2 Voluntary Efficiency Standards 144
9 Miscellaneous End-Use Services and Equipment 145
9.1 Market Overview 146
9.1.1 Medical Imaging Equipment 146
9.1.2 Vertical-Lift Technologies 146
9.1.3 Coffee Makers 146
9.1.4 Non-Refrigerated Vending Machines 146
9.1.5 Automated Teller Machines 146
9.1.6 Point-of-Service Terminals 148
9.1.7 Distribution Transformers 148
9.2 Annual Shipments and Installed Base 149
9.3 Product Cost Breakdown 151
9.4 Baseline Energy Consumption 151
9.5 Comparison of Baseline Energy Consumption to Previous Studies 155

9.6 Energy Savings Opportunities ... 157
9.6.1 Vertical-Lift Technologies ... 157
9.6.2 Distribution Transformers ... 157
9.7 Regulated and Voluntary Efficiency Standards ... 158
9.7.1 Medical Imaging Equipment ... 158
9.7.2 Vertical-Lift Technologies ... 158
9.7.3 Coffee Makers ... 158
9.7.4 Non-Refrigerated Vending Machines ... 158
9.7.5 Automated Teller Machines ... 159
9.7.6 Point-of-Service Terminals ... 159
9.7.7 Distribution Transformers ... 159
10 Appendix A: Technology Descriptions ... 162
10.1 Commercial Cooking Appliances ... 162
10.1.1 Fryers ... 162
10.1.2 Broilers ... 164
10.1.3 Griddles ... 166
10.1.4 Ovens ... 167
10.1.5 Ranges ... 171
10.1.6 Steamers ... 172
10.1.7 Microwave Ovens ... 174
10.2 Commercial Food Preparation ... 174
10.3 Commercial Dishwashers ... 175
10.3.1 Washing Strategies ... 176
10.3.2 Dishwasher Types ... 176
10.4 IT and Office Equipment ... 179
10.4.1 Personal Computers ... 179
10.4.2 Desktop Monitors ... 179
10.4.3 Server Computers ... 180
10.4.4 Imaging Equipment ... 180
10.4.5 Uninterruptible Power Supply ... 180
10.4.6 Network Equipment ... 181
10.5 Water Heaters ... 181
10.5.1 Storage Water Heaters ... 181
10.5.2 Instantaneous Water Heaters ... 183
10.5.3 Booster Heaters ... 184
10.5.4 Stand-Alone Water Heaters ... 184
10.6 Pool Heaters ... 185
10.7 Commercial Laundry ... 186
10.7.1 Single-Load Commercial Washers ... 186
10.7.2 Multi-load Washers / Washer Extractors ... 189
10.7.3 Single-Load Commercial Dryers ... 189
10.7.4 Multi-load Commercial Dryers ... 190
10.7.5 Dry-Cleaning Equipment ... 191
10.8 Miscellaneous End-Use Equipment ... 193
10.8.1 Medical Imaging Equipment ... 193
10.8.2 Elevators and Escalators ... 195
10.8.3 Coffee Makers ... 197

10.8.4 Non-Refrigerated Vending Machines 198
10.8.5 Automated Teller Machines 198
10.8.6 Point-of-Service Terminals 199

(This page intentionally left blank)

1 Introduction

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy's (EERE's), Building Technologies Office (BTO) 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
- Summarize market, technical, and economic information for each commercial appliance category where available.

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

BTO last characterized commercial appliance energy use in 2009 in a report called "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances."[9] This study is an update to that report, hereafter the "2009 Commercial Appliances Report." As such, this report aims to update the data where possible using newer sources and update the technology options that provide energy-saving opportunities. Even since 2009, the commercial appliance landscape has changed significantly, especially for information technology (IT) and office equipment, and new market information is available from U.S. Energy Information Agency's (EIA's) Commercial Building Energy Consumption Survey (CBECS) 2012 and other industry sources. Therefore, BTO determined it needed an updated characterization upon which to help guide their emerging technologies research and development (R&D) efforts.

1.1 Report Organization

Table 1-1 summarizes the contents in each section of the report.

[9] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report by Navigant Consulting, Inc., for U.S. Department of Energy. December 2009. Available: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf

Table 1-1: Report Organization

Section	Content / Purpose
Executive Summary	Top-level report summary on energy consumption, comparison to 2009 Commercial Appliances Report, and energy savings opportunities
1	Introduction (scope, background, trends, objectives, and approach)
2	Commercial cooking appliances
3	Commercial food preparation
4	Commercial dishwashers
5	IT and office equipment
6	Commercial water heaters
7	Commercial pool heaters
8	Commercial laundry equipment
9	Miscellaneous end-use services and equipment
Appendix A	Detailed technology descriptions for each of the covered technology categories

The majority of this report consists of individual analyses for each commercial appliance category, with each category's analysis contained within its own section. Each analysis contains some or all of the following topics (where applicable):

- Market overview
- Annual shipments
- Installed base
- Product cost breakdown
- Baseline energy consumption
- Comparison of baseline energy consumption to previous studies
- Energy savings opportunities
- Regulated and voluntary efficiency standards.

In addition, the Executive Summary section summarizes the key findings from each analysis, including:

- Primary energy consumption for commercial appliances profiled in this report
- Comparison of baseline energy consumption in 2015 to estimates in the 2009 Commercial Appliances Report
- Technical potential for energy savings opportunities
- Primary energy consumption for commercial appliances if each category adopted the most promising available and emerging (i.e., max tech) technologies.

1.2 Background

Commercial appliances encompass a broad range of appliances and equipment categories and constitute a significant portion of commercial building energy consumption. Figure 1-1 shows that commercial appliances and water heaters represent nearly 50 percent (8.94 Quads[10]) of U.S. commercial building primary energy consumption in 2015 according to EIA's Annual Energy Outlook (AEO).[11]

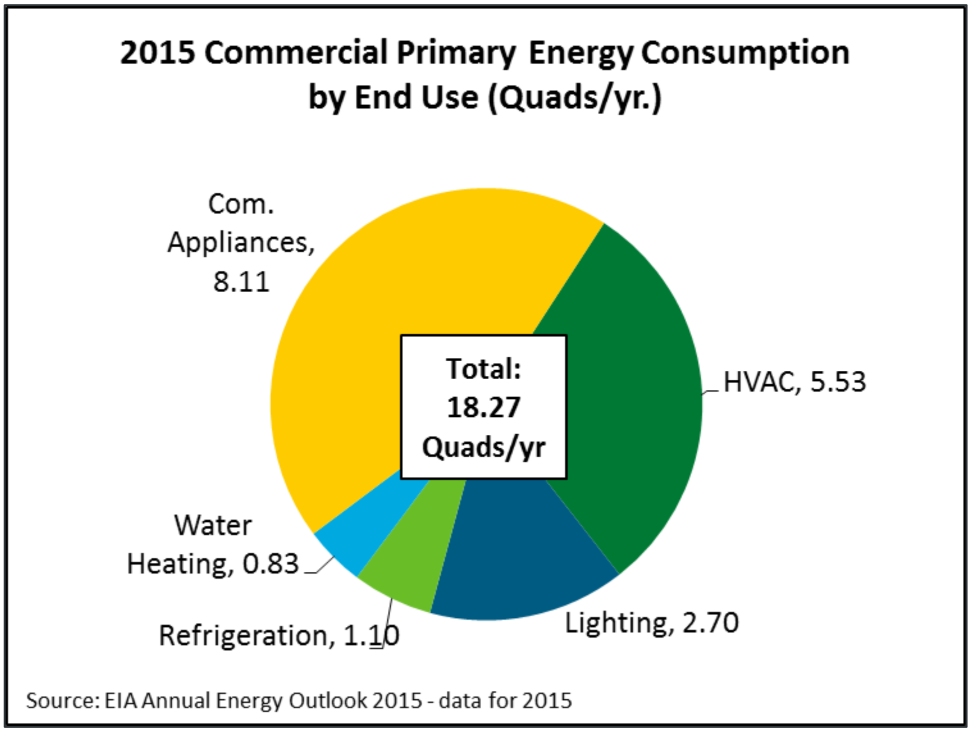


Figure 1-1: 2015 U.S. commercial sector primary energy consumption

This report analyzes the energy consumption and potential savings for specific end-use technologies within each appliance category, including specific breakdowns for gas-fired and electric equipment where applicable. This analysis includes eight commercial appliance categories:

- **Cooking appliances –** broilers, fryers, griddles, ovens, ranges, steamers, microwave ovens
- **Food preparation appliances –** a variety of electric appliances that aid in the preparation, storage, and serving of cooked food
- **Dishwashers –** undercounter, door-type, conveyor, flight-type
- **IT and office equipment –** PCs, desktop monitors, imaging equipment, server computers, network equipment, uninterruptible power supplies (UPS)

[10] Quadrillion Btu or 10^{15} Btu
[11] EIA. 2015. "2015 Annual Energy Outlook." U.S. Energy Information Administration. DOE/EIA-0383(2015). April 2015. Available at: http://www.eia.gov/forecasts/aeo/

- **Water heaters –** storage water heaters, instantaneous water heaters, booster heaters, stand-alone water heaters
- **Pool heaters –** for both indoor and outdoor pools
- **Commercial laundry** – single-load, multi-load, and industrial washers and dryers, as well as dry-cleaning equipment
- **Miscellaneous appliances –** medical imaging equipment, vertical-lift technologies, coffee makers, non-refrigerated vending machines, ATMs, POS terminals, and distribution transformers.

1.3 Trends

A review of AEO data shows that commercial building appliance energy consumption has increased 0.68 Quads (9%) from 7.43 Quads in 2010[12] to 8.11 Quads in 2015.[13,14] While some increase in appliance energy consumption is due to growth in floorspace, a greater portion of the growth is due to increasing use and increasing prevalence of commercial appliances. During the same period (2010-2015), AEO shows commercial floorspace has only increased by 3.6%, or 3 billion ft^2 to a total of 84.1 billion ft^2. Figure 1-2 shows the growth in commercial building floorspace over the last 30 years from EIA's CBECS. Because the most recent CBECS data is from 2012 (published in 2015), we estimate the value for 2015 based on a linear regression of the historical data (blue line). Historically, the annual growth rate for commercial floorspace since 1986 is 1.6%.

[12] AEO 2012 Table A5 (2010 data), EIA. 2012. "2012 Annual Energy Outlook." U.S. Energy Information Administration. DOE/EIA-0383(2012). June 2015.

[13] AEO 2015 Commercial sector energy consumption estimate for 2015, EIA. 2015. "2015 Annual Energy Outlook." U.S. Energy Information Administration. DOE/EIA-0383(2015). April 2015.

[14] Note – this report analyzes eight key commercial appliance categories that cover only a subset of the total commercial appliance energy consumption. Therefore, the estimates for all commercial appliances by AEO and other sources will be larger than the estimates in this report.

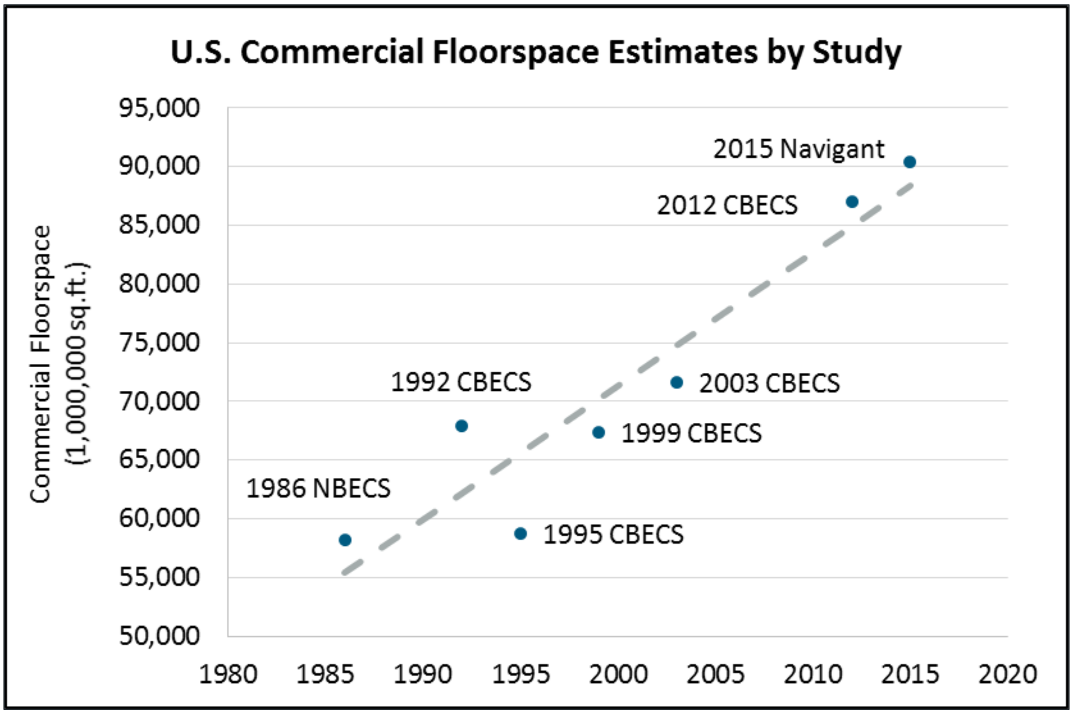


Figure 1-2: U.S. commercial floorspace estimates by study

Figure 1-3 compares the annual primary energy consumption estimates from this study to that of the 2009 Commercial Appliances Report, for which this report is an update. In total, commercial appliance energy consumption estimates increased from 2.92 Quads in 2009 to 3.97 Quads or 36% more, which reflects increases in consumption as well as coverage of additional end-uses. Each category shows an increase since 2009, with notably large increases in cooking, pool heaters, and miscellaneous loads, and a decrease in laundry (excluding overlap from water heating loads):

- Cooking has a significant increase of 0.38 Quads (73%), due primarily to a change in calculation methodology that we believe better reflects actual consumption. As previously discussed, we expanded the installed base to include buildings with food preparation and serving areas but do not list food service as their principal building activity.
- Pool heater energy consumption essentially doubled with a 0.11 Quad (110%) increase because newly available market data for swimming pool penetration in lodging facilities showed a significantly higher installed base.
- Laundry equipment decreased by 0.05 Quads (19%) based on changes in the calculation methodology to use newly available information sources.
- Miscellaneous building loads increased by 0.50 Quads (250%) primarily due to the inclusion of building distribution transformers (0.48 Quads).

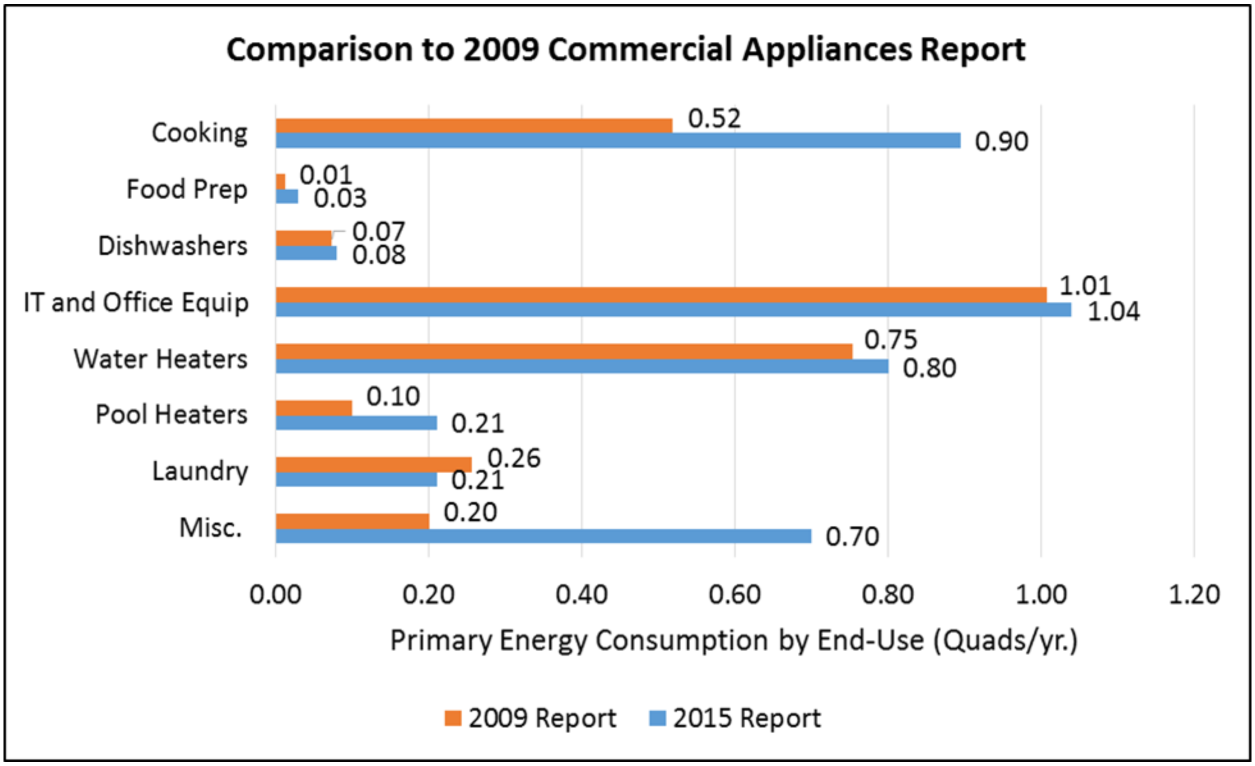


Figure 1-3: Comparison to 2009 Commercial Appliance Report

1.4 Objectives

The primary objectives of this study were to document the energy consumed by various commercial end-use equipment types within several major appliance categories and identify energy-saving technologies that could improve energy efficiency in each appliance category. Additionally, the study provides updated market, technical, and economic information for each commercial appliance category where available.

1.5 Approach

In general, we developed energy consumption and savings estimates through the following approach:

- Develop a unit energy consumption (UEC) estimate for baseline technologies using available information on average capacity, operating hours, fuel types, etc.
- Develop a national installed base estimate using CBECS data, shipments history, market penetration estimates, expected replacement cycles, and other information.
- Calculate national annual energy consumption (AEC) estimates by multiplying the UEC estimate and national installed base estimate for different equipment types, fuel types, building types, etc.
- Review third-party sources to develop the unit energy savings (UES) for energy savings opportunities.

- Calculate the technical potential for each energy savings opportunity by multiplying the UES by the relevant AEC.

This is a general approach; however, no single approach covered the wide range of commercial appliance types analyzed in this report. Often, the availability and quality of information for any given appliance varied substantially, even within the same general category. Therefore, we had to tailor our approach for individual appliances based on the available information. Each section of this report details the approach and information sources used to develop UEC, installed base, AEC, and other estimates.

The following subsections outline several of the key aspects to our underlying approach.

1.5.1 Baseline Technology

We developed an estimate for the energy consumption of the each appliance type and product category using available information on the typical efficiency and operating characteristics of the installed base.

1.5.2 Unit Energy Consumption (UEC)

Using primarily third-party sources, we estimate the UEC for a product employing the baseline technology. The actual UEC for appliances will vary substantially based on climate, capacity, operating hours, and other site-specific concerns. The UEC estimates represent the average energy consumption for a given commercial appliance in the U.S. Where available, we breakdown UEC estimates based on specific sub-segments in each appliance category (e.g., building type, equipment type, fuel type).

1.5.3 National Energy Consumption

National AEC estimates are calculated by multiplying the UEC estimate and national installed base estimate, developed using CBECS data, shipments history, market penetration estimates, expected replacement cycles, and other methods. AEC is expressed in primary energy[15] for each analysis in addition to site energy values. For hot water consuming appliances, we also separated AEC associated with the equipment itself and the building's water heater.

1.5.4 Unit Energy Savings (UES)

We developed UES estimates based on review of third-party sources such as ENERGY STAR specifications, research reports, and manufacturer literature. We developed a UES percentage for each energy savings opportunity and specified applicable equipment types (e.g., equipment type, fuel type) where necessary. These UES percentages represent efficiency improvements compared to products meeting federal, state, or other energy efficiency standards, rather than the average efficiency for the installed base. Since new equipment is generally more efficient than the installed base (because of appliance and equipment energy conservation standards, or simply

[15] 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. Site-to-source conversion factors of 3.15 for electricity and 1.09 for natural gas based on Peterson et al. 2015. "A Common Definition for Zero Energy Buildings." Prepared for the U.S. Department of Energy by The National Institute of Building Sciences. September 2015.

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 energy savings associated with normal equipment replacement, we calculate energy savings relative to typical new equipment, rather than the installed base.

1.5.5 Technical Potential

Technical potential represents the national primary energy savings that would accrue if all technically suitable applications are replaced with the individual energy-saving technology (i.e., 100% adoption). We calculate the technical potential for each energy savings opportunity by multiplying the UES by the relevant AEC.

Technical potential within any appliance category typically is not additive, and only signifies the magnitude of potential energy savings an individual technology could provide before considering economic and market effects (e.g., cost premium, payback, consumer preferences, etc.). Nevertheless, technical potential can help DOE and other stakeholders understand the potential impact for a range of energy savings opportunities and identify priority areas for future research, development, and demonstration (RD&D) investment.

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, as opposed to warming appliances that keep food warm or reheat refrigerated goods. This chapter focuses on seven major cooking appliance categories: fryers, broilers, griddles, ovens, ranges, steamers, and microwaves. Each appliance category includes a variety of appliances, though annual energy estimates are made only for a “representative” appliance in each of the seven categories. Appendix A: Technology Descriptions describes each of the seven cooking appliance categories are described. 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.

Table 2-1 provides a summary of the UEC, installed base, and AEC for U.S. commercial cooking equipment. The estimated 2015 primary AEC for cooking equipment is 0.895 Quads/yr.

Table 2-1: Cooking Equipment Energy Consumption Summary

Equipment Types	Fuel	Avg. Annual UEC (Gas – MMBtu/yr.) (Electric - kWh/yr.)	Installed Base (1,000s)	AEC—Site Energy (Gas -TBtu/yr.) (Electric – TWh/yr.)	AEC—Primary Energy (Quads/yr.) [a]
Broilers	Gas Electric	170 24,500	346 34	58.7 0.8	0.073
Fryers	Gas Electric	158 17,400	1,077 780	170.2 13.6	0.331
Griddles	Gas Electric	115 15,800	447 447	51.4 7.1	0.127
Ovens	Gas Electric	80 12,100	882 722	70.6 8.7	0.171
Ranges	Gas Electric	147 11,200	660 65	97.0 0.7	0.114
Steamers	Gas Electric	200 17,600	90 182	18.0 3.2	0.054
Microwaves	Gas Electric	N/A 2,000	N/A 1,162	N/A 2.3	0.025
Total	**Gas** **Electric**		**3,502** **3,392**	**466** **36**	**0.895**

[a] Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

2.1 Market Overview

2.1.1 Manufacturers

Exact market shares of the manufacturers are unknown at this time; however industry experts identified top manufacturers for several appliance classifications, as presented in Table 2-2.

Table 2-2: Manufacturers by Appliance [a]

Manufacturers	Fryer	Broiler	Griddle	Oven	Range	Steamer	Microwave
AccuTemp			X			XX	
Alto-Shaam, Inc.	X						
Amana							X
Anvil		X					
Blodgett				XX	XX	X	
Cleveland Range, LLC						XX	
Crown Food Service Equipment Ltd.						X	
Duke				X			
Eagle	X						
Electrolux				X			
Frymaster, LLC	XX						
Garland		X	X	XX	XX		
Henny Penny Corporation	X						
Hobart Corporation	X		X	X		X	
Intek Manufacturing, LLC						XX	
Keating of Chicago, Inc.	X						
Magikitch'n		X					
Market Forge Industries, Inc.						X	
Panasonic							X
Pitco Frialator	XX						
Samsung							X
Sharp							X
Solaris Steam						X	
Southbend		X				X	
Star Manufacturing	X	X	X				
Stellar Food Equipment						X	
Taylor			X				
Toastmaster			X				
Ultrafryer Systems, Inc.	X						
Unified Brands, Inc.						X	
Vulcan-Hart Company	X	X	X	X	X	X	
Wells Manufacturing	X						
Wolf		X	X		XX		

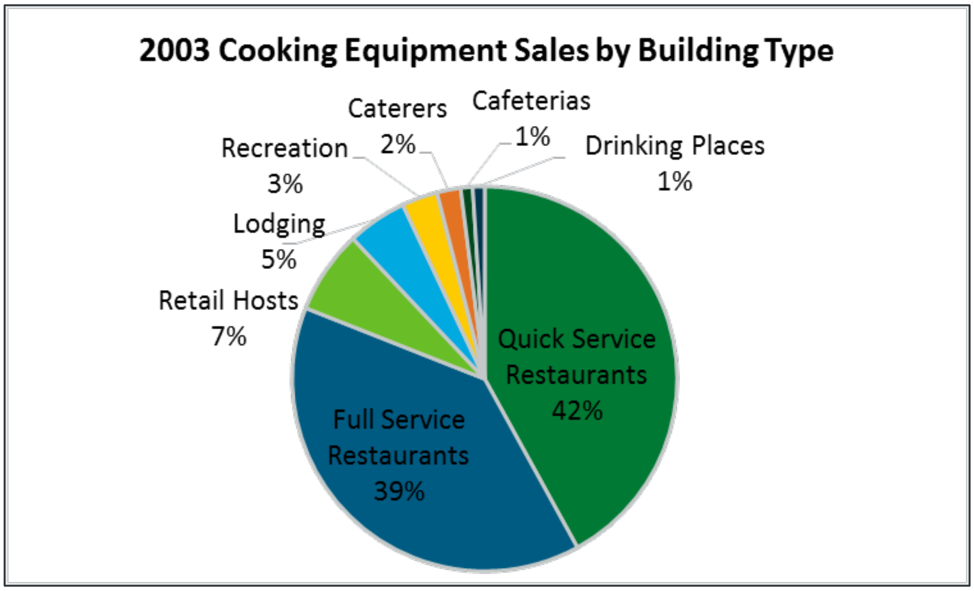
[a] "X" indicates that the company makes the product, and "XX" indicates top manufacturer. Source for table is the 2009 Commercial Appliance Report[16].

[16] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009. http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf

Commercial microwaves are manufactured by the same companies that make residential microwaves. However, not all residential model manufactures offer commercial sized microwaves.

2.1.2 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 2-1) show the majority of cooking equipment sales is to quick-service and full-service restaurants.



Source: CEE 2008[17]

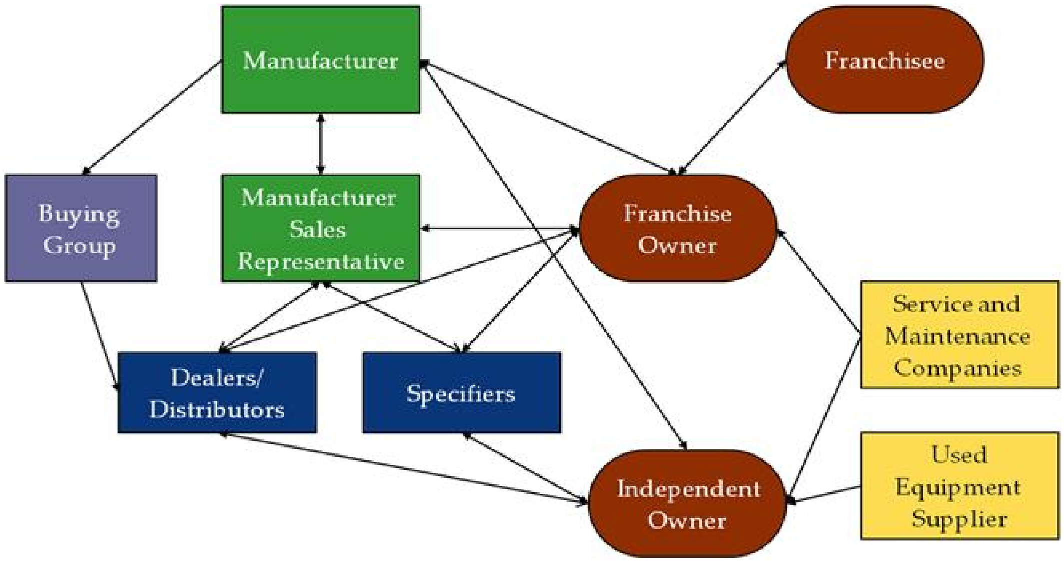
Figure 2-1: 2003 cooking equipment sales by building type

2.1.3 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. Manufacturers also rely on trade shows sponsored by the North American Association of Food Equipment Manufactures (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. Figure 2-2 illustrates the relationships between the different ownership types (independent and franchises) and those parties that affect their purchasing decisions.

[17] CEE. 2005. "Commercial Kitchens Initiative." Consortium for Energy Efficiency. Published: 2005. Updated: 2008.



Source: CEE 2007[18]

Figure 2-2: Relationship among parties in cooking appliance purchase decisions

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.[19] 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.

[18] CEE. 2007. "CEE Commercial Kitchens Initiative: A key opportunity for achieving energy and water savings." Consortium for Energy Efficiency. 2007.
[19] Equipoise Consulting Inc. 2004

2.2 Annual Shipments and Installed Base

2.2.1 Annual Shipments

Estimates for cooking appliance shipments come from NAFEM and the Environmental Protection Agency (EPA) ENERGY STAR program. The NAFEM report estimates total shipments by North American manufactures; including international shipments (outside of North America). In the 2009 Commercial Appliances Report, we made adjustments to estimate the total shipments within the US only. To obtain 2014 shipments, we used the ENERGY STAR 2014 Unit Shipment and Market Penetration Report to estimate total shipments, summarized in Table 2-3.

Table 2-3: Cooking Appliance Shipments

Appliance Type	2008		2014	
	Shipments Reported by NAFEM [a]	Navigant Estimated US Shipments [b]	Navigant Estimated Shipments [c]	ENERGY STAR Shipments (market share) [d]
Broilers	15,182	7,680	N/A [e]	N/A [e]
Fryers	129,349	63,900	87,000	20,000 (23%)
Griddles	19,581	10,200	10,000	2,000 (20%)
Ovens	346,780	183,000	45,100	23,000 (51%)
Ranges	83,192	44,900	N/A [e]	N/A [e]
Steamers	33,483	18,300	18,200	6,000 (33%)
Microwaves	202,680	97,800	N/A [e]	N/A [e]

[a] Source: NAFEM 2008[20]
[b] Estimated by Navigant, Adjustments were made using percentage of shipments outside of North America and population scaling. Calculated based on ENERGY STAR shipments divided by estimated market share. See 2009 Commercial Appliance Report for details.
[c] ENERGY STAR shipment data for 2014[21]
[d] No ENERGY STAR specification for these products

2.2.2 Installed Base

Consistent with the 2009 Commercial Appliances Report, we used three pieces of data to estimate the inventory of each appliance type, which, when multiplied together, equal the total installed base:

1. **Saturation** - Percent of establishments that use the appliance
2. **Building Stock** - Number of food service establishments
3. **Ownership** - Average number of units per establishment that uses the appliance

[20] NAFEM 2008 Size and Shape of the Industry Study: https://www.nafem.org/NAFEMIMIS/NAFEM/?WebsiteKey=9b3e4c0c-6b14-4acf-afc3-cd401bc59b43
[21] ENERGY STAR Unit Shipment Data, available: https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2014_USD_Summary_Report.pdf

A report by Arthur D. Little (ADL) in 1993 estimates saturation and ownership for non-microwave appliances; the data are separated into commercial and institutional class building types. Without better and/or newer data sources, the 2009 Commercial Appliances Report assumed these same saturation and ownership levels. Although saturation and ownership levels may have changed since the ADL report was published, no data were available to provide accurate updates in this study.

The 2009 Commercial Appliance Report obtained building stock from ADL (1993) and extrapolated to 2008. The 2015 report uses data from the CBECS published by the EIA. CBECS (2012) reports the number of buildings for food service and food preparation or serving areas in non-food service buildings. The number of unique buildings (eliminating any double counting) that CBECS (2012) reports is 869,000. We also examined 2012 data from the U.S. Census Bureau. The U.S. Census Bureau reports around 600,000 “food services and drinking places” for 2012. When we remove the number of establishments reported in CBECS (2012) in which the building activity is not included in the U.S. Census Bureau (commercial kitchen/food preparation area), the 2 estimates are fairly close. Thus, we believe using the 869,000 total establishments as reported by CBECS (2012) is appropriate. Because more recent data is not available, we created a scaling factor based on CBECS (2003) and CBECS (2012) to get the 2015 installed base, as shown in Table 2-4. Table 2-5 shows the projected number of commercial establishments. Please note that the 2009 Commercial Appliance Report gave estimates for both commercial and institutional establishments. CBECS data aggregates both commercial and institutional establishments, thus, in this report we are providing aggregate estimates for both types of establishments.

Table 2-4: Scaling Factor for Commercial Establishments

Source	Total “Food Service” Establishments [a]
CBECS (2003)	297,000
CBECS (2012)	380,000
Estimated 2015	408,000
Scaling Factor [b]	1.07

[a] Only represents “food service” as the principal building activity as reported in CBECS. CBECS (2003) does not report food preparation or serving areas in non-food service buildings
[b] Estimated establishments 2015 ÷ CBECS establishments (2012)

Table 2-5: Projected Number of Commercial and Institutional Establishments

Year	Commercial Establishments	Institutional Establishments	Total	Source
1993	240,000	87,000	327,000	ADL (1993)
2008	280,000	100,000	380,000	Calculation scaled using CBECS data
2012	869,000 [a]		869,000	CBECS (2012)
2015	932,000 [b]		932,000	Navigant Calculation

[a] Estimate contains both commercial and institutional establishments
[b] 2012 estimate x scaling factor in Table 2-4

The 2009 Commercial Appliance Report estimated the installed base of microwaves using a separate bottom-up approach as ADL (1993)[22] did not include microwaves in their study. It estimated installed based by multiplying the 2008 annual shipments by the effective useful life. We assume that the shipments of commercial microwaves has been constant for the last 10 years (historic shipment data was not available). Because more recent shipment data is not available, we created a scaling factor based on CBECS (2003) and CBECS (2012) to get the 2015 installed commercial microwave base. Table 2-6 shows the scaling factor analysis and Table 2-7 shows the installed base of commercial microwaves.

Table 2-6: Scaling Factor for Commercial Microwave Installed Base

Source	Total Establishments [a]
CBECS (2003)	297,000
CBECS (2012)	380,000
Estimated 2008	343,000
Estimated 2015	408,000
Scaling Factor [b]	1.19

[a] Only represents "food service" as the principal building activity as reported in CBECS. CBECS (2003) does not report food preparation or serving areas in non-food service buildings
[b] Estimated establishments 2015 ÷ Estimated establishments 2008

Table 2-7: Installed Base of Commercial Microwaves

Building Type	Value	Source Comments
2008 Annual Shipments	97,800	NAFEM 2008
Effective Useful Life	10	Estimated to be the same as ovens
2008 Total Installed Base	978,000	Navigant Calculation
2015 Total Installed Base [a]	1,162,000	Navigant Calculation

[a] 2008 Installed Base x scaling factor from Table 2-6, above.

[22] ADL 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.

We used the updated building stock and the ADL (1993) saturation and ownership estimates to estimate installed base in 2015. Table 2-8 details the total installed base calculations for each appliance in each sector.

Table 2-8: Installed Base by Equipment Type in Commercial and Institutional Establishments

Appliance Type	Equipment Class	Saturation [a]	Building Stock [b]	Ownership [a]	Total Installed Base [c]
Broiler	Overfired	9.0%	932,000	1.3	109,000
	Salamander	8.2%	932,000	1.2	92,000
	Underfired/Charbroilers	16.0%	932,000	1.2	179,000
	Total Broilers				**380,000**
Fryers	Pressure	12.4%	932,000	2.2	254,000
	Floor-Mounted	52.0%	932,000	2.3	1,115,000
	Countertop	30.8%	932,000	1.7	488,000
	Total Fryers				**1,857,000**
Griddles	Griddles & Grills	61.7%	932,000	1.4	805,000
	Sandwich Grills	6.7%	932,000	1.4	88,000
	Total Griddles				**893,000**
Ovens	Deck	27.8%	932,000	1.9	492,000
	Convection (1/2)	12.1%	932,000	1.2	135,000
	Convection (Full)	31.8%	932,000	1.6	474,000
	Combination	4.7%	932,000	1.6	70,000
	Rotary Rack	2.1%	932,000	1.1	22,000
	Rotary	1.8%	932,000	1.1	18,000
	Cook & Hold	14.5%	932,000	1.6	216,000
	Conveyor	3.9%	932,000	1.4	51,000
	Dough Proofer	11.2%	932,000	1.2	125,000
	Total Ovens				**1,604,000**
Ranges	Light Duty	17.4%	932,000	1.2	195,000
	Heavy Duty	35.6%	932,000	1.6	531,000
	Total Ranges				**725,000**
Steamers	Atmospheric	7.2%	932,000	1.5	101,000
	Low Pressure	7.1%	932,000	1.2	79,000
	High Pressure	6.6%	932,000	1.5	92,000
	Total Steamers				**272,000**

[a] Source: ADL (1993)[23]
[b] Source: Table 2-5
[c] Saturation x Building Stock x Ownership. Totals may not equal the sum of equipment classes due to rounding.

Table 2-9 summarizes these results including the breakdown for gas and electric-fueled units. Figure 2-3 illustrates the installed base results for all cooking equipment discussed in our report. Figure 2-3 shows the updated installed base by fuel type. In this report, we assumed the same fuel type shares as those presented in ADL (1993).[24]

[23] Ibid
[24] ADL 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.

Table 2-9: Installed Base by Fuel Type

Appliance Type	Total	Installed Base in thousands (Percentage)[a]	
		Gas	Electric
Broiler	380,000	346 (91%)	34 (9%)
Fryers	1,857,000	1,077 (58%)	780 (42%)
Griddles	893,000	447 (50%)	447 (50%)
Ovens	1,604,000	882 (55%)	722(45%)
Ranges	725,000	660 (91%)	65 (9%)
Steamers	272,000	90 (33%)	182 (67%)

[a] Source for percentages: ADL (1993)[25]

A 2014 study performed by Fisher-Nickel, Inc. for the California Energy Commission characterized gas-fired commercial foodservice equipment in California.[26] The report includes installed stock estimates for various commercial foodservice equipment types for California. We decided not to use this data because we feel that using national numbers presented in CBECS 2012 and scaling to 2015 would yield more accurate installed stock estimates than using California data and scaling to a national basis.

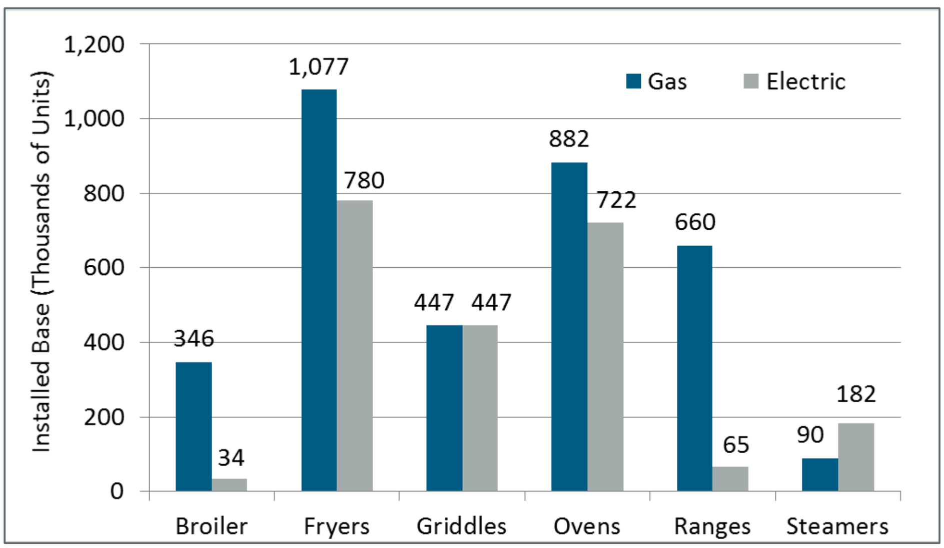


Figure 2-3: 2015 installed base by appliance and fuel type

[25] Ibid.

[26] Fisher-Nickel, Inc. 2014. “Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment.” Prepared for California Energy Commission. October 2014. http://www.energy.ca.gov/2014publications/CEC-500-2014-095/CEC-500-2014-095.pdf

2.3 Product Cost Breakdown

Commercial cooking equipment costs can vary substantially depending on equipment type, capacity, and other characteristics. Table 2-10 provides estimates on average costs for various commercial cooking equipment types.

Table 2-10: Estimated Average Cost for Commercial Cooking Appliances

Appliance Type	Equipment Class	Average Cost [a]
Broiler	Overfired	$11,600
	Salamander	$3,800
	Underfired/Charbroilers	$2,300
Fryers	Pressure	$9,800
	Floor-Mounted	$6,400
	Countertop	$1,900
Griddles	Griddles & Grills	$3,400
	Sandwich Grills	$900
Ovens	Deck	$13,400
	Convection	$5,300
	Proofer	$13,600
Ranges	Average Range	$4,900
Steamers	Average Steamer	$13,100

[a] Source: AutoQuotes[27]

2.4 Baseline Energy Consumption

The 2009 Commercial Appliance Report calculated AEC using an updated version of a model developed by ADL (1993). The general model structure remained the same while assumptions were updated with more recent data from sources such as the EPA and the Food Service Technology Center (FSTC).

When possible, we used data from the EPA ENERGY STAR Commercial Kitchen Equipment Savings Calculator spreadsheet.[28] When EPA ENERGY STAR data wasn't available, we used data presented in the FSTC appliance technology assessments. The UECs were calculated through appliance testing and typical rated energy input, duty cycle, and operating hours. We then used the updated installed base by fuel type (Table 2-9) to generate U.S. AEC (Table 2-12).

[27] AutoQuotes is a cloud-based catalog and quotation application for the foodservice equipment industry: http://aqnet.com/. Accessed December 2015.

[28] Found in the "Resources" section of the Commercial Food Service Equipment ENERGY STAR site: https://www.energystar.gov/products/certified-products/detail/commercial-food-service-equipment

Table 2-11: Cooking Appliance Use Characteristics, 2015

Cooking Equipment	Fuel	Operating Hrs./yr. [a]	Utilization Factor [b]	Rated Capacity (Btu/hr.) [b]	Rated Capacity (kW) [b]
Broilers	Gas	2,496	0.76	88,000	-
	Electric	3,120	0.70	-	11
Fryers	Gas	5,840	0.28	164,000	-
	Electric	5,840	0.21	-	22
Griddles	Gas	4,380	0.34	70,000	-
	Electric	4,380	0.25	-	12
Ovens	Gas	4,380	0.38	56,000	-
	Electric	4,380	0.27	-	15
Ranges	Gas	3,491	0.24	179,000	-
	Electric	3,744	0.25	-	12
Steamer	Gas	4,380	0.15	210,000	-
	Electric	4,380	0.17	-	24

[a] Source: FSTC and EPA ENERGY STAR[29]
[b] Source: FSTC[30]

Table 2-12: UEC and US AEC, 2015

Cooking Equipment	Fuel	2015 Inventory [a]	Annual Gas UEC (MMBtu/yr.) [b]	Annual Electric UEC (kWh/yr.) [b]	US AEC – Site (Gas - TBtu/yr.) (Electric - TWh/yr.) [c]	US AEC – Primary (Gas - TBtu/yr.) (Electric - TWh/yr.) [d]
Broilers	Gas	346,000	170	-	58.7	64.0
	Electric	34,000	-	24,500	0.8	9.0
Fryers	Gas	1,077,000	158	-	170.2	185.5
	Electric	780,000	-	17,400	13.6	145.9
Griddles	Gas	447,000	115	-	51.4	56.0
	Electric	447,000	-	15,800	7.1	75.8

[29] FSTC – Appliance Technology Assessments found on the Food Service Technology website. Accessed December 2015. Available at: http://www.fishnick.com/equipment/techassessment/
EPA ENERGY STAR - Found in the "Resources" section of the Commercial Food Service Equipment ENERGY STAR site: https://www.energystar.gov/products/certified-products/detail/commercial-food-service-equipment
[30] Ibid., FSTC.

Cooking Equipment	Fuel	2015 Inventory [a]	Annual Gas UEC (MMBtu/yr.) [b]	Annual Electric UEC (kWh/yr.) [b]	US AEC – Site (Gas - TBtu/yr.) (Electric - TWh/yr.) [c]	US AEC – Primary (Gas - TBtu/yr.) (Electric - TWh/yr.) [d]
Ovens	Gas	882,000	80	-	70.6	76.9
	Electric	722,000	-	12,100	8.7	93.9
Ranges	Gas	660,000	147	-	97.0	105.8
	Electric	65,000	-	11,200	0.7	7.9
Steamer	Gas	90,000	200	-	18.0	19.6
	Electric	182,000	-	17,600	3.2	34.5

[a] Source: Table 2-9
[b] Source: When available, EPA ENERGY STAR commercial kitchen savings calculator, otherwise, weighted avg. of data in FSTC 2002
[c] Equal to the Annual UEC x 2015 Inventory
[d] Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

As section 2.2.2, above, discusses, ADL (1993) 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. As presented in the 2009 Commercial Appliance Report, Table 2-13 uses these parameters to estimate UEC, and Table 2-14 shows the AEC of commercial microwaves.

Table 2-13: Microwave Annual UEC

Data	Value	Source Comments
Active Power consumption (watts)	2,100	Calculated: Avg. power from mfr. websites
Idle Power Consumption (watts)	3	Assumed same as residential models (TIAX 2006)
Hours/Day in use	3	Navigant 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
UEC (kWh/yr.)	2,000	Calculation [d]

[a] Navigant 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)[31]
[d] (Hours/Year Active x Active Power Consumption) + (Hours/Year Idle x Idle Energy Consumption)

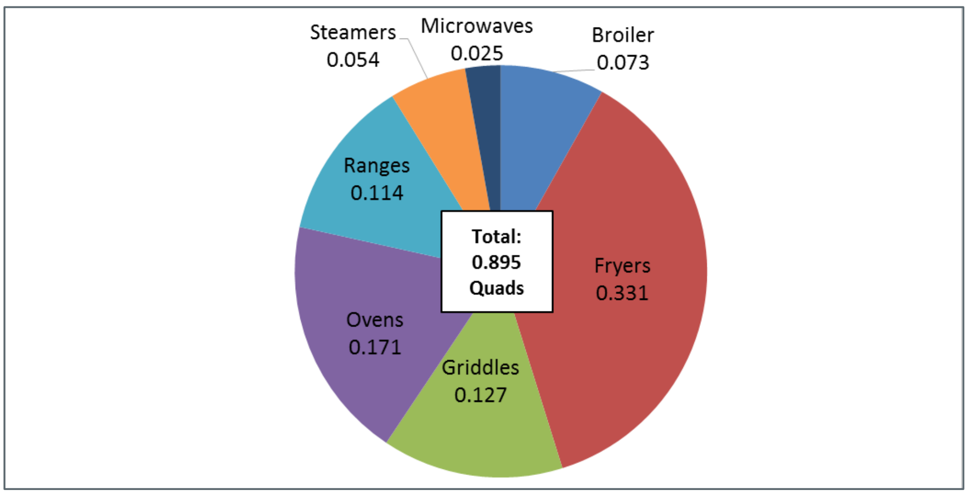
[31] TIAX, 2006. “Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers, Dehumidifiers, And Cooking Products, And Commercial Clothes Washers.” 2006

Table 2-14: Microwave AEC

Metric	Value	Units	Source Comments
UEC	2,000	kWh/yr.	Table 2-13
Installed Base	1,162,000	Units	Table 2-7
Total Energy Consumption – Site	2.32	TWh/yr.	Calculated
Primary Energy Consumption	25	TBtu/yr.	Calculated [a]
Primary AEC	0.025	Quads/yr.	Calculated

[a] Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

Figure 2-4 displays summary data on the energy consumption of all commercial cooking appliances.



Source: Table 2-12 and Table 2-14.

Figure 2-4: Summary of cooking energy consumption (Quads) by appliance

2.5 Comparison of Baseline Energy Consumption to Previous Studies

As was done in the 2009 Commercial Appliance Report, we compared our estimate of AEC to estimates from several other sources; these include ADL (1993), DOE Buildings Energy Databook (2008), and the 2009 Commercial Appliance Report. Figure 2-5 and Table 2-15 illustrate the comparison.

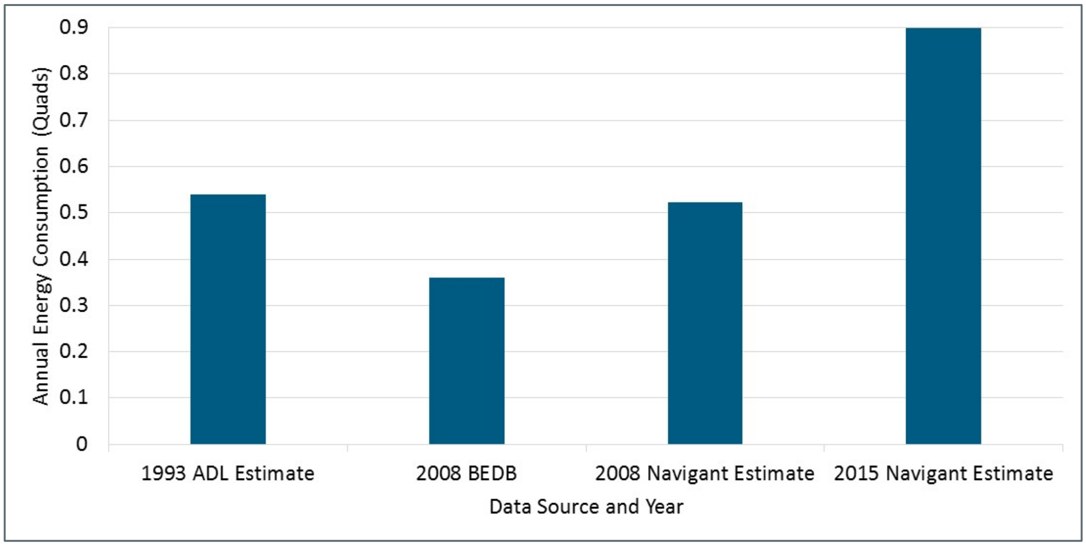


Figure 2-5: Estimated national energy consumption for cooking end-uses by various sources

Further comparisons can be made at the appliance level. Table 2-15 compares our energy consumption estimates to ADL's estimates from 1993 and to the 2008 estimates from the 2009 Commercial Appliance Report. This comparison locates key areas of differences beyond those that are simply attributed to growth over the time period.

The large percent differences exist because of differences in assumptions made in the 2009 Commercial Appliance Report and those made for this report. For this report we used a different source for installed base estimates. Rather than using data from over 20 years ago (ADL 1993) and scaling to 2015 based on total commercial square footage, as was done in the 2009 Commercial Appliance Report, we decided to use the number of commercial cooking establishments in CBECS (2012) and scale to 2015. We believe this is will yield more accurate installed base estimates than scaling based on total commercial square footage. In addition to changing the methodology of developing installed base estimates, we also used new energy consumption data from EPA ENERGY STAR. This data is more accurate at representing what currently exists in the market as compared to the data used in the 2009 Commercial Appliance Report.

The EIA AEO 2015 report estimates the commercial cooking energy consumption in 2012 at 0.27 Quads.[32] The EIA developed this estimate using data in CBECS (2003). As mentioned in Table 2-6, CBECS (2003) only estimates the number of establishments where "food service" is the principal building activity. CBECS (2012) also estimates this number, but additionally includes establishments where there is food preparation or serving areas in buildings where food service is not the principle building activity (i.e. fast-food or small restaurant, cafeteria or large restaurant, and commercial kitchen/food preparation area). These types of establishments will also include commercial cooking equipment, thus, we included those in our installed base estimate. Because the EIA AEO 2015 only accounts for the food service establishments in

[32] The commercial cooking energy consumption is in table A5 in the Annual Energy Outlook 2015 - EIA. 2015. "2015 Annual Energy Outlook." U.S. Energy Information Administration. DOE/EIA-0383(2015). April 2015. Available at: http://www.eia.gov/forecasts/aeo/

CBECS (2003), their estimate of total cooking energy consumption will be smaller than that estimated in this report.

The NRA 2013 Restaurant Industry Forecast report estimates that there were 980,000 restaurant locations in 2012. The NRA 2012 estimate is more than 100,000 higher than the estimate we developed in Table 2-5. We believe the NRA estimate is higher because they included establishments that would not use commercial cooking equipment, such as some quick service restaurants, while this report only considers establishment that use commercial cooking equipment.

Table 2-15: AEC Estimate Comparison

Cooking Equipment	Fuel	1993 ADL Estimate (TBtu/yr.)[a]	2008 Navigant Estimate (TBtu/yr.)[b]	2015 Navigant Estimate (TBtu/yr.)[c]	Percent Difference[d]
Broilers	Gas	28	31.7	64.0	102%
	Electric	4.5	4.9	9.0	84%
Fryers	Gas	27.5	42.2	185.5	340%
	Electric	32.7	37.3	145.9	291%
Griddles	Gas	13.7	16.3	51.4	215%
	Electric	25	25.3	75.8	200%
Ovens	Gas	123.1	88.2	76.9	-13%
	Electric	139.8	90.6	93.9	4%
Ranges	Gas	80.4	83.3	105.8	27%
	Electric	9.8	11	7.9	-29%
Steamer	Gas	16.6	20.6	19.6	-5%
	Electric	39.3	51.6	34.5	-33%
Microwave	Gas	NA	NA	NA	NA
	Electric	NA	20.0	25.0	25%

[a] ADL (1993)[33]
[b] Source: Table 2-31 in the 2009 Commercial Appliance Report[34]
[c] Source: Table 2-12 and Table 2-14
[d] Calculated: (Navigant 2015 – Navigant 2008) / Navigant 2008

2.6 Energy Savings Opportunities

2.6.1 Energy Consumption and Savings Percentage

Table 2-16 provides the estimated technical potential for commercial cooking equipment meeting ENERGY STAR performance specifications. Cooking products meet ENERGY STAR specifications through a variety of design improvements, control strategies, and other techniques to improve operating efficiency and reduce idle consumption.

[33] ADL. 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.
[34] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.
http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf

Table 2-16: Estimated Technical Potential for Commercial Cooking Appliances

Product	Type	Capacity/Mode	Fuel	UES Potential	Technical Potential Primary (Gas - TBtu/yr.) (Electric - TWh/yr.)
Fryers	Open Deep-Fat	Standard	Gas	15%	2.70
			Electric	5%	0.37
		Large Vat	Gas	15%	22.30
			Electric	10%	0.99
Griddles	Single- and Double-Sided	-	Gas	6%	5.9
			Electric	5%	0.85
Ovens	Convection	Full-Size	Gas	2%	11.4
		Full-Size	Electric	6%	0.70
		Half-Size	Electric	3%	0.07
	Combination	Steam Mode	Gas	0%	0.00
		Convection Mode	Gas	0%	0.00
		Steam Mode	Electric	0%	0.00
		Convection Mode	Electric	0%	0.00
Total			**Gas**	**10%**	**42.30**
			Electric	**6%**	**2.90**

Source: ENERGY STAR Commercial Food Service Calculator.[35]

2.6.2 Energy Savings Technologies

We examined the commercial cooking technologies described in the 2009 Commercial Appliance Report, and identified new technologies that have since been developed or under development. The technologies described below are new energy-saving technologies that were not identified in the 2009 Commercial Appliance Report. These technologies are best applied to one appliance type.

2.6.2.1 Fryers

1. ***Recirculation Tubes***

   Recirculation tubes route the flue gases through or around the sides of the frypot to promote heat transfer to the frying oil. More restrictive designs required a blower to pull the flue products through the heat exchangers.

[35] "Commercial Kitchen Equipment Savings Calculator," EPA, last updated February 2015; available: http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx

Table 2-17: Energy Savings Fryers Technologies

Technology	Percent Energy Savings	Source Comments
Recirculation Tubes	20%	FSTC 2002

2.6.2.2 Ranges

1. Halogen Range Tops

The heat source for a halogen range top is a set of halogen lamps beneath a glass ceramic cooktop. Pots and pans rest directly on the ceramic and are heated by radiant energy from the lamps. Halogen range tops have a fast response to controls and a sealed cooking surface. At the time of the FSTC guides (2002), this technology was not in commercial range units.

2. Automatic Burner Shut-Off and Re-ignition

In catering kitchens it is often more practical to leave open-flame burners lit when not being used, rather than turning the gas off and re-lighting it each time when needed. Gaz de France, along with Madec Mater Company, has patented the Top-Flam – an automatic shut-off and re-ignition device that is triggered by cookware detection. This is more efficient than leaving open-flame burners lit when not being used in commercial kitchens.

3. Induction Range Tops

Induction range tops use electromagnetic energy to heat cookware made of magnetic material. When the unit is turned on, the coils produce a high frequency alternating magnetic field, which ultimately flows through the cookware. Molecules in the cookware rapidly move back and forth, causing the cookware to become hot and cook the food.

The induction range is significantly different than other types of ranges. The range surface is a smooth and continuous glass plate. Because it is not directly heated during operation, the surface remains relatively cool, gaining residual heat from the cooking container. These units offer precise temperature control and are more efficient because the cookware is heated directly, without the need to heat the cooking surface.

Table 2-18: Energy Savings Ranges Technologies

Technology	Percent Energy Savings	Source Comments
Halogen Range Tops	2% over electric	2009 DOE Final Rule for Residential Ovens and Ranges
Automatic Burner Shut-Off and Re-ignition	50%	FSTC 2002
Induction Range Tops	10% over electric	FSTC 2002

2.6.2.3 Ovens

1. Air Impingement

Air impingement uses a ported manifold to direct jets of air, or "fingers," onto the product's surface in conveyor and some rotisserie ovens.

2. Combination Convection Microwave

Combination convection microwave ovens combine convection and microwave for high-speed cooking. These products use a modified high-velocity impingement system that propels hot air directly down onto the food, then pulls it around and underneath the product. This process is coupled with a microwave component to speed the cooking process.

3. Combination Halogen Microwave

Combination halogen microwave ovens combine quartz halogen cooking with microwave. As with the convection microwave, this oven offers a variety of cooking options and multi-stage cooking programs, all designed to reduce product cook time.

Table 2-19: Energy Savings Ovens Technologies

Technology	Percent Energy Savings	Source Comments
Air Impingement	50%	FSTC 2002
Combination Convection Microwave	50%	2009 DOE Final Rule for Residential Ovens and Ranges
Combination Halogen Microwave	50%	2009 DOE Notice of Public Rulemaking (NOPR) for Residential Ovens and Ranges

2.6.2.4 Steamers

1. Compartment Insulation

Improved insulation around the cooking compartment reduces heat loss to the kitchen and can have a significant effect on standby energy consumption.

Table 2-20: Energy Savings Steamers Technologies

Technology	Percent Energy Savings	Source Comments
Compartment Insulation	5%	2009 DOE Final Rule for Residential Ovens and Ranges

2.7 Regulated and Voluntary Efficiency Standards

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. Gas cooking appliances are not required to use electric ignition.

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. ENERGY STAR Fryers was launched in 2003; today 9 manufacturers offer 175 models that account for 23% of fryer sales. There is also an ENERGY STAR target for steamers; 6 manufacturers offer 145 models that account for 33% of steamer sales. In 2009, the

EPA recently established ENERGY STAR targets for commercial ovens and griddles. 14 manufacturers offer 91 models that account for 51% of ovens sales, and 9 manufacturers offer 68 models that account for 20% of griddles sales.
Table 2-21 provides the ENERGY STAR efficiency requirements for cooking equipment.

Table 2-21: ENERGY STAR Key Product Criteria for Commercial Cooking Equipment

Product	Type	Capacity/Mode	Fuel	Heavy-Load Cooking Energy Efficiency	Idle Energy Rate [a,b]
Fryers	Open Deep-Fat	Standard	Gas	≥ 50%	≤ 9,000 Btu/hr.
			Electric	≥ 80%	≤ 1,000 watts
		Large Vat	Gas	≥ 50%	≤ 12,000 Btu/hr.
			Electric	≥ 80%	≤ 1,100 watts
Griddles	Single- and Double-Sided	-	Gas	Reported	≤ 2,650 Btu/hr. per ft^2
			Electric	Reported	≤ 320 watts per ft^2
Ovens	Convection	Full-Size	Gas	≥ 46%	≤ 12,000 Btu/hr.
		Full-Size	Electric	≥ 71%	≤ 1,000 watts
		Half-Size	Electric	≥ 71%	≤ 1,600 watts
	Combination	Steam Mode	Gas	≥ 41%	≤ 200P + 6,511 Btu/hr.
		Convection Mode	Gas	≥ 56%	≤ 150P + 5,425 Btu/hr.
		Steam Mode	Electric	≥ 55%	≤ 0.133P + 0.6400 kW
		Convection Mode	Electric	≥ 76%	≤ 0.080P + 0.4989 kW
Steamers	Steam Cooker	3-pan	Gas	≥ 38%	≤ 6,250 Btu/hr.
		4-pan	Gas	≥ 38%	≤ 8,350 Btu/hr.
		5-pan	Gas	≥ 38%	≤ 10,400 Btu/hr.
		6-pan and larger	Gas	≥ 38%	≤ 12,500 Btu/hr.
		3-pan	Electric	≥ 50%	≤ 400 watts
		4-pan	Electric	≥ 50%	≤ 530 watts
		5-pan	Electric	≥ 50%	≤ 670 watts
		6-pan and larger	Electric	≥ 50%	≤ 800 watts

[a] For Griddles, the idle energy rate represents the *normalized* idle energy rate. Idle mode normalization calculations are found in the Griddle EPA ENERY STAR program requirements.[36]
[b] For Ovens, P in the idle energy rate equation is equal to the pan capacity, as defined in section 1.S of the Oven EPA ENERGY STAR program requirements.[37]

[36] EPA ENERGY STAR program requirements for griddles can be found on the ENERGY STAR website: https://www.energystar.gov/ia/partners/product_specs/program_reqs/Commercial_Griddles_Program_Requirements.pdf
[37] EPA ENERGY STAR program requirements for ovens can be found on the ENERGY STAR website: https://www.energystar.gov/sites/default/files/specs//private/Commercial%20Ovens%20Program%20Requirements%20V2%201.pdf

3 Commercial Food Preparation

Commercial kitchens contain a variety of electric appliances that aid in the preparation, storage, and serving of cooked food. Manufacturers design each appliance to perform one or more mechanical functions, including: mixing, slicing, cutting, peeling, grinding, juicing, food processing, etc. In addition to mechanical food preparation equipment, several other equipment categories keep food at proper temperatures before serving. Commercial equipment such as hot food holding cabinets, holding carts, steam tables, heat lamps, and other warming elements are not considered cooking equipment because they do not provide substantial cooking, browning, or other processes beyond maintaining prepared food at proper serving temperatures.

Appendix A: Technology Descriptions provides descriptions for major commercial food preparation equipment types.

Table 3-1 provides a summary of the UEC, installed base, and AEC for U.S. commercial food preparation equipment. The estimated 2015 primary AEC for food preparation equipment is 0.03 Quads/yr.

Table 3-1: Commercial Food Preparation Equipment Energy Consumption Summary

Installed Base (1,000s)	AEC—Site Energy (TBtu/yr.)	AEC—Primary Energy (Quads/yr.)
5,007	33	0.03

Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

As evidenced by Table 3-1, energy consumption for food preparation equipment is very small relative to other commercial building loads. Nevertheless, we include a brief analysis for food preparation equipment to maintain a consistent list of end-use appliance categories with the 2009 report and highlight the fact that most food preparation appliances have low UEC due to low operating hours.

3.1 Market Overview

Many commercial buildings use specialized equipment to deliver prepared food for sale to customers (e.g., food service), as part of guest services (e.g., lodging, hospital), and other internal activities (e.g., offices, public assembly). Compared to residential products, commercial models typically have improved durability, fewer aesthetic features, greater motor power, higher throughput, and other characteristics for improved performance in commercial kitchens.

A wide variety of companies manufacture food preparation equipment, and most offer products in more than one category. Market share information within individual categories is unavailable. Major commercial food preparation manufacturers include:

- **Mechanical food preparation equipment**: Avantco, Berkel, Doyon, Globe, Hamilton Beach, Hobart, KitchenAid, Robot Coupe, Volrath, Waring, Weston, others.[38]
- **Food warming equipment**: Cambro, Carter Hoffmann, Cres Cor, Delfield, Food Warming Equipment, Hatco, Metro, Traulsen, Vulcan, Wittco, others. [39]

3.2 Annual Shipments and Installed Base

3.2.1 Annual Shipments

Table 3-2 summarizes the annual sales and unit shipments for commercial food preparation equipment provided by NAFEM industry estimates. We estimated 2013 unit shipments by scaling 2009 unit shipments by the ratio of 2013 sales to 2009 sales. The annual unit shipments for commercial food preparation equipment range from 1-2 million units per year when including all categories. Blenders, food processors, graters, peelers, and slicers make up the largest share of unit shipments.

Table 3-2: Estimated Annual Sales and Unit Shipments for Commercial Food Preparation Equipment

Metric	2009 Values [a]	2013 Values [b]
Annual Sales ($M)	$223 M	$475 M
Ratio of 2013 to 2009	2.12	
Annual Unit Shipments (rounded)	941,000	1,999,000

Note: 2013 unit shipments estimated by scaling 2009 unit shipments using the ratio of 2013 sales to 2009 sales.
a. NAFEM 2010[40]
b. NAFEM 2014[41]

3.2.2 Installed Base

Because we could not find installed base estimates for most food preparation equipment categories, we developed our own estimate based on the number of buildings in CBECS 2012 with substantial cooking energy consumption. Table 3-3 summarizes the number of buildings with cooking energy use and the estimated market penetration of major food preparation appliances. In total, we estimate commercial buildings contain over 5 million food preparation appliances, or an average of 3 appliances for every building with substantial cooking energy. This approach follows the methodology of the 2009 Commercial Appliance Report, but includes additional building categories. We assume these additional building types, including office, public assembly, service, and other building categories, have a low penetration of commercial food preparation appliances, similar to offices. The estimated installed base for commercial food

[38] Major manufacturers of electric food preparation equipment from webrestaurantstore.com, and centralrestaurant.com.
[39] Commercial hot food holding cabinet manufacturers listed in ENERGY STAR product database. November 2015. http://www.energystar.gov/products/commercial_food_service_equipment/commercial_hot_food_holding_cabinets
[40] NAFEM. 2010. "2010 Size & Shape of the Industry." North American Association of Food Equipment Manufacturers. October 2010.
[41] NAFEM. 2014. "State of the Industry Report – Implications for Foodservice Equipment & Supplies Manufacturers." North American Association of Food Equipment Manufacturers. September 2014.

preparation equipment rises from the 2009 report's estimate of 2.8 million to 5.0 million when including these additional building types and general increases in commercial building stock.

Table 3-3: Annual Shipments of Commercial Dishwashers

Building Type	Total Buildings (1,000) [a]	Buildings with Cooking End-Use (1,000) [a]	Typical Installed Appliances [b]	Number of Appliances [b]	Installed Base (1,000)
Education	389	169	Mixer, Processor, Slicer	3	507
Food Sales	177	111	Mixer, Blender, Processor, Slicer, Peeler	5	555
Food Service	380	353	Mixer, Blender, Processor, Slicer, Peeler	5	1,765
Health Care Inpatient	10	9	2 x (Mixer, Processor, Slicer, Peeler)	8	72
Lodging	158	94	Mixer, Blender, Processor, Slicer, Peeler	5	470
Mercantile	602	157	Slicer, Blender	2	314
Office	1,012	130	Slicer, Blender	2	260
Public Assembly	352	143	Slicer, Blender	2	286
Public Order and Safety	84	56	Slicer, Blender	2	112
Religious Worship	412	261	Slicer, Blender	2	522
Service	619	39	Slicer, Blender	2	78
Warehouse	796	33	Slicer, Blender	2	66
Total	**4,991**	**1,555**	**n/a**	**3**	**5,007**

a. EIA CBECS 2012 (2015) Table B33[42]
b. Navigant Assumption, consistent with 2009 Commercial Appliances Report

3.3 Product Cost Breakdown

Table 3-4 provides the average unit cost for several major subcategories based on NAFEM estimates for annual unit shipments and sales. Equipment cost for commercial food preparation equipment within any subcategory varies substantially due to the capacity, durability, and other features. For example, a meat slicer may cost $500 or $5,000 depending on the size, speed, level of automation, and durability of the equipment type. Because of the wide range within each equipment subcategory, we do not provide more detailed cost estimates for different food preparation equipment categories in this report.

[42] EIA CBECS 2012 (2015) Table B33

Table 3-4: Average Price and Range for Food Preparation Equipment

Equipment Type	Price Range	Shipment Weighted Average Price
Food Processor	$125-$1,750	$188
Mixer	$425-$14,063	$4,846
Blender	$175-$350	$226
Food Preparation Average (All Types)	-	$237

Source: NAFEM 2010[43]

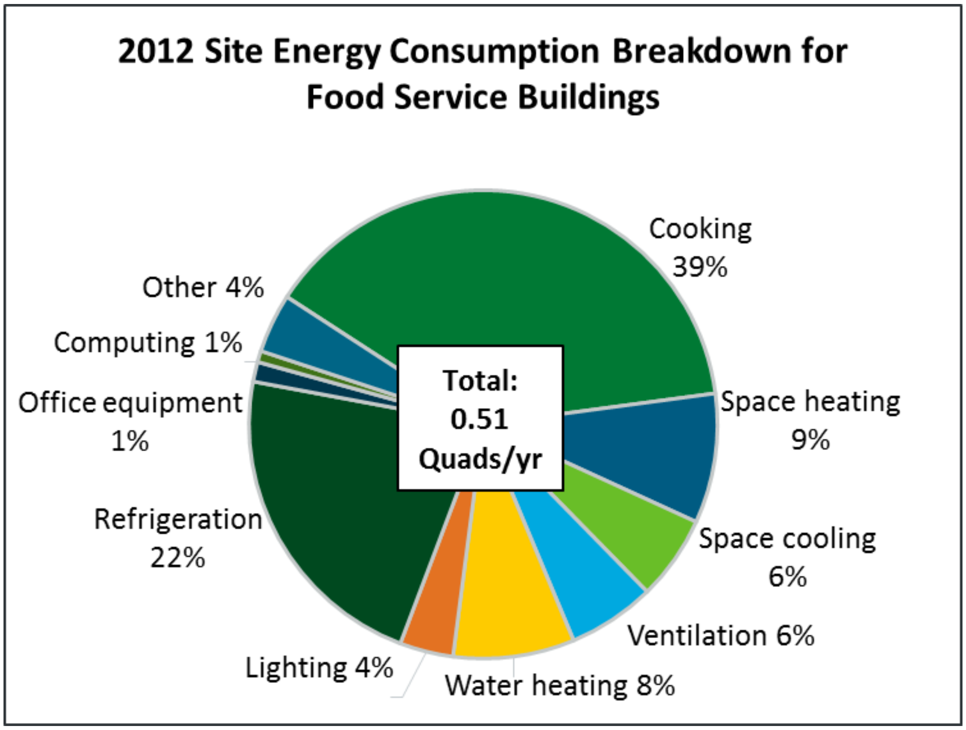
3.4 Baseline Energy Consumption

Most food preparation equipment types contain high power motors (e.g., 0.5-1.0 HP and above), but operate very infrequently relative to other commercial building loads. Even for most commercial food service kitchens, mechanical food preparation equipment such as blenders, mixers, and slicers operate only in short bursts several times a day. Food warming equipment operates more consistently throughout the day, but has a small installed base relative to mechanical equipment.[44] Without more detailed operating and installed base information, we developed a "top-down" baseline energy consumption estimate for commercial food preparation equipment. This approach follows the methodology of the 2009 Commercial Appliance Report, but includes additional building categories.

Figure 3-1 provides a breakdown of end-use consumption for an average food service building. The "Other" consumption category includes food preparation equipment, dishwashers, cash registers, sound systems, and other end-uses.

[43] NAFEM. 2010. "2010 Size & Shape of the Industry." North American Association of Food Equipment Manufacturers. October 2010.

[44] ENERGY STAR shipment analysis for commercial hot food holding cabinets estimates 5-7 thousand shipments per year vs. 1-2 million shipments for other food preparation equipment. ENERGY STAR Unit Shipment Data Report 2014, available: http://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2014_USD_Summary_Report.pdf?86f6-7243



Source: EIA CBECS 2016[45]

Figure 3-1: Energy consumption breakdown for food service buildings

As Table 3-5 shows, we estimate that food preparation equipment consumes 26 TBtu/yr. of primary energy annually. We calculate this value by subtracting commercial dishwasher electricity consumption (Section 4.4) from the "Other" total for food service and food sales. We exclude the dishwasher electricity consumption associated with the building water heater and only include booster heater and machine electricity consumption. This represents a high-end estimate because the "Other" category includes many other end-uses.

Table 3-5: Estimated Share of "Other" Energy Consumption to Food Preparation Equipment

Building End-Use	End-Use Energy Consumption (TBtu/yr.)
"Other" Total for Food Service and Food Sales [a]	104
Dishwasher Total for All Building Types [b]	78
Food Preparation	**TBD**

a. CBECS Table TBD [46]
b. Section 4.4

[45] CBECS Table 5. Major fuel consumption by end use, 2012. Release Date March 18, 2016 http://www.eia.gov/consumption/commercial/reports/2012/energyusage/index.cfm
[46] CBECS Table 6. Electricity consumption by end use, 2012. Release Date March 18, 2016 http://www.eia.gov/consumption/commercial/reports/2012/energyusage/index.cfm

3.5 Energy Savings Opportunities

Few energy efficiency options exist for mechanical food preparation equipment beyond electric motor efficiency. Virtually 100% of energy consumption for these mechanical food preparation products is from the electric motors that drive the mechanical action of the product (e.g., slicer, mixer, blender). Incorporating higher efficiency motors in mechanical food preparation appliances could improve energy efficiency, but would have poor payback periods due to their relatively short operating times.[47] Additionally, recent federal standards[48] for small electric motors have reduced energy consumption for this appliance category.

As discussed further in Section 3.6, EPA's ENERGY STAR program certifies commercial hot food holding cabinets that offer up to 70% energy savings over baseline models.[49] These high-efficiency models include improved insulation, door gaskets, and temperature controls to reduce heat loss and energy consumption. Additionally, these warming products could be connected to the building's energy management system to ensure proper shutdown when the product is not needed overnight.

3.6 Regulated and Voluntary Efficiency Standards

There are currently no regulatory programs in place for commercial food preparation equipment as an appliance. Nevertheless, federal standards do cover the small electric motors found in many equipment subcategories. Small electric motors must conform to the efficiency standards described in the direct final rule from March 9, 2010 (75 FR 10874) with an effective date of March 9, 2015.[50]

EPA's ENERGY STAR offers a certification for commercial hot food holding cabinets, with the second specification effective October 1, 2011. Table 3-6 provides the ENERGY STAR efficiency requirements for commercial hot food holding cabinets. Commercial hot food holding cabinets meeting the ENERGY STAR v2.0 specification comprised 13% of shipments in 2014. Before raising the performance standard in the v2.0 specification,[51] up to 75% of shipments qualified as ENERGY STAR models under the v1.0 specification.[52]

---

[47] Goetzler et al. 2013. "Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment." Prepared by Navigant Consulting, Inc. for U.S. Department of Energy, Building Technologies Office. December 2013.

[48] DOE. 2010. "Energy Conservation Program: Energy Conservation Standards for Small Electric Motors – Final Rule." U.S. Department of Energy. 75 FR 10874. March 9, 2010. Available at: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/40

[49] EPA. 2011. "Commercial Hot Food Holding Cabinets Key Product Criteria." U.S. Environmental Protection Agency. ENERGY STAR. October 2011. Available at: https://www.energystar.gov/index.cfm?c=hfhc.pr_crit_hfhc

[50] DOE. 2010. "Energy Conservation Program: Energy Conservation Standards for Small Electric Motors – Final Rule." U.S. Department of Energy. 75 FR 10874. March 9, 2010. Available at: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/40

[51] ENERGY STAR Unit Shipment Data Report 2014, available: http://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2014_USD_Summary_Report.pdf?86f6-7243

[52] ENERGY STAR Unit Shipment Data Report 2009, available:: http://www.energystar.gov/ia/partners/downloads/2009_USD_Summary.pdf?cb84-24cd

Table 3-6: ENERGY STAR Specification v2.0 for Commercial Hot Food Holding Cabinets

Product Interior Volume (Cubic Feet)	Product Idle Energy Consumption Rate (Watts)
0 < V < 13	≤ 21.5 V
13 ≤ V < 28	≤ 2.0 V + 254.0
28 ≤ V	≤ 3.8 V + 203.5

Source: Version 2.0 ENERGY STAR Program Requirements for Hot Food Holding Cabinets [53]

[53] EPA. 2011. "Commercial Hot Food Holding Cabinets Key Product Criteria." U.S. Environmental Protection Agency. ENERGY STAR. October 2011. Available at: https://www.energystar.gov/index.cfm?c=hfhc.pr_crit_hfhc

4 Commercial Dishwashers

Restaurants, cafeterias, hotels, hospitals and other commercial buildings use dishwashers to quickly clean dishware, glassware, utensils, and cookware for reuse in commercial kitchens. Commercial dishwashers differ from residential models due to their shorter cycle times, potential high-temperature operation to sanitize dishes, and no drying cycle. This equipment category includes 4 main product designs: undercounter, door-type, conveyor, and flight-type dishwashers. Dishwashers use electrical energy to operate the machine and thermal energy through domestic hot water supplied by the building's water heater. Low-temperature dishwashers use a chemical sanitizing agent to supplement the building's hot water supply, whereas high-temperature models use a supplementary booster heater to reach sanitizing temperatures. Most commercial dishwashers do not use a formal drying cycle, and often use chemical drying agents or a final high-temperature rinse which quickly dries dishes as they leave the machine.

Appendix A: Technology Descriptions provides descriptions for major commercial dishwasher equipment type.

Table 4-1 provides a summary of the UEC, installed base, and AEC for U.S. commercial dishwashers when including building water heater consumption. We estimate that in 2015, the primary AEC for commercial dishwashers is 175 TBtu/yr. or 0.175 Quads/yr. This estimate includes the energy consumption to heat domestic hot water for use during dishwashing.

Table 4-1: Commercial Dishwasher Energy Consumption Summary – Including Building Water Heater Consumption

Equipment Types	Temperature	Average Elec. UEC (kWh/yr.)	Average Gas UEC (MMBtu/yr.)	Installed Base	AEC—Primary Energy (TBtu/yr.)[a]
Undercounter	Low-temp	6,000	20	60,000	5
	High-temp	9,000	13	96,000	11
Door-type	Low-temp	18,000	88	111,000	32
	High-temp	26,000	58	177,000	61
Conveyor	Low-temp	25,000	88	41,000	15
	High-temp	41,200	73	65,000	34
Flight-type	Low-temp	-	-	-	0
	High-temp	65,000	126	20,000	17
			Total:	**570,000**	**175**

a. Includes machine energy consumption, booster heater consumption (as applicable), and building water heater consumption for all fuels. Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

When excluding energy use in the building's hot water heater, the total primary energy use in the U.S. drops to 79 TBtu/yr. or 0.079 Quads/yr. In comparison to Table 4-1, only 45% of the total energy consumption for this equipment type takes place at the dishwasher itself and emphasizes the impact that high-efficiency water heating systems can have on commercial kitchen energy consumption.

4.1 Market Overview

Commercial building operators can either purchase or lease dishwashers. Leasing is common, with as many as 60% of businesses (and up to 70-80% of cash-strapped small businesses) opting for leasing as opposed to purchasing.[54] While many manufacturers lease commercial dishwashers, only a few manufacturers dominate the market, with Auto-Chlor and Ecolab constituting 60-70% of leased units in operation.[55] The lease agreements typically include cleaning detergent, sanitizers, drying agents, as well as equipment maintenance. Alternatively, lease-to-own agreements give the building operator an opportunity to purchase the equipment at a discounted cost after a period of years. Because they maintain the equipment while at the customer site, leasing companies commonly recondition older equipment for reuse. This practice keeps potentially less efficient dishwashers on the market longer, displacing the purchase of new equipment.

Table 4-2 outlines the product offerings of major commercial dishwasher manufacturers by equipment type and efficiency class. Higher efficiency products are increasingly accepted as most manufacturers offer ENERGY STAR certified products in at least one equipment class and 64% of shipments in 2014 met ENERGY STAR standards.[56] This high penetration of ENERGY STAR models is even more indicative of the industry's commitment to energy efficiency when considering the updated ENERGY STAR specification started in 2013.

Table 4-2: Commercial Dishwasher Manufacturers and Product Offerings

Manufacturer	Undercounter	Door-type	Pot, Pan, Utensil	Conveyor	Flight-type
American Dish Service (ADS)		X		X	
Auto-Chlor	O	X		O	
Blakeslee	X	O	O	O	O
Champion	X	X	X	X	X
CMA Dishmachines	X	X		X	
Dihr	X	O	O	O	O
Ecolab	X	X		X	
Electrolux	X	X	X	X	
Energy Mizer	O	X		O	
Fagor	O	O	O	O	
Hobart	X	X	X	X	X

[54] Estimate based on interview with Auto-Chlor representative, Kirk Northcutt, January 2, 2014.
[55] Ibid.
[56] ENERGY STAR Unit Shipment Data Report 2014, available: http://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2014_USD_Summary_Report.pdf?86f6-7243

Manufacturer	Undercounter	Door-type	Pot, Pan, Utensil	Conveyor	Flight-type
Insinger	O	X	O	O	O
Jackson	X	X		X	O
Jet-Tech	X	X	X		
Knight	O	O			
Kromo	X	O			
Lamber SNC	O	X		O	
Meiko	X	X	X	X	X
Moyer Diebel	X	X		X	
Perlick	X				
Stero	X	X		X	X
Winterhalter	O	O	O	O	O

X denotes the manufacturer offers ENERGY STAR models for this equipment type
O denotes the manufacturer does not offer an ENERGY STAR model for this equipment type

4.2 Annual Shipments and Installed Base

4.2.1 Annual Shipments

EPA estimated 41,000 total commercial dishwasher shipments in 2014 based on compiled data from 16 partner manufacturers. Of these, 64% of shipments are ENERGY STAR qualified models. It is possible that this is a conservatively low estimate of total shipments since EPA does not included in these data non-partner manufacturers' shipments. Given the pervasiveness of the ENERGY STAR brand, we expect that only small niche manufacturers would be excluded from these data and assume these data represent the entirety of the market. Additionally, this estimate includes only new shipments and does not cover dishwashers reconditioned for resale. Table 4-3 summarizes the estimated annual dishwasher shipments and distribution by equipment type. The 41,000 estimated shipments in 2015 represent a 0.8% annual growth rate compared to 37,320 shipments in 2003.[57]

[57] ENERGY STAR® for Commercial Dishwashers: Sizing up the Savings Opportunity Rachel Schmeltz, US EPA 2006

Table 4-3: Annual Shipments of Commercial Dishwashers

Equipment Type	2015 US Shipments [a]	Distribution by Type [b]
Undercounter	17,630	43%
Door-type	14,760	36%
Conveyor	7,790	19%
Flight-type	820	2%
All Models	**41,000**	**100%**

a. Annual Shipments from 2014 ENERGY STAR Unit Shipment data; assumes no change in 2015;[58]
b. Distribution by type from NAREM 2010[59]

4.2.2 Installed Base

Table 4-4 shows the breakdown of the installed base by product type.[60] Many estimates of installed base for commercial dishwashers cite data from FSTC from 2001 of 505,000 units and an EPA assumption from 2006 of 475,000 units.[61] The 2009 Commercial Appliances Report relies on the EPA estimate and extrapolates to 2008. A 2010 study for the California Urban Water Conservation Council instead extrapolates from the FSTC original data using population growth data, to estimate 540,000 units in 2009.[62] This study relies on the 2009 data and further extrapolates to 2015, for a total estimated installed base of 570,000 units.

Table 4-4: 2015 U.S. Installed Base for Commercial Dishwashers

Equipment Type	2015 US Installed Base [a]	Distribution by Type
Undercounter	157,000	27.5%
Door-type	288,000	50.5%
Conveyor	105,000	18.5%
Flight-type	20,000	3.5%
All Models	**570,000**	**100%**

a. Based on 2010 estimate of 540,000, and extrapolated based on average annual growth of commercial floorspace (1.1%) in food service sector (CBECS 2003 vs. CBECS 2012).[63]
b. Distribution from average of: EPA, 2006[64] and 2010 shipment distribution in Table 4-3, assuming over time that installed base becomes increasingly similar to shipment distribution.

---

[58] ENERGY STAR Unit Shipment Data Report 2014, available: http://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2014_USD_Summary_Report.pdf?86f6-7243
[59] NAFEM. 2010 Size and Shape of the Industry Study Results: Warewashing, Janitorial and Safety Equipment. October 2010.
[60] Distribution between product types from NAFEM. 2010 Size and Shape of the Industry Study Results: Warewashing, Janitorial and Safety Equipment. October 2010.
[61] ENERGY STAR® for Commercial Dishwashers: Sizing up the Savings Opportunity Rachel Schmeltz, US EPA 2006
[62] "A Report on Potential Best Management Practices – Commercial Dishwashers," Prepared for The California Urban Water Conservation Council (CUWCC) by Koeller and Company and H.W. Hoffman & Associates, LLC. June 2010. Available: http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/non_residential/commercial_food_service/Commercial-Dishwashers-CUWCC-PBMP-July-2010.pdf
[63] Commercial Building Energy Consumption Survey,(CBECS) by EIA, available: http://www.eia.gov/consumption/commercial/
[64] ENERGY STAR® for Commercial Dishwashers: Sizing up the Savings Opportunity Rachel Schmeltz, US EPA 2006

Because these estimates rely on older data and assumptions, we analyzed turnover/replacement rates to validate our estimate. CEE provides estimates of the useful life of the 4 types of dishwashers; a weighted average of these values is 14.8.[65] At this rate, sales for replacement purposes only are approximately 38,000 units. We estimate that this sector is growing at 1.1% per year (see Table 4-4), which increases annual shipments by ~6,000 units; the total annual shipments is therefore slightly higher than, but within range of, the 41,000 estimate of annual shipments by EPA (which, as noted, may be conservative).

Table 4-5 summarizes the key assumptions used for developing installed base assumptions. We assume a split of gas versus electric water heating based on the CBECS 2012 split by floorspace in the food service sector: 58% gas and 42% electric. This is a notable increase in electric units from the 2009 Commercial Appliances Report assumption, which showed 70% gas and 30% electric based on CBECS 2003 data. This change directly impacts energy consumption as discussed in Section 4.4.

Table 4-5: Installed Base Assumptions

Equipment Characteristics	Feature Breakdown		Source
Wash Temperature	39% low-temp	61% high-temp	CUWCC, 2010[66]
Building Water Heater Fuel	58% gas	42% electric	CBECS 2012[67]
Booster Heater Fuel (high-temp only)	5% gas	95% electric	2009 Commercial Appliances Report

Table 4-6 provides a detailed breakdown of the estimated installed base for each type of commercial dishwasher.

[65] Erickson, Kim. 2009. "CEE Program Design Guidance Commercial Dishwashers." Consortium for Energy Efficiency. May 2009.
[66] "A Report on Potential Best Management Practices – Commercial Dishwashers," Prepared for The California Urban Water Conservation Council (CUWCC) by Koeller and Company and H.W. Hoffman & Associates, LLC. June 2010. Available: http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/non_residential/commercial_food_service/Commercial-Dishwashers-CUWCC-PBMP-July-2010.pdf
[67] Commercial Building Energy Consumption Survey,(CBECS) by EIA, available: http://www.eia.gov/consumption/commercial/

Table 4-6: Commercial Dishwasher Installed Base Breakdown.

Type	Temperature	Building WH Type	Booster Heater Type	Distribution of Installed Base	Installed Base
All	**All**	**All**	**All**	**100%**	**570,000**
Undercounter	**All**	**All**	**All**	**43.0%**	**157,000**
	Low-temp	Gas	N/A	9.6%	35,000
	Low-temp	Electric	N/A	6.9%	25,000
	High-temp	Gas	Gas	0.8%	3,000
	High-temp	Electric	Gas	14.6%	53,000
	High-temp	Gas	Electric	0.6%	2,000
	High-temp	Electric	Electric	10.5%	38,000
Door-type	**All**	**All**	**All**	**36.0%**	**288,000**
	Low-temp	Gas	N/A	8.1%	65,000
	Low-temp	Electric	N/A	5.8%	46,000
	High-temp	Gas	Gas	0.6%	5,000
	High-temp	Electric	Gas	12.2%	98,000
	High-temp	Gas	Electric	0.5%	4,000
	High-temp	Electric	Electric	8.8%	70,000
Conveyor	**All**	**All**	**All**	**19.0%**	**105,000**
	Low-temp	Gas	N/A	4.3%	24,000
	Low-temp	Electric	N/A	3.1%	17,000
	High-temp	Gas	Gas	0.3%	2,000
	High-temp	Electric	Gas	6.5%	36,000
	High-temp	Gas	Electric	0.2%	1,000
	High-temp	Electric	Electric	4.6%	26,000
Flight-type	**All**	**All**	**All**	**2.0%**	**20,000**
	Low-temp [a]	Gas	N/A	N/A	N/A
	Low-temp [a]	Electric	N/A	N/A	N/A
	High-temp	Gas	Gas	0.1%	1,000
	High-temp	Electric	Gas	1.1%	11,000
	High-temp [b]	Gas	Electric	0.0%	-
	High-temp	Electric	Electric	0.8%	8,000

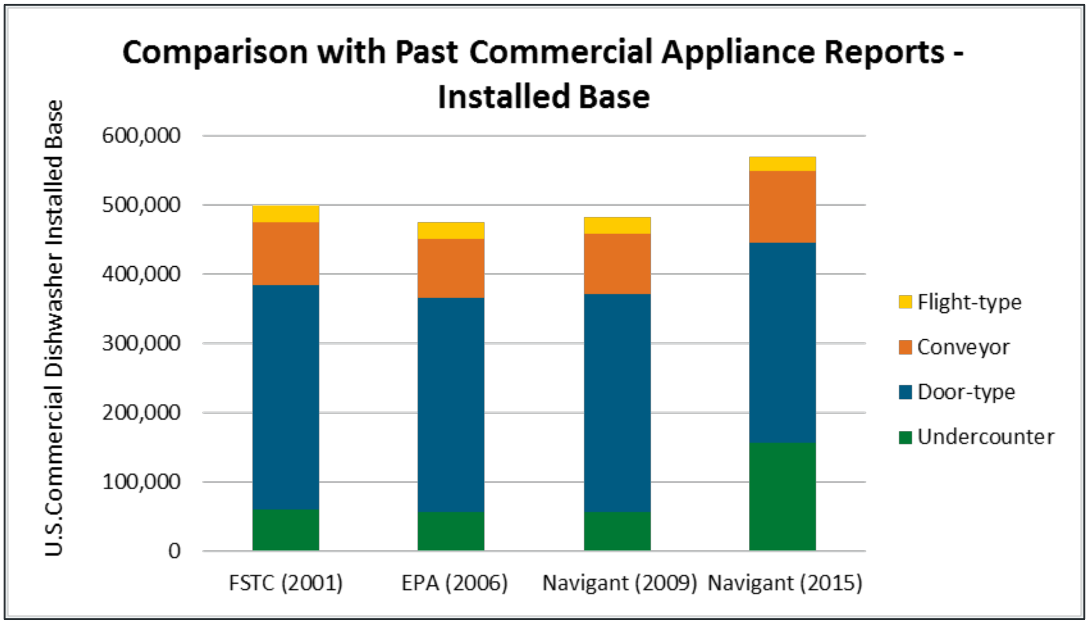
Notes:

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

a. While this configuration may exist in small numbers, it is uncommon; in our analysis, the installed base rounds to zero.
b. Manufacturers only offer flight-type dishwashers with a high-temp sanitizing configuration

To help understand the potential uncertainty in this analysis and the relative change versus other historical installed base estimates, Figure 4-1 shows our 2015 estimates alongside 3 historical estimates. Note that the 2009 Commercial Appliances Report inadvertently switched the percentage of the installed base for door-type units and conveyor units; the data are corrected in this figure.



Sources: EPA (2006), 2009 Commercial Appliances Report[68]

Figure 4-1: Comparison of data sources for installed base

Table 4-7 outlines the expected useful life for different commercial dishwasher types. Longer EULs could potentially convince building owners or operators to consider higher efficiency equipment with greater incremental cost, since a moderately long payback period (e.g., 5 years) is still early in the product's life.

Table 4-7: Expected Useful Life for Commercial Dishwashers

Equipment Type	Expected Useful Life (Years)
Undercounter	10
Door-type	15
Conveyor	20
Flight-type	>20

Source: Koeller and Company and H.W. Hoffman & Associates, LLC. 2010[69]

[68] 2001 and 2006 data from: ENERGY STAR® for Commercial Dishwashers: Sizing up the Savings Opportunity Rachel Schmeltz, US EPA 2006. 2009 Data from 2009 Commercial Appliances Report.
[69] Koeller and Company and H.W. Hoffman & Associates, LLC. 2010. "A Report on Potential Best Management Practices – Commercial Dishwashers," Prepared for The California Urban Water Conservation Council (CUWCC) by Koeller and Company and H.W. Hoffman & Associates, LLC. June 2010. Available: http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/non_residential/commercial_food_service/Commercial-Dishwashers-CUWCC-PBMP-July-2010.pdf

4.3 Product Cost Breakdown

Commercial dishwasher costs can vary substantially depending on equipment type, temperature, capacity, and other characteristics. Table 4-8 provides estimates on baseline and incremental costs for different commercial dishwasher categories.

Table 4-8: Estimated Baseline and Incremental Cost for Commercial Dishwashers

Equipment Type	Temperature	Baseline Cost	Incremental Cost	Incremental Cost
		Source 1		Source 2
Undercounter	Low-temp	$4,800	$1,000	$50
	High-temp	$6,900	$2,100	$120
Door-type	Low-temp	$6,500	$2,000	$0
	High-temp	$6,900	$2,100	$770
Conveyor	Low-temp, single-tank	$11,000	$3,000	$0
	Low-temp, multiple-tank	$18,000	$4,000	$970
	High-temp, single-tank	$12,000	$3,000	$2,050
	High-temp, multiple-tank	$20,000	$4,000	$970
Flight-type	Flight-type dishwashers are custom-built, high volume models with a wide range of features. Costs range from $50,000-$100,000 and greater.			

Source 1: Koeller and Company and H.W. Hoffman & Associates, LLC. 2010[70]
Source 2: ENERGY STAR Commercial Kitchen Equipment Savings Calculator. 2015[71]

4.4 Baseline Energy Consumption

Commercial dishwasher energy consumption varies widely depending on the type of equipment, the sanitizing rinse temperature, the building water heating fuel, and the booster water heater fuel. This analysis relies on ENERGY STAR estimates from EPA, available as default values in their Commercial Kitchen Equipment Savings Calculator.[72] Table 4-9 provides detailed estimates of site energy consumption for each type of product. The primary driver of energy consumption is the volume of water required – typically specified on a per-dishrack basis. The best models consume 0.5 gallons per rack, while a conventional model may consume more than 2 gallons per rack. Other assumptions, including daily operating hours and racks washed per day also factor into the calculations.

[70]Koeller and Company and H.W. Hoffman & Associates, LLC. 2010. "A Report on Potential Best Management Practices – Commercial Dishwashers," Prepared for The California Urban Water Conservation Council (CUWCC) by Koeller and Company and H.W. Hoffman & Associates, LLC. June 2010. Available: http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/non_residential/commercial_food_service/Commercial-Dishwashers-CUWCC-PBMP-July-2010.pdf

[71] EPA. 2015. "Commercial Kitchen Equipment Savings Calculator," EPA, last updated February 2015; available: http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx

[72] EPA. 2015. "Commercial Kitchen Equipment Savings Calculator," EPA, last updated February 2015; available: http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx

Table 4-9: Commercial Dishwasher Site UEC

Equipment Type	Wash Temp	Building Water Heater Fuel	Booster Heater Fuel	Machine Electric Use (kWh/yr.)	Booster Heater Energy Use		Building Water Heater Energy Use		Total Site Energy Use	
					Gas MMBtu/yr.	Electric kWh/yr.	Gas MMBtu/yr	Electric kWh/yr.	Gas MMBtu/yr.	Electric kWh/yr.
Under-counter [a]	Low	Gas	none	2,829	N/A	N/A	34	-	34	2,800
	Low	Electric	none	2,829	N/A	N/A	-	8,136	-	11,000
	High	Gas	Gas	4,300	12	-	21	-	34	4,300
	High	Gas	Electric	4,300	-	2,929	21	-	21	7,200
	High	Electric	Gas	4,300	12	-	-	5,126	12	9,400
	High	Electric	Electric	4,300	-	2,929	-	5,126	-	12,400
Door-type [a]	Low	Gas	none	2,409	N/A	N/A	154	-	150	2,400
	Low	Electric	none	2,409	N/A	N/A	-	36,870	-	39,300
	High	Gas	Gas	4,234	54	-	95	-	150	4,200
	High	Gas	Electric	4,234	-	12,942	95	-	95	17,200
	High	Electric	Gas	4,234	54	-	-	22,649	54	26,900
	High	Electric	Electric	4,234	-	12,942	-	22,649	-	39,800
Conveyor [a]	Low	Gas	none	10,147	N/A	N/A	150	-	150	10,100
	Low	Electric	none	10,147	N/A	N/A	-	35,992	-	46,100
	High	Gas	Gas	13,198	70	-	122	-	190	13,200
	High	Gas	Electric	13,198	-	16,661	122	-	120	29,900
	High	Electric	Gas	13,198	70	-	-	29,157	70	42,400
	High	Electric	Electric	13,198	-	16,661	-	29,157	-	59,000
Flight-type [b]	Low	Gas	none	N/A	N/A	N/A	N/A	N/A	-	-
	Low	Electric	none	N/A	N/A	N/A	N/A	N/A	-	-
	High	Gas	Gas	21,117	111	-	195	-	310	21,100
	High	Gas	Electric	21,117	-	26,658	195	-	200	47,800
	High	Electric	Gas	21,117	111	-	-	46,652	110	67,800
	High	Electric	Electric	21,117	-	26,658	-	46,652	-	94,400

a. Based on ENERGY STAR® Calculator [73]
b. Estimated by scaling energy consumption of conveyor dishwashers using scaling factor or 1.6 (Table 4-10)

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 AEC 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

[73] "Commercial Kitchen Equipment Savings Calculator," EPA, last updated February 2015; available: http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx

machines by equipment capacity (meals/hour). Table 4-10 summarizes capacity range and typical capacity for conveyor and flight-type dishwashers.

Table 4-10: Energy Scaling Factor for Flight-Type Dishwashers

Equipment 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
c. Calculated: Flight-type Typical Capacity/Conveyor Typical Capacity

While the ENERGY STAR data are widely cited, other sources dispute some of these assumptions. For example, Pacific Gas and Electric's technical workpaper for door-type units (part of their regulatory filings to the California public utilities commission for energy efficiency rebates) assumes approximately half as many racks per day as the ENERGY STAR data. The workpaper states:

> "…monitored data from 5 different food service facilities including fast casual, fine dining, cafes, and quick service restaurants yielded an average of 141 racks per day. This value coincides with value by the dishwasher leasing companies of estimated at 4000 racks per month, or approximately 133 racks per day."[74]

Given this comparison, the underlying EPA-based assumptions that we use in this analysis (see Table 4-11) may be considered an over estimation of the energy consumption of commercial dishwashers.

Table 4-11: ENERGY STAR Assumptions on Operating Characteristics

Equipment Type	Racks per Day	Gallons per Rack (Low-Temp)	Gallons per Rack (High-Temp)
Undercounter	75	1.73	1.09
Door-type	280	2.10	1.29
Conveyor (single-tank) [a]	400	1.31	0.87
Conveyor (multi-tank) [a]	600	1.04	0.97
Pot, pan, utensil [b]	280	N/A	0.70

Source: ENERGY STAR Commercial Kitchen Equipment Savings Calculator[75]
a. Combined for the purposes of this study by averaging energy consumption
b. Combined with door-type units in this study

[74] "Energy Efficiency door-Type Commercial Dishwashers" a technical workpaper prepared by Pacific Gas & Electric Company; last revised February 10, 2015; available via California Technical Forum website: http://www.caltf.org/s/PGECOFSTNEW_Rev0_Dishwashers_02202015.docx

[75] "Commercial Kitchen Equipment Savings Calculator," EPA, last updated February 2015; available: http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx

The total nationwide AEC for commercial dishwashers is 175 trillion Btus per year (TBtu/yr. - primary energy). The biggest contributors are door-type units, due to their large installed base, and units with electric booster heaters. Table 4-12 shows the details behind the primary energy calculations for each product type; the product variations are sorted within each system architecture (e.g., undercounter) by primary energy consumption.

Table 4-12: Commercial Dishwashers Primary AEC

Type	Wash Temp	Building Water Heater Fuel	Booster Heater Fuel	Primary Gas (TBtu/yr.)	Primary Electricity (TBtu/yr.)	Total Primary Energy (TBtu/yr.)	Total Excluding Building Water Heaters (TBtu/yr.)
Under-counter	Low-temp	Gas	N/A	1.3	1.1	2.4	1.1
	Low-temp	Electric	N/A	0.0	2.9	2.9	0.8
	High-temp	Gas	Gas	0.1	0.1	0.2	0.2
	High-temp	Gas	Electric	1.2	4.1	5.4	4.1
	High-temp	Electric	Gas	0.0	0.2	0.2	0.1
	High-temp	Electric	Electric	0.0	5.0	5.0	3.0
Door-type	Low-temp	Gas	N/A	10.9	1.7	12.6	1.7
	Low-temp	Electric	N/A	0.0	19.3	19.3	1.2
	High-temp	Gas	Gas	0.8	0.2	1.0	0.5
	High-temp	Gas	Electric	10.1	18.3	28.4	18.1
	High-temp	Electric	Gas	0.2	1.2	1.4	0.4
	High-temp	Electric	Electric	0.0	30.1	30.1	12.9
Conveyor	Low-temp	Gas	N/A	3.9	2.6	6.6	2.6
	Low-temp	Electric	N/A	0.0	8.4	8.4	1.9
	High-temp	Gas	Gas	0.4	0.3	0.7	0.4
	High-temp	Gas	Electric	4.8	11.8	16.6	11.6
	High-temp	Electric	Gas	0.1	0.5	0.5	0.2
	High-temp	Electric	Electric	0.0	16.1	16.1	8.3
Flight-type	Low-temp[a]	Gas	N/A	N/A	N/A	N/A	N/A
	Low-temp[a]	Electric	N/A	N/A	N/A	N/A	N/A
	High-temp	Gas	Gas	0.3	0.2	0.6	0.3
	High-temp	Gas	Electric	2.3	5.6	8.0	5.6
	High-temp[b]	Electric	Gas	0.0	0.0	0.0	0.0
	High-temp	Electric	Electric	0.0	8.1	8.1	4.1
Total				**37**	**138**	**175**	**79**

Source: calculated from installed base (Table 4-6, above) and UEC (Table 4-9, above)

a. Manufacturers only offer flight-type dishwashers with a high-temp sanitizing configuration

b. While this configuration may exist in small numbers, it is uncommon; in our analysis, the installed base rounds to zero.

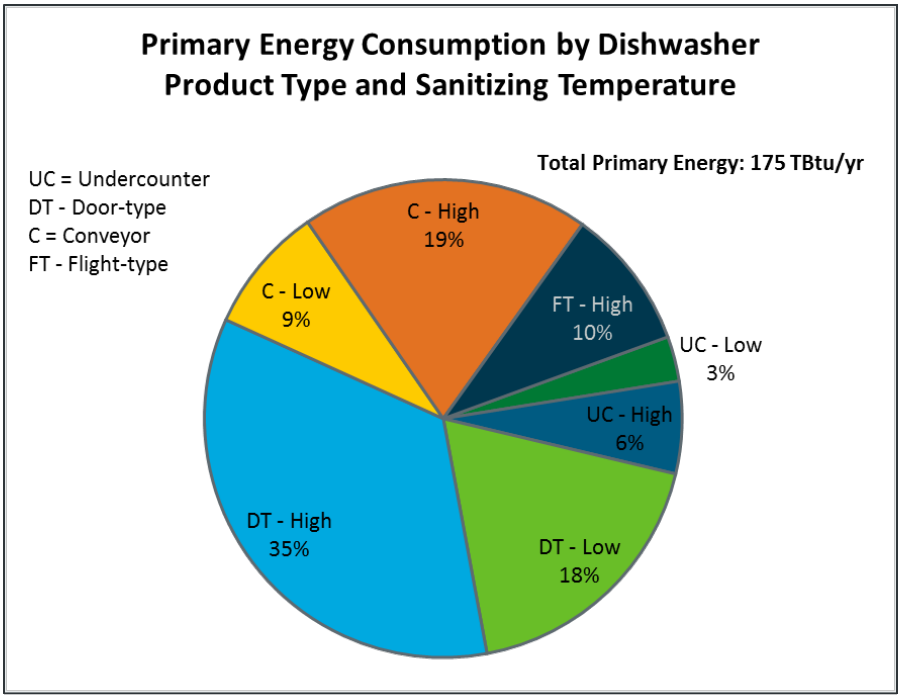
Table 4-13 provides a summary of primary energy consumption for commercial dishwashers, broken down by fuel, model, sanitizing temperature, and by the 3 categories of energy using components: booster water heater, building water heater, and machine operations.

Table 4-13: AEC Breakdown - Primary Energy Consumption by Source

Equipment Type		Primary Gas Consumption (TBtu/yr.)		Primary Electricity Consumption (TBtu/yr.)			Total Primary Energy Consumption (TBtu/yr.)
		Booster	Building WH	Booster	Building WH	Machine	
Under-counter	Low-temp	0.0	1.3	0.0	2.2	1.8	5
	High-temp	0.1	1.3	2.9	2.2	4.4	11
	Subtotal	***0.1***	***2.6***	***2.9***	***4.4***	***6.3***	***16***
Door-type	Low-temp	0.0	10.9	0.0	18.2	2.9	32
	High-temp	0.5	10.6	23.4	18.0	8.1	61
	Subtotal	***0.5***	***21.6***	***23.4***	***36.2***	***10.9***	***93***
Conveyor	Low-temp	0.0	3.9	0.0	6.6	4.5	15
	High-temp	0.2	5.0	11.1	8.5	9.2	34
	Subtotal	***0.2***	***9.0***	***11.1***	***15.0***	***13.7***	***49***
Flight-type	Low-temp	N/A	N/A	N/A	N/A	N/A	0
	High-temp	0.1	2.6	5.4	4.0	4.5	17
	Subtotal	***0.1***	***2.6***	***5.4***	***4.0***	***4.5***	***17***
	Total	1	36	43	60	35	175

Source: data in Table 4-13, above

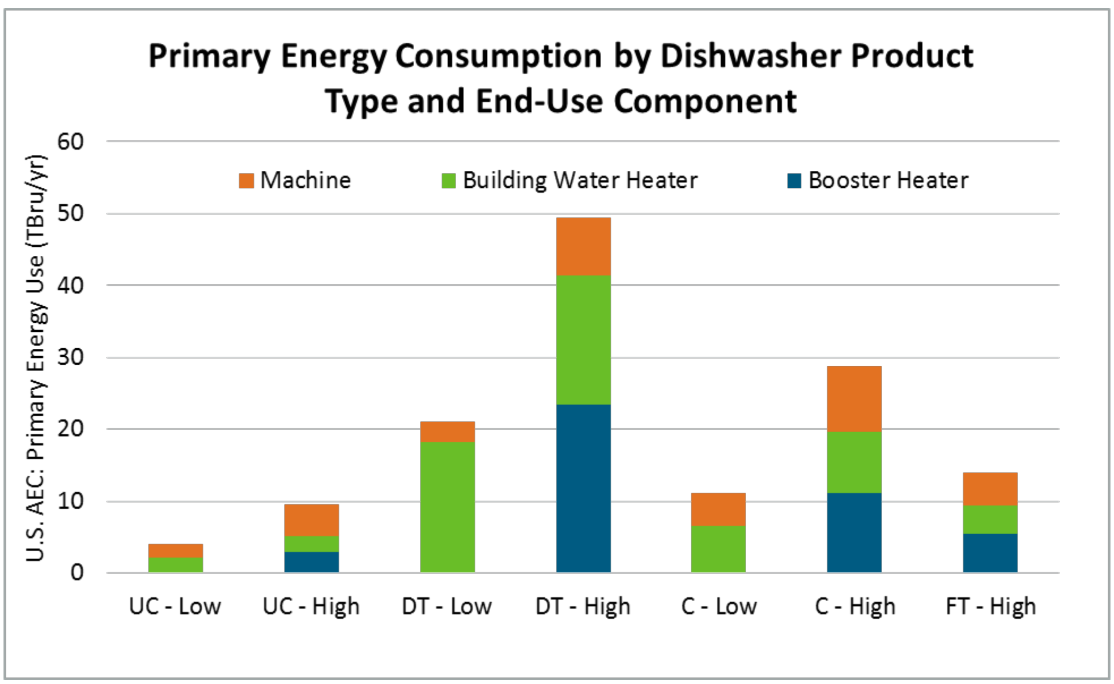
Door-type dishwashers consume more than 50% of the total primary energy in the U.S. for commercial dishwashers with high-temp door-type models as the single largest category. Figure 4-2 shows the split by product type.



Source: data in Table 4-13, above.

Figure 4-2: Primary energy consumption by dishwasher equipment type and temperature

Figure 4-3 provides a breakdown of commercial dishwasher AEC by product type and energy-consuming component. Low-temp models do not include booster water heating as they do not need to increase water temperatures supplied by the domestic water heating system.

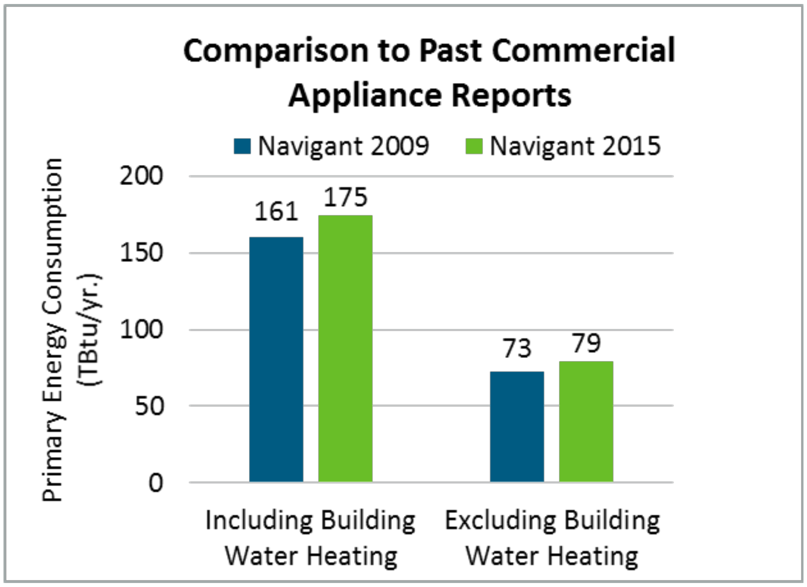


Source: data in Table 4-13, above; UC = Undercounter, DT = Door-type, C = Conveyor, FT = Flight-type

Figure 4-3: Primary energy use by dishwasher product type and end-use component

4.5 Comparison of Baseline Energy Consumption to Previous Studies

Figure 4-4 compares the estimated 2015 commercial dishwasher primary energy consumption with estimates from the 2009 Commercial Appliances Report. We are unaware of other estimates for national commercial dishwasher AEC. This AEC estimate represents an increase of 9% since the 2009 Commercial Appliances Report or 14 TBtu/yr. when including building water heating and 7 TBtu/yr. when excluding building water heating. We believe this value is directionally accurate, but it is difficult to make a claim for the relative accuracy of this estimate without greater investigation into the uncertainty of the data sources.



Sources: Table 4-12, 2009 Commercial Appliances Report[76]

Figure 4-4: Comparison of energy consumption estimates with 2009 Commercial Appliance Report

4.6 Energy Savings Opportunities

ENERGY STAR commercial dishwashers offer up to 40% energy and water savings by incorporating advanced rinse nozzle and arm designs, additional insulation, improved curtain designs to minimize airflow, heat recovery for incoming water preheating, reusing rinse water, and other features.[77] Table 4-14 provides the estimated technical potential for commercial dishwashers meeting ENERGY STAR performance specifications. In aggregate, ENERGY STAR commercial dishwashers could reduce annual primary energy consumption by 33% when including building water heating consumption and 26% when only considering equipment-level consumption.

[76] 2001 and 2006 data from: ENERGY STAR® for Commercial Dishwashers: Sizing up the Savings Opportunity Rachel Schmeltz, US EPA 2006. 2009 Data from 2009 Commercial Appliances Report.
[77] EPA. 2015. "Benefits of ENERGY STAR Certified Commercial Food Service (CFS) Equipment – Commercial Dishwashers." Available at: http://www.energystar.gov/ia/products/downloads/Dishwashers_Product_Factsheet_Final.pdf

Table 4-14: Estimated Technical Potential for Commercial Dishwashers

Type	Wash Temp	Building Water Heater Fuel	Booster Heater Fuel	Total Energy Savings		Total Energy Savings Excluding Building Hot Water	
				Savings %	Savings (TBtu/yr.)	Savings %	Savings (TBtu/yr.)
Under-counter	Low-temp	Gas	N/A	17%	0.4	0%	0.0
	Low-temp	Electric	N/A	23%	0.7	0%	0.0
	High-temp	Gas	Gas	28%	0.1	31%	0.1
	High-temp	Gas	Electric	27%	1.5	29%	1.2
	High-temp	Electric	Gas	26%	0.1	31%	0.0
	High-temp	Electric	Electric	26%	1.3	29%	0.9
Door-type	Low-temp	Gas	N/A	38%	4.8	0%	0.0
	Low-temp	Electric	N/A	41%	8.0	0%	0.0
	High-temp	Gas	Gas	28%	0.3	26%	0.1
	High-temp	Gas	Electric	29%	8.3	28%	5.1
	High-temp	Electric	Gas	30%	0.4	26%	0.1
	High-temp	Electric	Electric	30%	9.0	28%	3.6
Conveyor	Low-temp	Gas	N/A	29%	1.9	0%	0.0
	Low-temp	Electric	N/A	38%	3.2	0%	0.0
	High-temp	Gas	Gas	32%	0.2	25%	0.1
	High-temp	Gas	Electric	35%	5.8	31%	3.6
	High-temp	Electric	Gas	37%	0.2	25%	0.1
	High-temp	Electric	Electric	38%	6.1	31%	2.6
Flight-type	Low-temp [a]	Gas	N/A	30%	0.0	30%	0.0
	Low-temp [a]	Electric	N/A	30%	0.0	30%	0.0
	High-temp	Gas	Gas	30%	0.2	30%	0.1
	High-temp	Gas	Electric	30%	2.4	30%	1.7
	High-temp[b]	Electric	Gas	30%	0.0	30%	0.0
	High-temp	Electric	Electric	30%	2.4	30%	1.2
Total				**33%**	**57.1**	**26%**	**20.5**

Source: Calculated from baseline AEC (Table 4-6 above and savings percentages from ENERGY STAR Commercial Food Service Calculator (where available).[78] We assume the energy savings percentages of multi-tank conveyor dishwashers for all conveyor dishwasher types. Flight-type dishwashers are custom-built machines and have a wide variety of water and energy consumption characteristics. Energy savings estimate of 30% is conservatively based on a review of ENERGY STAR discussions on flight-type dishwashers[79,80] and water utility rebates.[81]

[78] "Commercial Kitchen Equipment Savings Calculator," EPA, last updated February 2015; available: http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx
[79] EPA. 2011. "ENERGY STAR Discussion Document: Flight Type Commercial Dishwashers." Available at: http://www.energystar.gov/sites/default/files/specs//private/Flight_Type_Discussion_Document.pdf
[80] EPA. 2011. "Commercial Dishwasher Plots Draft 2." Available at: http://www.energystar.gov/sites/default/files/specs//private/Commercial_Dishwasher_Plots_Draft_2_--_Flight_Type.pdf
[81] Austin Water. 2014. "Restaurants and Commercial Kitchens." Available at: https://www.austintexas.gov/sites/default/files/files/Water/Conservation/commercialrestaurantweb.pdf

Manufacturers also offer products that exceed ENERGY STAR specifications for energy and water savings. Table 4-15 provides the estimated hot water savings (gal/rack) for ENERGY STAR and best-in-class commercial dishwashers in 2010 and 2015. These advanced dishwashers incorporate a greater number of high-efficiency components to reduce the amount of hot water and operating energy to clean a rack of dishes.

Table 4-15: Estimated Hot Water Savings from ENERGY STAR and Best-in-Class Dishwashers

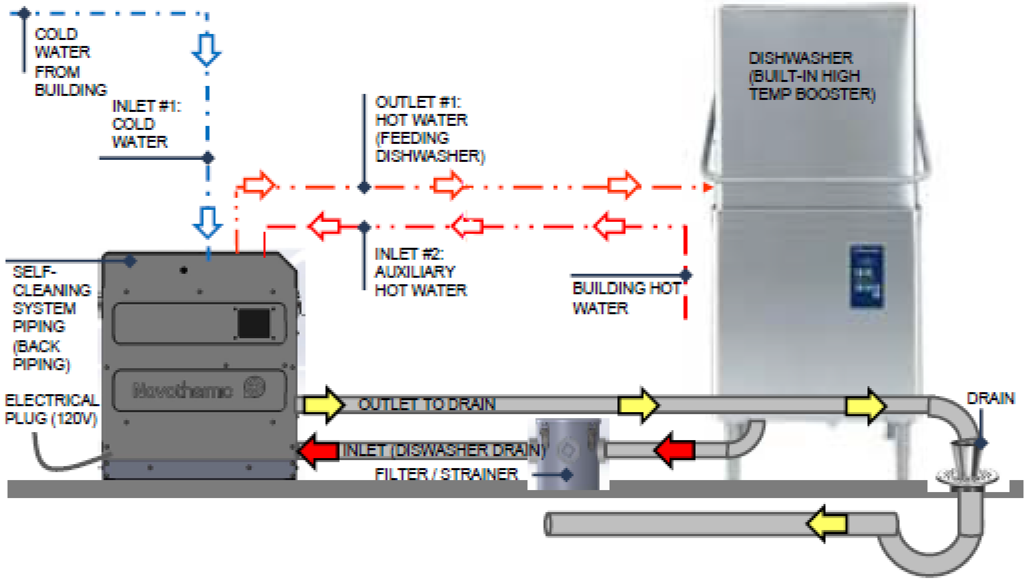
Wash Temp	Equipment Type	Unit Hot Water Consumption - gal/rack (% savings over baseline in parentheses)			
		Baseline [a]	ENERGY STAR v2[b]	Best-in-Class (2010)[a]	Best-in-Class (2015)[c]
Low-temp	Undercounter	1.95	1.19 (39%)	0.74 (62%)	0.74 (62%)
	Door-type	1.85	1.18 (36%)	0.73 (61%)	0.89 (52%)
	Conveyor, single-tank	1.23	0.79 (36%)	0.49 (60%)	0.56 (54%)
	Conveyor, multiple-tank	0.99	0.54 (45%)	0.39 (61%)	0.39 (61%)
High-temp	Undercounter	1.50	0.86 (43%)	0.70 (53%)	0.62 (59%)
	Door-type	1.40	0.89 (36%)	0.70 (50%)	0.33 (76%)
	Conveyor, single-tank	1.10	0.70 (36%)	0.35 (68%)	0.30 (73%)
	Conveyor, multiple-tank	1.10	0.54 (51%)	0.28 (75%)	0.34 (69%)

Source: a. FSTC. 2010. "Design Guide – Energy-Efficient Water Heating, Delivery and Use."[82]
b. ENERGY STAR Commercial Dishwasher Specification, Version 2.0[83] c. ENERGY STAR Certified Product Database[84]

Because of the long equipment lifetimes and relatively high initial equipment cost, retrofit technologies for commercial dishwashers could offer attractive energy savings opportunities rather than full equipment replacement. For example, baseline commercial dishwashers could incorporate an external add-on heat recovery system to preheat incoming water. Figure 4-5 provides a schematic of a prototype dishwasher heat recovery system from Novothermic. The manufacturer claims the technology can provide up to 50% dishwasher water heating cost savings.[85] Anticipated laboratory testing will further reveal energy savings estimates.[86]

---

[82] FSTC. 2010. "Design Guide – Energy Efficient Water Heating, Delivery and Use." Food Service Technology Center. March 26, 2010. Available at: http://www.fishnick.com/design/waterheating/Water_Heating_Design_Guide_Final_FNi_disclaimer.pdf
[83] ENERGY STAR Commercial Dishwasher Specification, Version 2.0 https://www.energystar.gov/index.cfm?c=comm_dishwashers.pr_crit_comm_dishwashers
[84] ENERGY STAR Certified Product Database – Commercial Dishwashers. Accessed October 29, 2015. Available at: http://www.energystar.gov/productfinder/product/certified-commercial-dishwashers/
[85] Novothermic. Accessed October 2015. http://www.novothermic.com/en
[86] Champoux, Benoit. 2015. Novothermic. Personal Communication with Jim Young of Navigant. September 11, 2015.



Source: Champoux, Benoit. "Heat Recovery from Dishwasher Drain Water – Innovation towards Smarter Energy & Water Use." February 2015. [87]

Figure 4-5: Schematic of retrofit dishwasher heat recovery system

Several advanced cleaning systems could potentially offer energy savings for commercial dishwashers, but require additional R&D to evaluate their relative efficiency to conventional dishwashers. These technologies include:

- Supercritical CO_2 dishwashers would use the unique properties of supercritical fluids to submerge and clean dishes without the use of water. The CO_2 fluid could then be separated from the food particles for reuse.
- Ultrasonic dishwashers generate high frequency sound waves to create cavitation bubbles in water that can clean submerged dishware. The technology is commercialized for industrial, jewelry, and other specialized cleaning systems, but requires additional development to operate with relatively fragile commercial dishware.

The Technical Support Document from the 2012 residential dishwasher rulemaking contains additional information on these technologies.[88]

4.7 Regulated and Voluntary Efficiency Standards

There are currently no regulatory programs in place for commercial dishwashers.

EPA's ENERGY STAR program offers a certification for commercial dishwashers, with the second specification effective in February 1, 2013. Table 4-16 provides the ENERGY STAR

[87] Champoux, Benoit. 2015. "Heat Recovery from Dishwasher Drain Water – Innovation towards Smarter Energy & Water Use." Novothermic. 2015 ACEEE Hot Water Forum. February 2015.
[88] DOE. 2012. "Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers." U.S. Department of Energy. EERE-2011-BT-STD-0060. Available at: http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0060-0007

efficiency requirements for commercial dishwashers. ENERGY STAR certified products comprised an estimated 64% of commercial dishwasher shipments in 2014.[89]

Table 4-16: ENERGY STAR Key Product Criteria for Commercial Dishwashers

Equipment Type	High-Temp Efficiency Requirements		Low-Temp Efficiency Requirements	
	Idle Energy Rate	Water Consumption*	Idle Energy Rate	Water Consumption [a]
Undercounter	≤ 0.50 kW	≤ 0.86 GPR	≤ 0.50 kW	≤ 1.19 GPR
Door-type, stationary single-tank	≤ 0.70 kW	≤ 0.89 GPR	≤ 0.60 kW	≤ 1.18 GPR
Pot, pan, and utensil	≤ 1.20 kW	≤ 0.58 GPSF	≤ 1.00 kW	≤ 0.58 GPSF
Conveyor, single-tank	≤ 1.50 kW	≤ 0.70 GPR	≤ 1.50 kW	≤ 0.79 GPR
Conveyor, multiple-tank	≤ 2.25 kW	≤ 0.54 GPR	≤ 2.00 kW	≤ 0.54 GPR
Flight-type, single-tank	Reported [b]	GPH ≤ 2.975x + 55.00	Reported [b]	GPH ≤ 2.975x + 55.00
Flight-type, multiple-tank	Reported [b]	GPH ≤ 4.96x + 17.00	Reported [b]	GPH ≤ 4.96x + 17.00

Source: ENERGY STAR Commercial Dishwasher Specification, Version 2.0[90]

a. GPR = gallons per rack; GPSF = gallons per square foot of rack; GPH = gallons per hour; x = maximum conveyor speed (feet/min as verified through NSF 3 certification) x conveyor belt width (feet).

b. ENERGY STAR does not specify an idle energy rate for flight-type dishwashers, but the manufacturer must report the value.

[89] ENERGY STAR Unit Shipment Data Report 2014, available: http://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2014_USD_Summary_Report.pdf?86f6-7243

[90] ENERGY STAR Commercial Dishwasher Specification, Version 2.0 https://www.energystar.gov/index.cfm?c=comm_dishwashers.pr_crit_comm_dishwashers

5 IT and Office Equipment

Information technology (IT) and office equipment includes a wide variety of electrical devices that support business activities through communication, imagining, data storage and other functions. Many types of IT and office equipment have both residential and commercial applications. For many products, the same equipment can serve both sectors (e.g., desktop monitors), while other categories differ on their capacity (e.g., large office printer vs. small home printer), with higher-capacity products designed for commercial applications. This report only considers equipment designed for and installed in commercial buildings. Therefore, the installed base estimates do not include the residential markets, and the UEC of commercial equipment is typically higher than consumer products.

Table 5-1 provides a brief description for major equipment types and subcategories. Appendix A: Technology Descriptions provides more detailed descriptions of each equipment type and subcategory.

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

Major Equipment Types	Equipment Subcategories
Personal Computers	Desktop and laptop computers
Desktop Monitors	Primary and secondary monitors
Imaging Equipment	Printers, multifunction devices (MFDs), fax machines, document scanners
Server Computers	Enterprise/corporate, small/medium data centers, hyperscale cloud data centers
Network Equipment	Switching products, enterprise routers, enterprise WLAN, security applications
Uninterruptable Power Supply	Enterprise and data centers

Table 5-2 provides a summary of the UEC, installed base, and AEC for U.S. commercial IT and office equipment. The estimated 2015 primary AEC for IT and office equipment is 1.04 Quads/yr. This sector includes over 700 million devices, with various network equipment comprising over 60% of the installed base.

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

Equipment Types	Average UEC (kWh/yr.)	Installed Base (1,000s)	AEC—Site Energy (TWh/yr.)	AEC—Primary Energy (Quads/yr.)
Personal Computers	n/a	106,000	24.2	0.26
Desktop Computers	285	76,000	21.6	0.23
Laptop Computers	87	30,000	2.6	0.03
Desktop Monitors	130	91,000	11.8	0.13
Imaging Equipment	n/a	40,000	10.1	0.11
Printers	284	26,000	7.4	0.08
MFDs	432	5,000	2.3	0.02
Fax Machines	52	6,000	0.3	0.00
Document Scanners	23	4,000	0.1	0.00
Server Computers	2,274	14,000	30.7	0.33
Network Equipment	n/a	472,000	13.4	0.14
Switching Products	17	454,000	7.9	0.09
Enterprise Routers	466	4,000	1.7	0.02
Enterprise WLAN	107	11,000	1.2	0.01
Security Applications	940	3,000	2.5	0.03
UPS	442	15,000	6.7	0.07
	Total:	738,000	97	1.04

Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15.

Figure 5-1 provides a breakdown for each IT and office equipment category's primary energy consumption. Server computers have the largest energy consumption for any equipment category with 32% of the national total, but PCs and their associated monitors consume a combined 37% of the national total.

The following sections discuss the derivation of these values in detail.

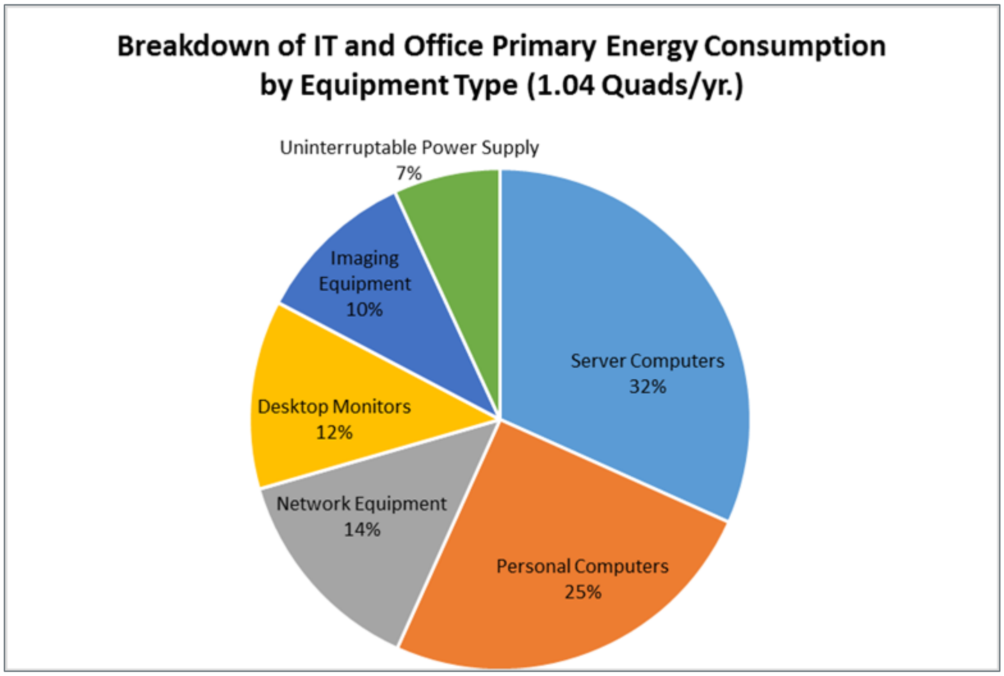


Figure 5-1: Percentage breakdown of IT and office equipment primary energy consumption by major equipment type, 2012

5.1 Market Overview

5.1.1 Personal Computers

PCs include both desktop, laptop, thin client, and integrated computer workstations. The residential and commercial market for PCs exceeded 50 million shipments in 2014, as shown in Table 5-3. Desktop PCs once held the majority of the PC market, but consumer preferences and technology advances have allowed laptop PCs to capture over 80% of U.S. shipments.

Table 5-3: 2014 Personal Computer Shipments by Type

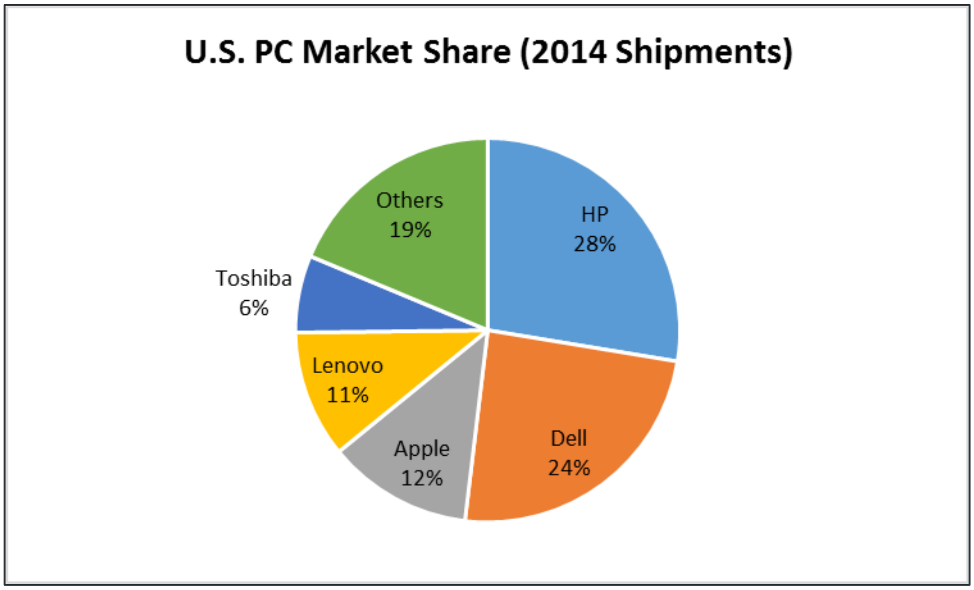
PC Type	2014 Shipments	Percentage of Total
Desktop	8,249	16%
Laptop	40,539	81%
Other	1,340	2%
Total	50,128	100%

Source – ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary[91]

Figure 5-2 provides the market shares for PC manufacturers in the U.S., including desktop and laptop PCs for both residential and commercial markets. Although a variety of companies offer

[91] ENERGY STAR. 2015. "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.

products, the top 5 PC manufacturers capture 81% of the U.S. market – HP, Dell, Apple, Lenovo, and Toshiba.



Data Source: IDC Worldwide Quarterly PC Tracker, January 12, 2015[92]

Note: The data includes sales to residential market.

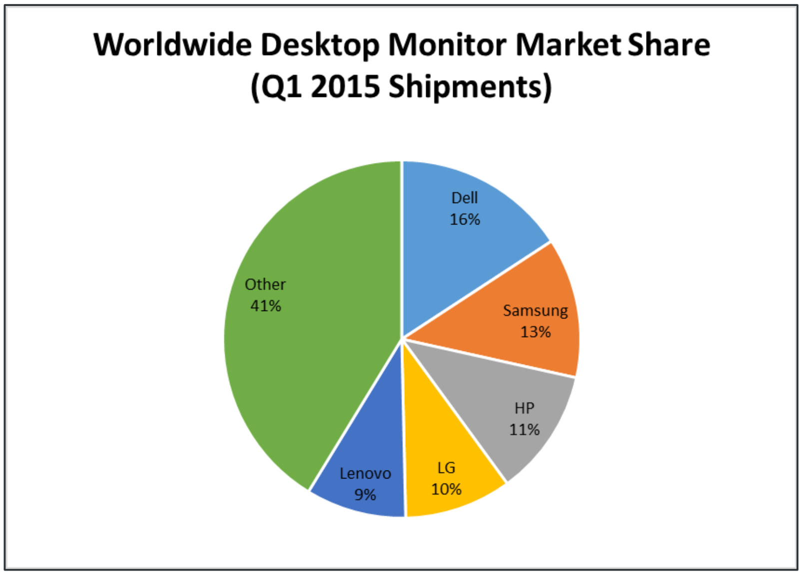
Figure 5-2: U.S. PC market share by shipments, 2014

5.1.2 Desktop Monitors

Desktop monitors include displays for desktop and thin client PCs as well as secondary displays for laptop and other PCs. The residential and commercial market for desktop monitors almost reached 20 million shipments in 2014, with over 88% of the market qualifying for ENERGY STAR certification.[93] Figure 5-3 provides the market shares for desktop monitor manufacturers in the U.S., including both residential and commercial markets. Many companies offer desktop monitors, but the top 5 manufacturers capture 59% of the market – Dell, Samsung, HP, LG, and Lenovo.

[92] IDC. 2015. "PC Leaders Continue Growth And Share Gains As Market Remains Slow, According to IDC." International Data Corporation. January 12, 2015. Available at: http://www.idc.com/getdoc.jsp?containerId=prUS25372415

[93] ENERGY STAR. 2015. "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.



Data Source: IDC Worldwide Quarterly PC Monitor Tracker, June 2015.[94]
Note: The data includes sales to residential market.

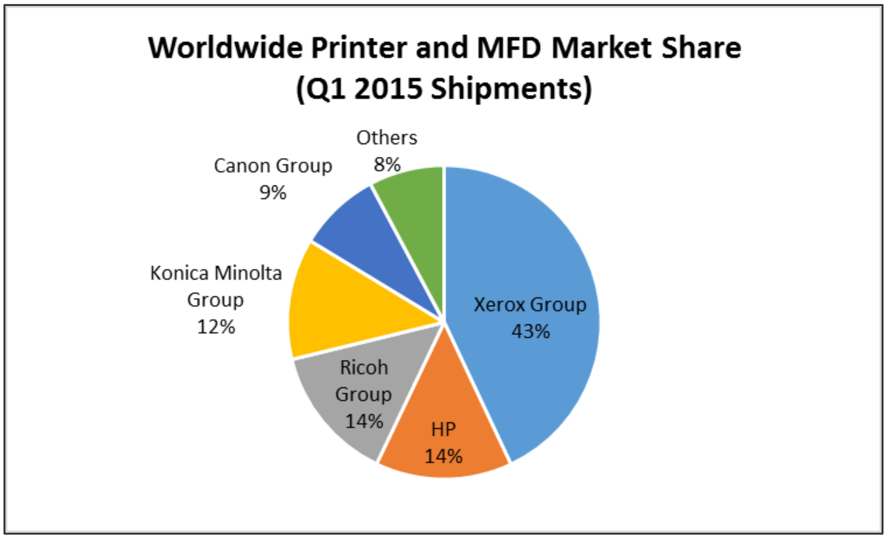
Figure 5-3: Worldwide desktop monitor market share by shipments, Q1 2015

5.1.3 Imaging Equipment

Commercial imagining equipment category includes printers, MFDs, fax machines, and document scanners. The U.S. residential and commercial market bought over 12.5 imaging devices in 2014.[95] As Figure 5-4 shows, the top 5 manufacturers of printers and MFDs (i.e., Xerox, HP, Ricoh, Konica Minolta, and Cannon) capture over 90% of the global marketplace.

[94] IDC. 2015. "Worldwide PC Monitor Market Sees Declining Shipments in the First Quarter of 2015, According to IDC." International Data Corporation. June 24, 2015. Available at: http://www.idc.com/getdoc.jsp?containerId=prUS25636815

[95] ENERGY STAR. 2015. "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.



Source: IDC Worldwide Quarterly Production Printer Tracker, May 2015[96]
Note: The data includes sales to residential market.

Figure 5-4: Worldwide printer and MFD market share by shipments, Q1 2015

5.1.4 Network Equipment

The network equipment category includes several different device types that support communication between computer systems and other devices. This category includes the following technologies:[97]

- **Switching Products:** A network device that filters, forwards, and floods frames (i.e., data packets) based on the destination address of each frame.
- **Enterprise Router:** A network device that determines the optimal path along which network traffic should be forwarded.
- **Enterprise WLAN Controller:** A network device whose primary function is to manage wireless local area network (WLAN) traffic through one or more wireless access point devices.
- **Security Appliance:** A stand-alone network device whose primary function is to protect the network from unwanted traffic.

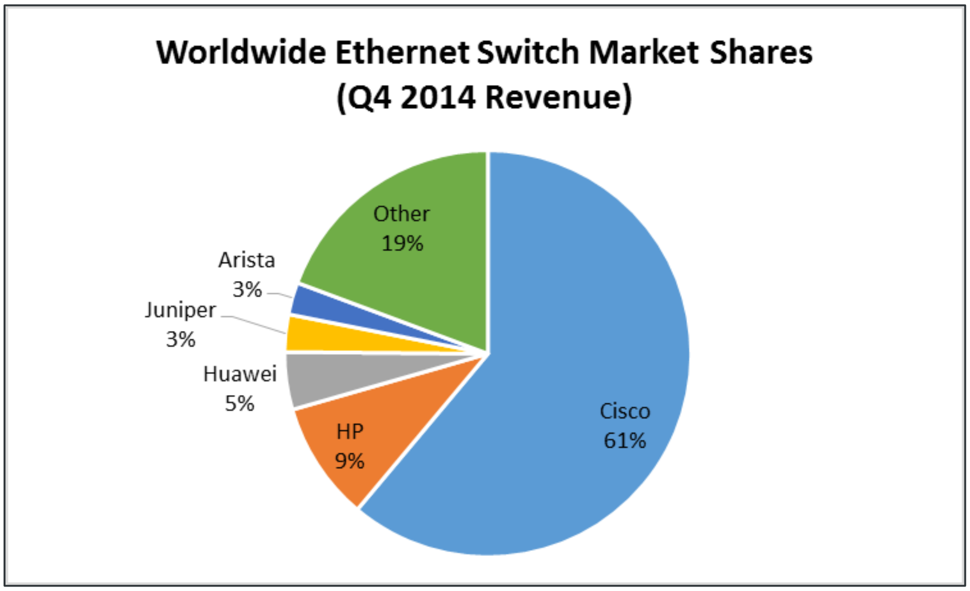
[96] IDC. 2015. "Worldwide Production Printer Shipments Experience 7.5% Growth in the First Quarter of 2015, According to IDC." International Data Corporation. May 26, 2015. Available at: http://www.idc.com/getdoc.jsp?containerId=prUS25643615
[97] Denkenberger et al. 2014. "Network Equipment." Codes and Standards Enhancement (CASE) Initiative For PY 2013: Title 20 Standards Development. May 15, 2014. Available at: http://www.energy.ca.gov/appliances/2013rulemaking/documents/comments/12-AAER-2A_Consumer_Electronics/12-AAER-2A_CA_IOUs_Response_to_CEC_Data_Request_Network_Equipment_2014-05-15_TN-73026.pdf

As Table 5-4 shows, the estimated annual shipments for commercial network equipment devices exceeded 94 million, with switching products comprising the majority of sales. This sector experiences high shipment volume due to the growing penetration of communication systems and the relatively short timeframe until technology obsolescence, which is estimated at 5 years.[98]

Table 5-4: Network Equipment Shipments

Network Equipment Type	2015 Estimated Shipments (1,000s)[99]
Switching Products	90,873
Enterprise Routers	743
Enterprise WLAN	2,144
Security Appliances	542
Total	94,302

As shown in Figure 5-5, Figure 5-6, and Figure 5-7, Cisco has the largest worldwide market share for network equipment with 61% of Ethernet switches, 48% for WLAN, and 17% of security appliances.



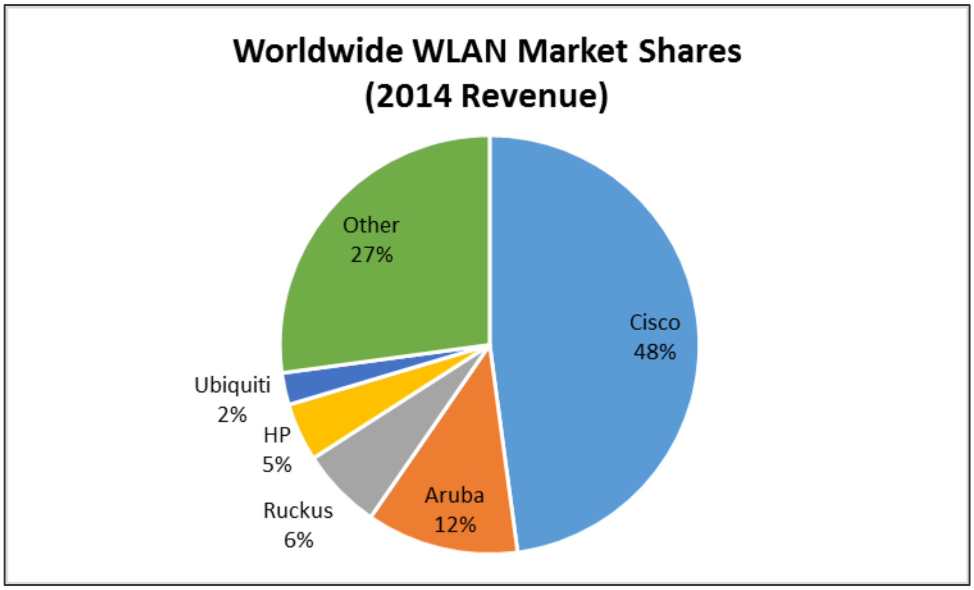
Source: IDC Worldwide Quarterly Ethernet Switch Tracker[100]

Figure 5-5: Worldwide Ethernet switch market share by revenue, Q4 2014

98 Ibid

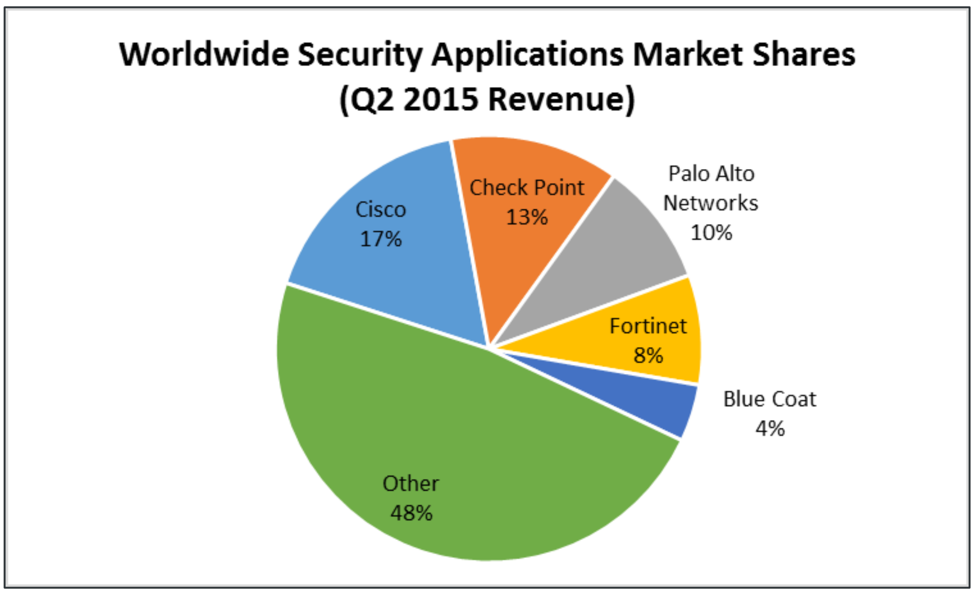
99 Ibid

100 IDC. 2015. "IDC's Worldwide Quarterly Ethernet Switch and Router Tracker Shows Ethernet Switch Market Surpassing $6 Billion and Improved Router Market Worldwide Quarterly Ethernet Switch Tracker." International Data Corporation. March 2, 2015. Available at: http://www.idc.com/getdoc.jsp?containerId=prUS25453715



Source: IDC's Worldwide Quarterly WLAN Tracker [101]

Figure 5-6: Worldwide enterprise WLAN market share by revenue, 2014



Source: IDC Worldwide Quarterly Security Appliance Tracker, September 14, 2015 [102]

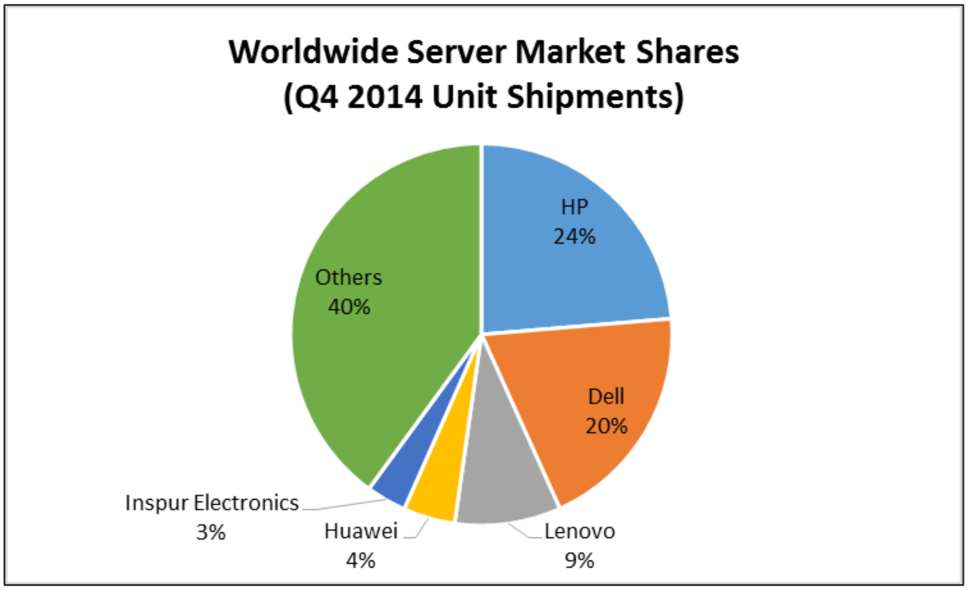
Figure 5-7: Worldwide security applications market share by shipping volume, Q2 2015

[101] IDC. 2015. "Worldwide WLAN Market Shows Slowed Growth in First Quarter of 2015, According to IDC." International Data Corporation. May 28, 2015. Available at: http://www.idc.com/getdoc.jsp?containerId=prUS25642715

[102] IDC. 2015. "Worldwide Security Appliance Market Continues Its Growth Trajectory in the First Half of 2015, According to IDC." International Data Corporation. September 14, 2015. Available at: http://www.idc.com/getdoc.jsp?containerId=prUS25907015

5.1.5 Server Computers

Server computers provide computing, storage, and other services for communication networks located either on-site within an office building or off-site in large data centers. In 2014, the worldwide server computer market had revenues of $50.9 billion and unit shipments of 10.8 million (projected from 2.7M in Q4 2014).[103] As shown in Figure 5-8, HP and Dell provide 24% and 20% of worldwide server shipments, respectively, with many other manufacturers offering products. Additionally, several corporations with many large data centers have started designing their own severs to best fit their needs, and building their own servers through contract manufacturers.



Source: Gartner (March 2015)[104]

Figure 5-8: Worldwide server computer market share by unit shipments, Q4 2014

5.1.6 Uninterruptible Power Supplies

Uninterruptible power supplies (UPS) improve the reliability for PCs, servers, and other devices by providing backup power immediately to reduce interruptions caused by momentary power fluctuations (e.g., voltage surges, voltage sags, and sudden outages). The estimated annual shipments for UPS devices in the U.S. is approximately 3.8 million units, with major manufacturers Schneider Electric, Eaton, Emerson, and many others.

5.2 Annual Shipments and Installed Base

5.2.1 Annual Shipments

Table 5-5 provides a summary of the estimated U.S. annual shipments for different IT and office equipment categories. Appendix A: Technology Descriptions provides additional explanation on the annual shipment estimation methodologies for each category.

[103] Gartner. 2015. “Gartner Says Worldwide Server Market Grew 4.8 Percent in Shipments, While Revenue Increased 2.2 Percent in Fourth Quarter of 2014.” Gartner Inc. March 3, 2015. Available at: http://www.gartner.com/newsroom/id/2997118
[104] Ibid

Table 5-5: Estimated IT/Office Equipment Annual Shipments

Equipment Types	Estimated Annual Shipments (1,000s)	Source
Personal Computers	49,000	ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary[105] Note: Scanner shipments are global, while all others are for the U.S. only
Desktop Computers	8,000	
Laptop Computers	41,000	
Desktop Monitors	20,000	
Imaging Equipment	13,000	
Printers & MFDs	12,000	
Fax Machines	n/a	
Document Scanners	1,000 (Globally)	
Server Computers	11,000	IDC Server Vendor Shipments Estimates, Q4 2014[106]
Network Equipment	94,000	Estimate based on 5 year design life of installed base[107]
Switching Products	91,000	
Enterprise Routers	1,000	
Enterprise WLAN	2,000	
Security Applications	1,000	
UPS	4,000	ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary [108]

5.2.2 Installed Base

Table 5-6 provides a summary of the estimated U.S. installed base for different IT and office equipment categories. We utilized CBECS 2012 data, where available, and additional market research reports. This estimate only includes equipment serving commercial buildings and does not include residential applications.

---

[105] ENERGY STAR. 2015. "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.

[106] Gartner. 2015. "Gartner Says Worldwide Server Market Grew 4.8 Percent in Shipments, While Revenue Increased 2.2 Percent in Fourth Quarter of 2014." Gartner Inc. March 3, 2015. Available at: http://www.gartner.com/newsroom/id/2997118

[107] Denkenberger et al. 2014. "Network Equipment." Codes and Standards Enhancement (CASE) Initiative For PY 2013: Title 20 Standards Development. May 15, 2014. Available at: http://www.energy.ca.gov/appliances/2013rulemaking/documents/comments/12-AAER-2A_Consumer_Electronics/12-AAER-2A_CA_IOUs_Response_to_CEC_Data_Request_Network_Equipment_2014-05-15_TN-73026.pdf

[108] ENERGY STAR. 2015. "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.

Table 5-6: Estimated IT/Office Equipment Installed Base

Equipment Types	Estimated Installed Base (1,000s)	Source / Notes
Personal Computers	106,000	Calculation
Desktop Computers	76,000	CBECS Microdata, Microdata PCTerminal
Laptop Computers	30,000	CBECS Microdata, Microdata Laptop
Desktop Monitors	91,000	CBECS microdata analysis based on number of desktop and laptop computers and responses for multiple monitors
Imaging Equipment	40,000	Calculation
Printers	26,000	CBECS Microdata Printer
MFDs	5,000	CBECS Microdata Copier
Fax Machines	6,000	2010 TIAX Commercial Miscellaneous Electric Loads (CMELS) Report[109]
Document Scanners	4,000	
Server Computers	14,000	Historical values from National Resources Defense Council (NRDC)[110] and Lawrence Berkeley National Laboratory (LBNL)[111] Reports; projected for 2015 with a 3% annual growth rate
Network Equipment	472,000	Calculation
Switching Products	454,000	Historical values from 2010 LBNL report and then projected for 2015 with average annual growth rates (2008-2012)[112]
Enterprise Routers	4,000	
Enterprise WLAN	11,000	
Security Applications	3,000	
UPS	15,000	Calculation based on 2009 installed base and growth rate of server market. Note – limited recent information exists on UPS installed base

5.3 Product Cost Breakdown

Equipment cost for IT and office equipment varies substantially due to the capacity and performance of different products. For example, an office printer may cost $200 or $2,000 depending the capacity, performance, and functionality of each device. Additionally, the individual product cost does not reflect bulk purchases and maintenance contracts common for

[109] McKenney et al. 2010. "Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type." Report for DOE Building Technologies Program. May 2010.
[110] Whitney and Delforge. 2014. "Data Center Efficiency Assessment – Scaling Up Energy Efficiency Across the Data Center Industry: Evaluating Key Drivers and Barriers." National Resources Defense Council. August 2014. Available at: http://www.nrdc.org/energy/files/data-center-efficiency-assessment-IP.pdf
[111] CLEER Model. Version 2. June 24, 2013. Developed by Lawrence Berkeley National Laboratory and Northwestern University. Available at: http://cleermodel.lbl.gov/Model.
[112] Lanzisera et al. 2010. "Data Network Equipment Energy Use and Savings Potential in Buildings." Lawrence Berkeley National Laboratory. 2010.

many equipment types. Because of the wide range within each equipment subcategory, we do not provide cost estimates for IT and office equipment in this report.

5.4 Baseline Energy Consumption

Table 5-7 summarizes the average UEC for IT and office equipment categories. The UEC for products within the same category ranges substantially based on the underlying technology (e.g., laser vs. inkjet printers) and performance (e.g., enterprise vs. high-performance servers).

Table 5-7: Estimated IT/Office Equipment Baseline Energy Consumption

Equipment Types	Average UEC (kWh/yr.)	Source / Notes
Desktop Computers	285	ENERGY STAR Office Energy Calculator[113]
Laptop Computers	87	
Desktop Monitors	130	2014 Fraunhofer study for 2010-2013 LCD models, all monitors assumed as LCD, Average Size 21''[114]
Printers	284	ENERGY STAR Calculator, assumes color printer, 40 images per minute, 50-50 inkjet and laser split[113]
MFDs	432	ENERGY STAR Calculator, assumes color printer, 40 images per minute, 25-75 inkjet and laser split[113]
Fax Machines	52	ENERGY STAR Calculator[113]
Document Scanners	23	
Server Computers	2,274	Subcategory breakdown from 2014 NRDC Report[115] and consumption estimates from LBNL CLEERModel[116]
Switching Products	17	2010 LBNL[117] report for annual consumption and 2014 CEC CASE Report for installed base[118]
Enterprise Routers	466	
Enterprise WLAN	107	
Security Applications	940	
Uninterruptable Power Supply	442	2009 Commercial Appliances Report assumption[119]

[113] ENERGY STAR. 2014. "Savings Calculator for ENERGY STAR Qualified Office Equipment." U.S. Environmental Protection Agency. December 2014.
[114] Urban et al. 2014. "Energy Consumption of Consumer Electronics in U.S. Homes in 2013." Fraunhofer USA. Final Report to the Consumer Electronics Association. June 2014.
[115] Whitney and Delforge. 2014. "Data Center Efficiency Assessment – Scaling Up Energy Efficiency Across the Data Center Industry: Evaluating Key Drivers and Barriers." National Resources Defense Council. August 2014. Available at: http://www.nrdc.org/energy/files/data-center-efficiency-assessment-IP.pdf
[116] CLEER Model. Version 2. June 24, 2013. Developed by Lawrence Berkeley National Laboratory and Northwestern University. Available at: http://cleermodel.lbl.gov/Model.
[117] Lanzisera et al. 2010. "Data Network Equipment Energy Use and Savings Potential in Buildings." Lawrence Berkeley National Laboratory. 2010.
[118] Denkenberger et al. 2014. "Network Equipment." Codes and Standards Enhancement (CASE) Initiative For PY 2013: Title 20 Standards Development. May 15, 2014. Available at: http://www.energy.ca.gov/appliances/2013rulemaking/documents/comments/12-AAER-2A_Consumer_Electronics/12-AAER-2A_CA_IOUs_Response_to_CEC_Data_Request_Network_Equipment_2014-05-15_TN-73026.pdf
[119] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.

Table 5-8 provides a summary of the national site and primary energy consumption for U.S. commercial IT and office equipment. The estimated 2015 site and primary energy consumption for IT and office equipment is 96.8 TWh/yr. and 1.04 Quads/yr., respectively. National energy consumption is calculated by multiplying the average UEC for each equipment type by its estimated installed base. This estimate only includes equipment serving commercial buildings and does not include residential applications.

Table 5-8: Current IT/Office Equipment Energy Consumption Summary

Equipment Types	Average UEC (kWh/yr.)	Installed Base (1,000s)	AEC—Site Energy (TWh/yr.)	AEC—Primary Energy (Quads/yr.)
Personal Computers	n/a	106,000	24.2	0.26
Desktop Computers	285	76,000	21.6	0.23
Laptop Computers	87	30,000	2.6	0.03
Desktop Monitors	130	91,000	11.8	0.13
Imaging Equipment	n/a	40,000	10.1	0.11
Printers	284	26,000	7.4	0.08
MFDs	432	5,000	2.3	0.02
Fax Machines	52	6,000	0.3	0.00
Document Scanners	23	4,000	0.1	0.00
Server Computers	2,274	14,000	30.7	0.33
Network Equipment	n/a	472,000	13.4	0.14
Switching Products	17	454,000	7.9	0.09
Enterprise Routers	466	4,000	1.7	0.02
Enterprise WLAN	107	11,000	1.2	0.01
Security Applications	940	3,000	2.5	0.03
UPS	442	15,000	6.7	0.07

Site kWh to Site Btu conversion of 3,412 Btu-to-kWh and site-to-source conversion factor of 3.15 for electricity

5.5 Comparison of Baseline Energy Consumption to Previous Studies

Table 5-9 and Figure 5-9 compare the estimated 2015 IT and office equipment primary energy consumption with estimates from previous research reports. Even though each study focuses on a different set of equipment, the estimates for common equipment categories often varies substantially. Several technical, market, and data availability trends may have caused these differences, including:

- Greater market penetration of PCs over time, followed by a decrease in overall PC energy consumption as the market transitions to lower consumption laptop PCs.

- Decreasing consumption of desktop monitors as the market transitioned from cathode ray tube (CRT) to liquid crystal display (LCD) technology. This per unit decrease is somewhat dampened by an increase in the number of secondary monitors.
- Increased installed base of server computers and network equipment.
- Newly available market data, such as CBECS 2012, that provides greater insight into installed base and operating characteristics.

The fact that energy consumption estimates vary substantially over time and the fact that this category comprises a significant percentage of overall appliance energy consumption highlights the need for increased market research in this appliance category. In particular, sever computers, uninterruptible power supplies, and network equipment are key areas that should be studied further because of their increasing energy consumption and prevalence in U.S. business operations.

Table 5-9: Comparison of IT/Office Equipment Annual Primary Energy Consumption with Past Research Reports

Equipment Type	Navigant (2015)	ACEEE (2013)[120]	TIAX (2010)[121]	Navigant (2009)[122]	Roth et al. (2002)[123]	ADL (1993)[124]
Personal Computers	0.26	0.54	0.73	0.33	0.20	0.06
Imaging Equipment	0.11	0.16	0.16	0.14	0.20	0.17
Server Computers	0.33	0.36	0.34	0.32	0.11	0.08
Desktop Monitors	0.13	0.18	0.29	0.07	0.23	n/a
UPS	0.07	0.07	n/a	0.07	0.06	n/a
Network Equipment	0.14	n/a	n/a	0.06	0.06	n/a

[120] Kwatra et al. 2013. "Miscellaneous Energy Loads in Buildings." American Council for an Energy-Efficient Economy (ACEEE). Report Number A133. June 2013.
[121] McKenney et al. 2010. "Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type." Report for DOE Building Technologies Program. May 2010.
[122] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.
[123] Roth et al. 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 2002.
[124] ADL. 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.

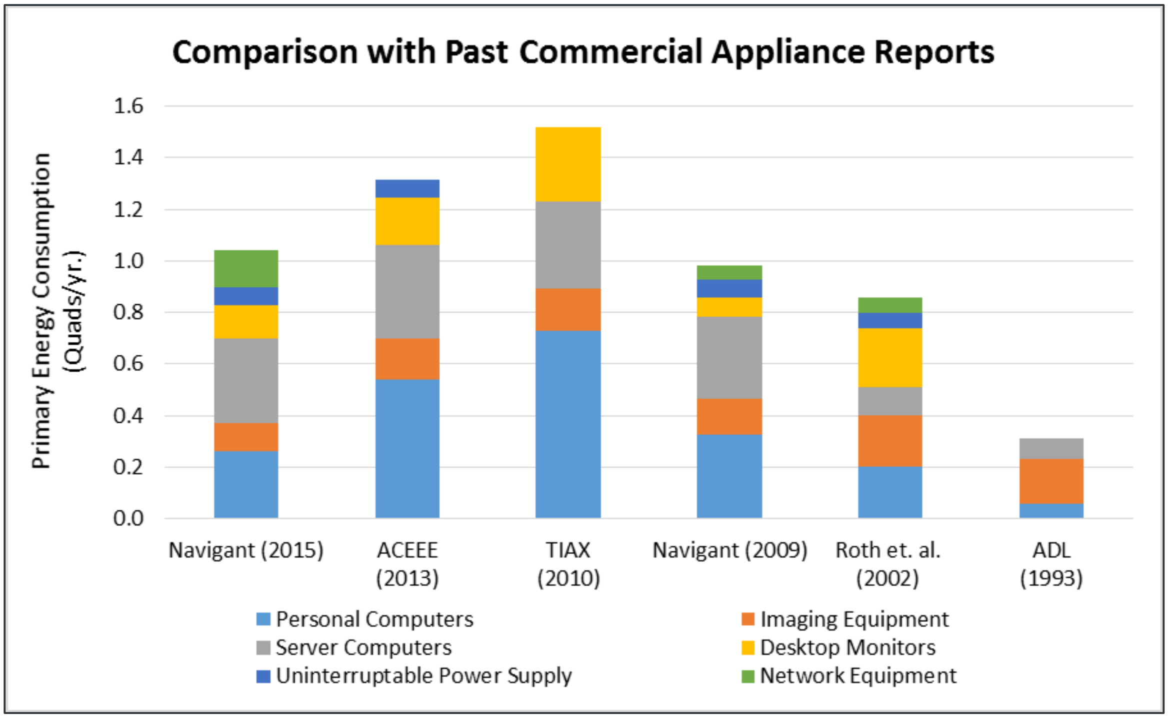


Figure 5-9: Comparison of energy consumption estimates with past commercial appliance reports

5.6 Energy Savings Opportunities

5.6.1 Energy Consumption and Savings Percentage

Table 5-10 below summarizes the UES potential, applicable primary energy usage, and technical potential for each IT and office equipment category. Further discussed in Section 5.6.2, most categories can achieve UES of 20%-60% through improved power supply efficiency, power management strategies to reduce idle or standby consumption, high-efficiency components, and other technologies. IT and office equipment has a technical potential of 0.43 Quads/yr. or 41% of 2015 U.S. consumption, shown in Figure 5-10.

Table 5-10: Comparison of IT/Office Equipment Annual Primary Energy Consumption with Past Research Reports

Equipment Type	UES Potential	Applicable Energy Consumption (Quads/yr.)	Technical Potential (Quads/yr.)	Source / Notes
Desktop Computers	44%	0.23	0.10	ENERGY STAR Calculator[125]
Laptop Computers	41%	0.03	0.01	
Desktop Monitors	67%	0.13	0.08	ENERGY STAR Most Efficient Database[126]
Printers	34%	0.08	0.03	ENERGY STAR Calculator,[125] weighted by type
MFDs	46%	0.02	0.01	
Fax Machines	29%	0.00	0.00	
Document Scanners	57%	0.00	0.00	
Server Computers	46%	0.33	0.15	FEMP estimate[127]
Switching Products	22%	0.09	0.02	Estimated from LBNL report[128]
Enterprise Routers	22%	0.02	0.00	
Enterprise WLAN	22%	0.01	0.00	
Security Applications	22%	0.03	0.01	
UPS	8%	0.07	0.01	FEMP estimate[129]

[125] ENERGY STAR. 2014. "Savings Calculator for ENERGY STAR Qualified Office Equipment." U.S. Environmental Protection Agency. December 2014.

[126] ENERGY STAR. 2015. "ENERGY STAR Most Efficient 2015 — Computer Monitors 20 to 23 inches." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=most_efficient.me_comp_monitor_20_to_23_inches

[127] FEMP. 2015. "Covered Product Category: Enterprise Servers." Federal Energy Management Program. January 2015. Available at: http://energy.gov/eere/femp/covered-product-category-enterprise-servers

[128] Lanzisera et al. 2010. "Data Network Equipment Energy Use and Savings Potential in Buildings." Lawrence Berkeley National Laboratory. 2010.

[129] FEMP. 2015. "Covered Product Category: Uninterruptible Power Supplies (for Data Center, Computer, and Telecommunication Applications)." Federal Energy Management Program. January 2015. Available at: http://energy.gov/eere/femp/covered-product-category-uninterruptible-power-supplies

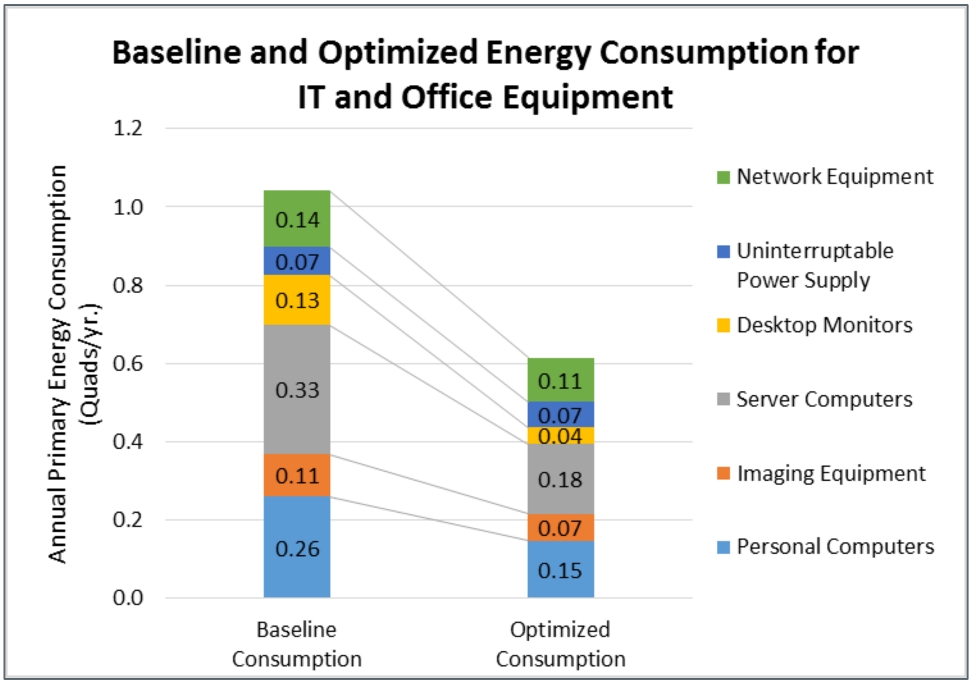


Figure 5-10: Baseline and optimized energy consumption for IT and Office equipment

5.6.2 Energy Savings Technologies

Table 5-11 describes the technologies and strategies IT and office equipment can use to achieve energy savings. Many equipment types have an incentive to improve their energy efficiency due to operational and financial goals. For example, high-efficiency laptop computers can offer longer battery life for the same battery capacity, which is a major selling point for business travelers. Further, more efficient server computers can have a cascading benefit for data center operating cost by decreasing the sever cooling demand, and the associated purchasing cost for larger cooling equipment, electrical infrastructure, backup power requirements, etc. In other instances, the market has transitioned to more energy-efficient products for non-energy benefits of new technologies. For example, high-efficiency desktop monitors using LCD displays have almost completely replaced CRT monitors due to their smaller size and weight, and laptops have replaced desktop PCs due to their increased portability.

Table 5-11: Energy-Saving Technologies for IT and Office Equipment

Covered Products	UES %	Energy-Saving Technologies and Strategies
Personal Computers	41%-44%	Improved power supply, power management features, improved display, improved processors and hard drives
Desktop Monitors	67%	Power management features, light-emitting diode (LED) backlight for display
Imaging Equipment	29%-57%	Power management features, improved fuser roll temperature management, combining multiple products for greater utilization
Server Computers	46%	Improved power supply, power management features, server virtualization
Network Equipment	22%	Energy-Efficient Ethernet (IEEE 802.3az-2010) that includes features such as reduced idle power consumption, modified power output based on chord length, improved processors, cooling fans, and other components
Uninterruptible Power Supplies	8%	Power management features, higher conversion efficiency, transformer-less designs

Estimated savings percentage ranges from Table 5-10 above.

5.7 Regulated and Voluntary Efficiency Standards

Mandatory federal energy efficiency standards currently do not cover any of the IT and office equipment discussed in this section. Nevertheless, several voluntary standards certify more efficient products and components for IT and office equipment, including:

- EPA's ENERGY STAR program certifies several commercial IT and office equipment categories and continually updates the testing methodology and performance criteria with technology developments. Table 5-12 provides a summary of the current status and estimated market share for equipment covered by ENERGY STAR certifications.
- The Alliance for Telecommunications Industry Solutions (ATIS) develops testing standards to measure and compare the energy efficiency of telecommunications and network equipment through their Telecommunications Energy Efficiency Ratio (TEER) metric.[130]
- The 80Plus program certifies computer, server, and other power supplies that achieve at least 80% AC to DC power conversion efficiency at various loading levels, which improves system efficiency by 33% or more.[131]

[130] Bossmin, Dave. 2015. "ATIS Sustainability in Telecom: Energy and Protection Committee." ATIS. June 3, 2015. Available at: https://docbox.etsi.org/workshop/2015/201506_EEWORKSHOP/SESSION01_Setting_the_Scene/ATIS_STEP_Bossmin.pdf
[131] Ecos Consulting. 2006. "Energy-Efficient Computers Run With 80 PLUS." Available at: http://www.plugloadsolutions.com/docs/broch/80PLUS_brochurepages.pdf

Table 5-12: ENERGY STAR Certification Status and Estimated Market Share for Office and IT Equipment

Covered Products	Version	Status	Estimated Market Share[132]
Computers	6.1	In effect	34% desktop, 93% notebook
Displays	7.0	Under development	88% LCD monitors
Enterprise Servers	2.0	In effect	7%
Imaging Equipment	2.0	In effect	45% printers and MFDs
Small Network Equipment	1.0	In effect	n/a
UPS	1.0	In effect	n/a
Large Network Equipment	1.0	Under development	n/a

[132] ENERGY STAR. 2015. "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.

6 Commercial Water Heaters

Traditional commercial water heating equipment includes storage tank heaters, booster heaters, and instantaneous (tankless). The vast majority of commercial water heaters use natural gas or electricity, although some use propane/liquefied petroleum gas (LPG), oil or solar thermal (typically with a secondary backup source). Water heaters are classified by their energy source, storage volume (as applicable), and energy input capacity, which is reported either as MMBtu/hr. for natural gas heaters and kW for electric heaters. Appendix A: Technology Descriptions provides a detailed description of major technology categories.

This section primarily focuses on the energy consumption for gas-fired and electric storage water heaters and does not consider water heaters using other fuels, instantaneous or residential water heaters, indirect water heaters connected to large boiler systems, and commercial models used in multi-family (MF) buildings as part of this main analysis. Discussion of these topics is limited to readily available information provided by CBECS and other research on commercial storage water heaters.

Table 6-1 provides a summary of the UEC, installed base, and national energy consumption for U.S. commercial water heaters. The estimated 2015 primary AEC for the 2,000,000 commercial water heaters is 0.801 Quads/yr.

Table 6-1: Commercial Water Heater Energy Consumption Summary

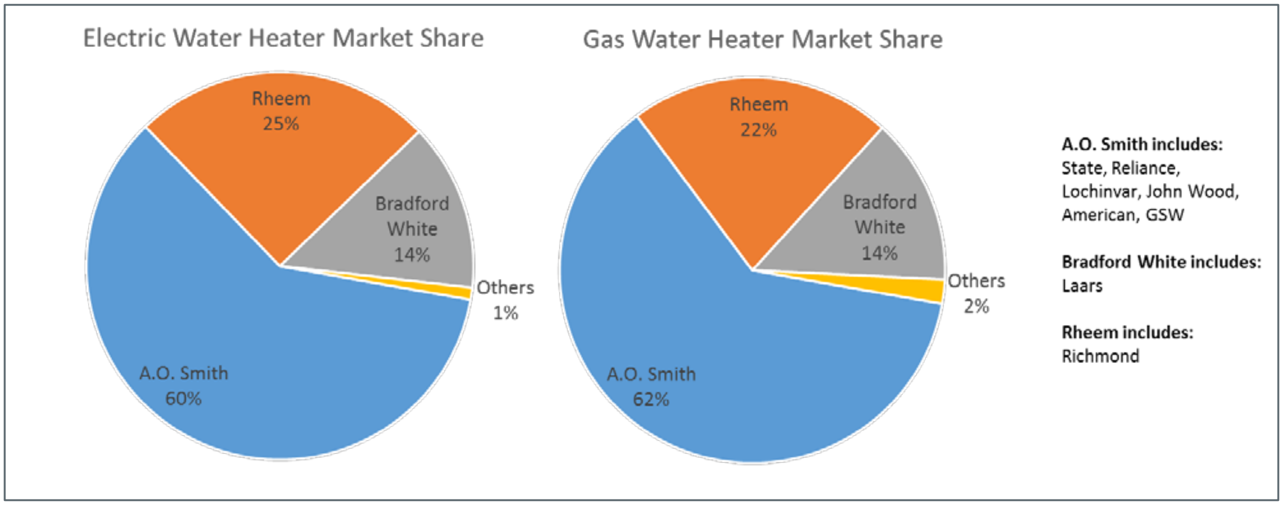
Equipment Types	Average UEC (MMBtu/yr.)	Installed Base	AEC—Site Energy (TBtu/yr.)	AEC—Primary Energy (Quads/yr.)
Natural Gas	315	1,200,000	379	0.413
Electricity	154	800,000	123	0.389
Total	**-**	**2,000,000**	**502**	**0.801**

Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

6.1 Market Overview

A small group of manufacturers comprise the U.S. commercial water heater market today and include: A.O. Smith, Rheem, and Bradford White. Figure 6-1 shows the market shares of these top companies which together, constitute 98%+ of the market for both electric and gas water heaters. Limited data exist for commercial water heater market shares, and these figures use data from a 2009 Appliance Magazine report, with the exception that Lochinvar is combined with A.O. Smith, who purchased the brand in 2011.[133]

[133] Press release available from July 19, 2011: http://investor.aosmith.com/releasedetail.cfm?releaseid=592526



Source: Appliance Magazine (2009)[134]

Figure 6-1: 2009 market share of water heater manufacturers

The commercial water heater market primarily consists of large storage water heaters (i.e., >75,000 Btu/hr. and >55 gallons). Lacking detailed market data, examination of the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) product database can provide insight into the types of commercial water heaters sold in the U.S. Of the AHRI-certified commercial water heaters (1,590 active models as of May 2015), the following breakdown exists:

- 86% are storage types water heaters,
- 8% are supply boilers, and
- 7% are gas instantaneous water heaters.

While manufacturers also offer many electric instantaneous models, the models generally have small heating capacities, more closely associated with residential water heating and are therefore excluded from the AHRI commercial database. These electric instantaneous models are commonly installed as point-of-use water heaters rather than intended as whole building centralized solutions. Some commercial buildings use electric instantaneous models for restroom sinks. These data are not necessarily representative of the installed base or the shipments, but are indicative of the market as manufacturers increase their product lines as competition and sales volumes increase for certain technology categories. More detailed data on shipments of instantaneous models and supply boilers are unavailable.

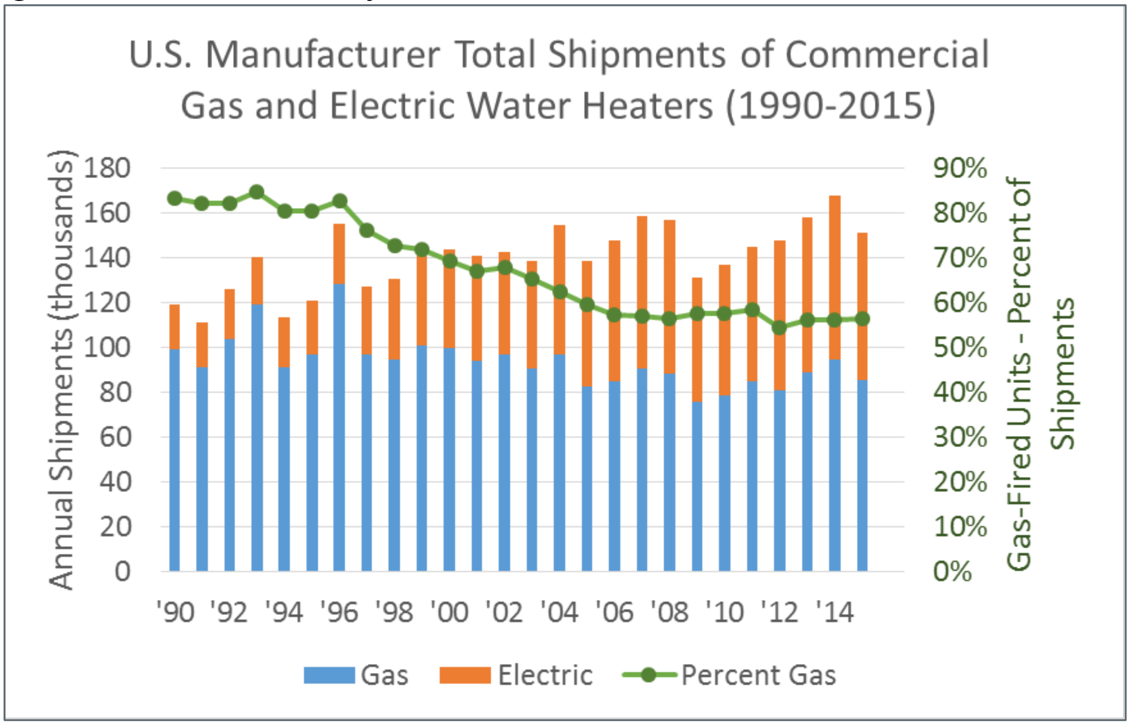
6.2 Annual Shipments and Installed Base

6.2.1 Annual Shipments

AHRI provides annual shipment data for electric and gas commercial storage water heaters. [135] U.S. manufacturers shipped 168,000 gas and electric commercial storage water heaters in 2014

[134] Appliance Magazine. 2009. "32nd Annual Portrait of the U.S. Appliance Industry." September 2009.
[135] AHRI. 2015. "Commercial Storage Water Heaters Historical Data." Accessed August 2015. Available at: http://www.ahrinet.org/site/494/Resources/Statistics/Historical-Data/Commercial-Storage-Water-Heaters-Historical-Data;

(most recent available data). Figure 6-2 shows the shipments of gas and electric water heaters between 1990 and 2014. The total number of shipments has been relatively stable over the last 10-15 years (~1% annual growth on average), but the percentage of units using gas has decreased from greater than 80% in the early and mid-1990s to 56% in 2014.



Source: AHRI Shipment Data (2015)[135]

Figure 6-2: U.S. manufacturer shipments of water heaters

Annual shipments and market penetration information for instantaneous and residential storage water heaters is unavailable. A 2012 CEE report describing conversations with instantaneous water heater manufacturers describes the market for commercial instantaneous water heater shipments as increasing in recent years but still amounting to only ~10% of storage water heater volumes (i.e., 12,000-15,000 units per year).[136]

Commercial water heaters are typically sold to end-users by plumbing and installation contractors who purchase equipment 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 1,200 independent wholesale plumbing distributors, with more than 4,400 selling locations serving residential, commercial, and industrial markets.[137] In addition, manufacturers sells residential models through retail channels at major home improvement and supply chains.

[136] Rodgers, Kara. 2012. "CEE Commercial Water Heating Initiative Description." Consortium for Energy Efficiency. June 5, 2012.
[137] A.O. Smith. 2015. "Annual Report 2014." March 2015. Available at: http://www.aosmith.com/uploadedFiles/Web_Assets/Documents/2014%20Annual%20Report.pdf

6.2.2 *Installed Base Estimates*

6.2.2.1 *Installed Base by Shipments*

We estimated the current installed base of storage water heaters by adjusting the AHRI annual shipment data according to a water heater survival model. We believe that this methodology provides a more reliable estimate than CBECS data, which does not distinguish between equipment types and system designs that use storage, instantaneous, or boiler systems. Boiler systems with indirect water heating loops, which are common in large commercial buildings are not included in this study.[138]

Similar to the 2009 Commercial Appliances Report, we created water heater equipment survival curves to estimate the fraction of equipment surviving to a given age. We based the survival for gas-fired and electric storage water heaters on the lifetime survival rates determined for the 2010 residential water heater rulemaking.[139] This methodology assumes a Weibull distribution with 13 year average lifetime with a range of 6-20 years. Table 6-2 shows the resulting installed base estimates for commercial gas and electric storage water heaters.

Table 6-2: Estimated U.S. Installed Base of Commercial Storage Water Heaters in 2015

Water Heater Type	Installed Base
Commercial Gas Storage Water Heaters	1,200,000
Commercial Electric Storage Water Heaters	800,000
Total	**2,000,000**

Source: Estimates based on AHRI shipment data and Navigant Consulting water heater survival model

Assuming a single storage water heater in each building, the estimate of 2,000,000 commercial storage water heaters represents roughly 45% of the 4,458,000 commercial buildings with water heaters reported in the 2012 CBECS. The remaining 55% of buildings are believed to use water heaters not included in AHRI shipment data such as instantaneous water heaters, indirect water heaters connected to large boiler systems, supply boilers, and residential water heaters for smaller commercial buildings. The installed base estimation is further complicated by the fact that approximately 10 million MF homes use commercial water heaters, which are not included in the CBECS survey.[140] As discussed previously, these systems are not included within the primary analysis.

6.2.2.2 *Installed Base Breakdown by Commercial Sector*

To estimate the installed base of electric and gas storage water heaters in each CBECS building type, we calculated the number of buildings with commercial storage water heaters estimated from CBECS 2012, and then adjusted for the installed base estimate from shipments (described

[138] Boiler systems serve space heating and process heating loads in addition to service water heating for commercial buildings.
[139] 2010 Residential Water Heater Rulemaking. Final Rule. Technical Support Document. Appendix 8-C Lifetime Distributions. April 8, 2010.
[140] EPA. 2010. "ENERGY STAR Water Heater Market Profile." U.S. Environmental Protection Agency. Accessed May 2015: http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/Water_Heater_Market_Profile_2010.pdf?0544-2a1e

above). CBECS 2012 provides the following information pertaining to commercial water heating equipment:

- 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 "Centralized" water heating systems (i.e., commercial storage water heaters)
- Number of buildings with "Distributed" water heating systems (i.e., instantaneous and residential-size water heaters
- Number of buildings with both "Combined" distributed and centralized systems (i.e., buildings with at least one commercial storage water heater and one instantaneous or residential-size water heater).

Using this information, we assume that each building designated as "Centralized" or "Combined" includes at least one commercial storage water heater, but those designated as "Distributed" do not. Therefore, the number of buildings with commercial storage water heaters for each fuel type is estimated as the difference between the total number of buildings and those designated as "Distributed". We assume a 50/50 split by fuel type for the "Distributed" buildings based on a review of CBECS for buildings with distributed systems of only one fuel type.[141] Subtracting the "Distributed" segment from the produces the implied number of buildings with electric and natural gas storage tank water heaters for each commercial building sector.

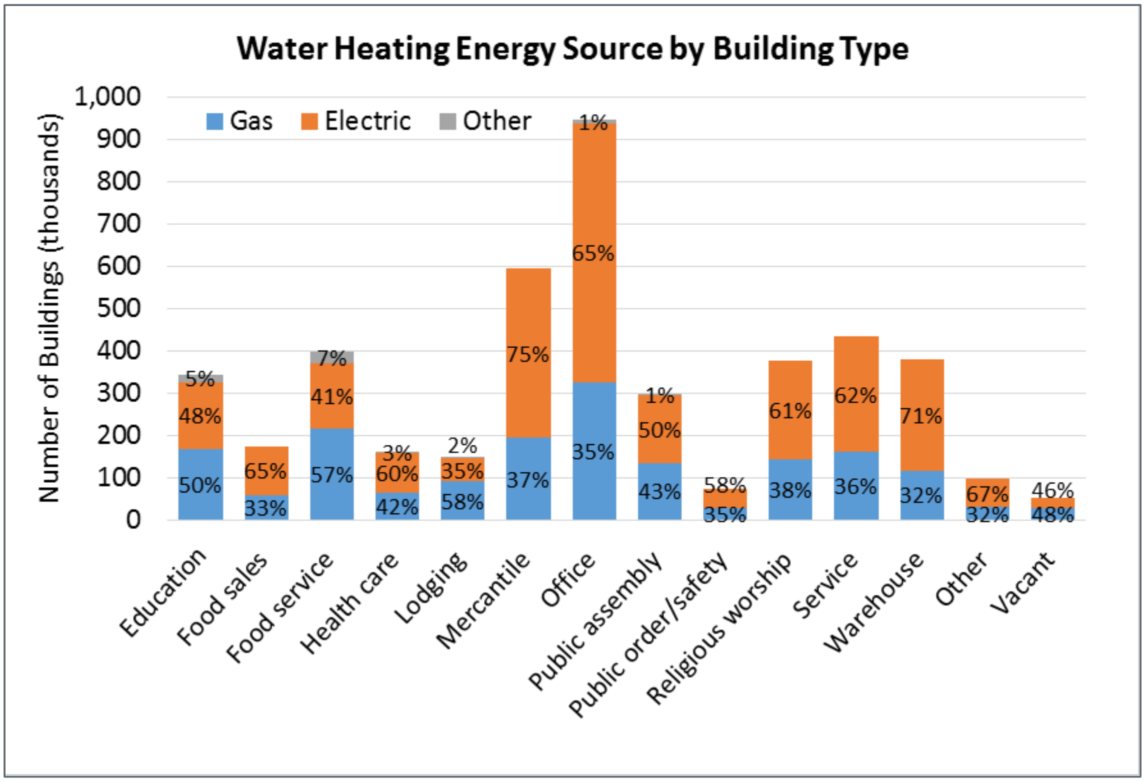
Finally, we estimate the number of commercial water heaters installed in each building type by multiplying the estimated installed base by shipments by each building sector's percentage for the total number of applicable buildings in CBECS. For example, if the Food Sales building type comprised 5% of all buildings with electric water heaters from CBECS, we assumed Food Sales would have 5% of the installed base of electric storage water heaters from the shipments analysis.

6.2.2.3 Installed Base by Floorspace

CBECS 2012 estimates that 4.5 million commercial buildings (79%) have water heating, representing 71 billion square feet (90%) of commercial floorspace.[142] Figure 6-3 shows the breakdown by energy source of the water heating equipment in each building type.

[141] 2010 Residential Water Heater Rulemaking. Final Rule. Technical Support Document. Appendix 8-C Lifetime Distributions. April 8, 2010.

[142] CBECS 2012, Table B42. Water-heating equipment, number of buildings and floorspace, 2012



Source: CBECS 2012, Table B31. Water heating energy sources, number of buildings, 2012

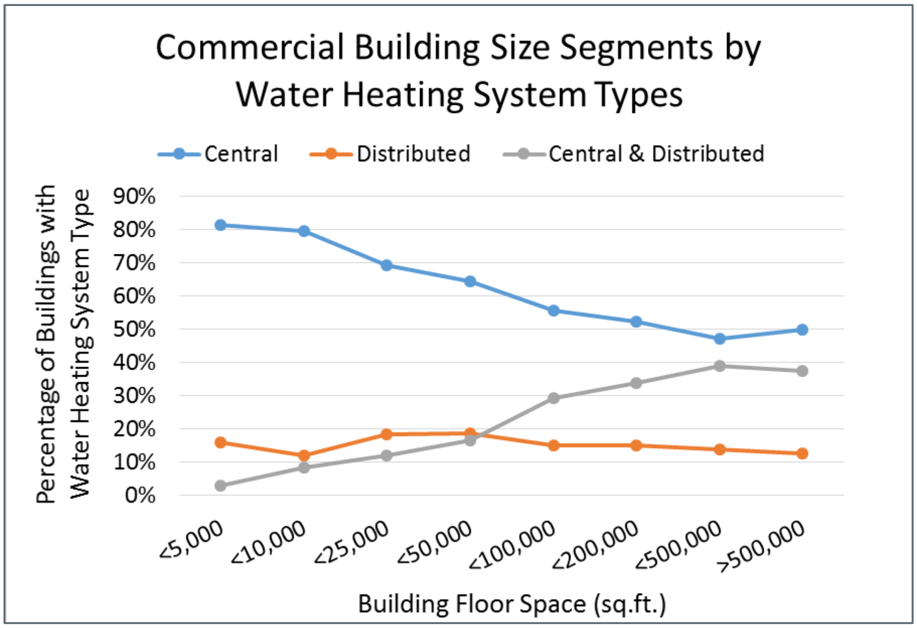
Figure 6-3: Water heating energy source by building type

CBECS 2012 estimates that 636,000 buildings within the applicable commercial building categories (15% of those with water heating) use a "distributed system" for water heating. As mentioned previously, CBECS defines these systems in the survey as a "point-of-use" system, including those that also use a centralized system as well (263,000, or 6% of those with water heating).[143] Based on these data, we assume an installed base of approximately 500,000-700,000 instantaneous water heaters.[144] CBECS data show that distributed systems are twice as likely to use electricity over natural gas (often residential scale equipment, see Section 6.1, above). Regardless of equipment type, small buildings are more likely to use electricity than large buildings. In CBECS, electricity is used for water heating in 64% of buildings under 5,000 square feet but only 50% of buildings over 200,000 square feet.[145] Figure 6-4 shows the split of buildings by size that use centralized versus distributed water heating systems and Figure 6-5 shows the breakdown of building water heater fuel type by building size.

[143] CBECS 2012, Table B42. Water-heating equipment, number of buildings and floorspace, 2012.

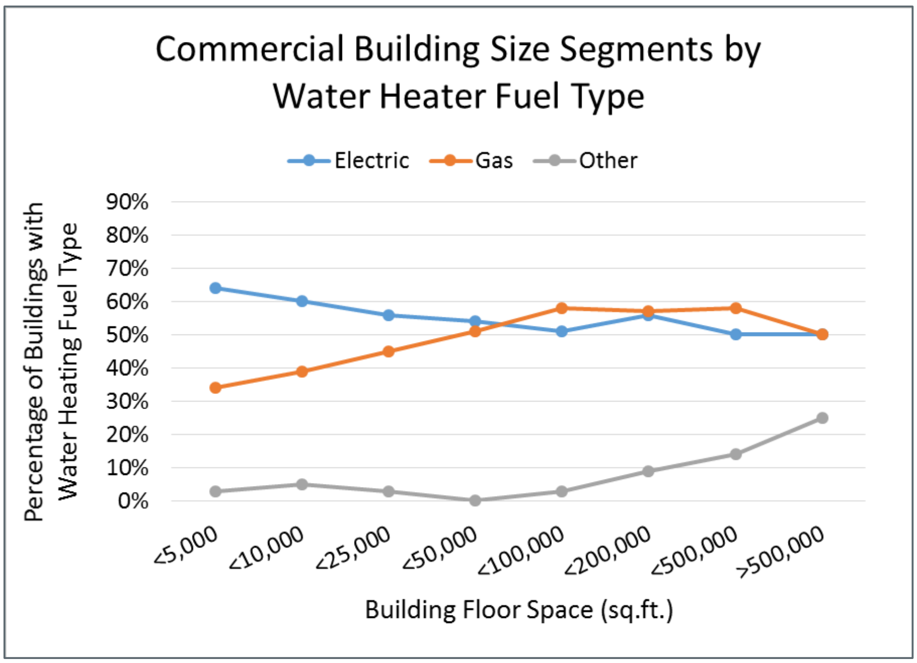
[144] This estimate assumes the instantaneous water heaters provide a substantial portion of the service water heating load for the building with 1,000-2,000 operating hours per year. Building designers could employ many point-of-use water heaters around a building (e.g., bathroom sinks in low traffic areas) with minimal usage.

[145] Ibid



Source: CBECS 2012 Tables B31 and B42

Figure 6-4: Commercial building size segments by water heater system types



Source: CBECS 2012 Tables B31 and B42

Figure 6-5: Commercial building size segments by water heater fuel type

6.3 Product Cost Breakdown

Table 6-3 below shows the typical cost breakdown for standard commercial water heating equipment as of 2013. Commercial electric instantaneous are small point-of-use water heaters and not offered as whole building solutions with large thermal capacities.

Table 6-3: Typical Cost Breakdown for Standard Commercial Water Heating Equipment, 2013

Commercial Water Heating Equipment Type	Capacity	Retail Equipment Cost	Total Installed Cost	Annual Maintenance Cost
Gas Storage	100 gal, 200 kBtu/hr.	$3,700 - $6,100	$4,230 - $6,630	$110 - $210
Gas Booster	3-5 gal	$4,500 – $6,500	$4,800 – $6,800	$160
Gas Instantaneous	180-250 kbtu/hr.	$1,300 - $1,650	$1,550 - $2,200	Negligible
Electric Storage	120 gal, 45 kW	$3,600 - $5,600	$4,240 - $6,340	$110 - $210
Electric Booster	6-16 gal	$1,250 - $2,700	$1,450 - $2,900	Negligible
Electric Instantaneous	Unavailable	$150 - $250	Unavailable	Unavailable

Source: EIA. 2014. "Updated Buildings Sector Appliance and Equipment Costs and Efficiencies." March 2014. Available at: http://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf

6.4 Baseline Energy Consumption

We developed a model that calculates total AEC of commercial storage tank water heaters by estimating the installed base, number of operating hours, and typical capacities for water heaters in each CBECS building type. We used the same operating hour and capacity estimates from previous analyses, and updated the typical energy efficiency for the installed base of water heaters (i.e., 0.80 TE installed base in 2015 vs. 0.77 TE in 2009 and 0.60 TE in 1993). The last 2 columns of Table 6-4 show the total primary consumption of electric and natural gas storage water heaters for each commercial sector based on our model.

Table 6-4: Commercial Water Heating Energy Consumption Calculations

Building Type	Fuel Type	Annual Operating Hours [a]	Input Rated Capacity [b,c] (Btu/hr.)	UEC (MMBtu/yr.)	Total Site Energy Consumption (TBtu/yr.)	Total Primary Energy Consumption (Quad/yr.)
Education	Gas	1,600	240,000	384	49.9	0.054
	Electric	2,200	125,000	275	13.8	0.043
Food Sales	Gas	1,400	90,000	126	5.5	0.006
	Electric	2,150	50,000	108	4.2	0.013
Food Service	Gas	3,200	280,000	896	164.0	0.179
	Electric	4,900	150,000	735	37.5	0.118
Health Care – Inpatient	Gas	3,650	490,000	1,789	8.9	0.010
	Electric	5,550	200,000	1,110	0.4	0.001
Health Care – Outpatient	Gas	1,100	120,000	132	5.3	0.006
	Electric	1,700	65,000	111	3.1	0.010
Lodging	Gas	2,100	340,000	714	57.1	0.062
	Electric	3,200	140,000	448	8.5	0.027
Retail (Other than Mall)	Gas	1,100	120,000	132	7.4	0.008
	Electric	1,700	65,000	111	9.2	0.029

Building Type	Fuel Type	Annual Operating Hours [a]	Input Rated Capacity [b,c] (Btu/hr.)	UEC (MMBtu/yr.)	Total Site Energy Consumption (TBtu/yr.)	Total Primary Energy Consumption (Quad/yr.)
Office	Gas	1,100	90,000	99	22.4	0.024
	Electric	1,700	40,000	68	13.4	0.042
Public Assembly	Gas	1,100	120,000	132	13.9	0.015
	Electric	1,700	65,000	111	5.7	0.018
Public Order and Safety	Gas	1,600	240,000	384	8.4	0.009
	Electric	2,200	100,000	220	3.5	0.011
Religious Worship	Gas	1,100	120,000	132	13.2	0.014
	Electric	1,700	65,000	111	8.1	0.025
Service	Gas	1,100	120,000	132	13.7	0.015
	Electric	1,700	65,000	111	9.2	0.029
Warehouse and Storage	Gas	600	90,000	54	3.5	0.004
	Electric	920	50,000	46	3.7	0.012
Other	Gas	1,100	120,000	132	2.8	0.003
	Electric	1,700	65,000	111	2.3	0.007
Vacant	Gas	1,100	120,000	132	2.5	0.003
	Electric	1,700	65,000	111	0.8	0.002
TOTAL	-	-	-	-	**502**	**0.801**

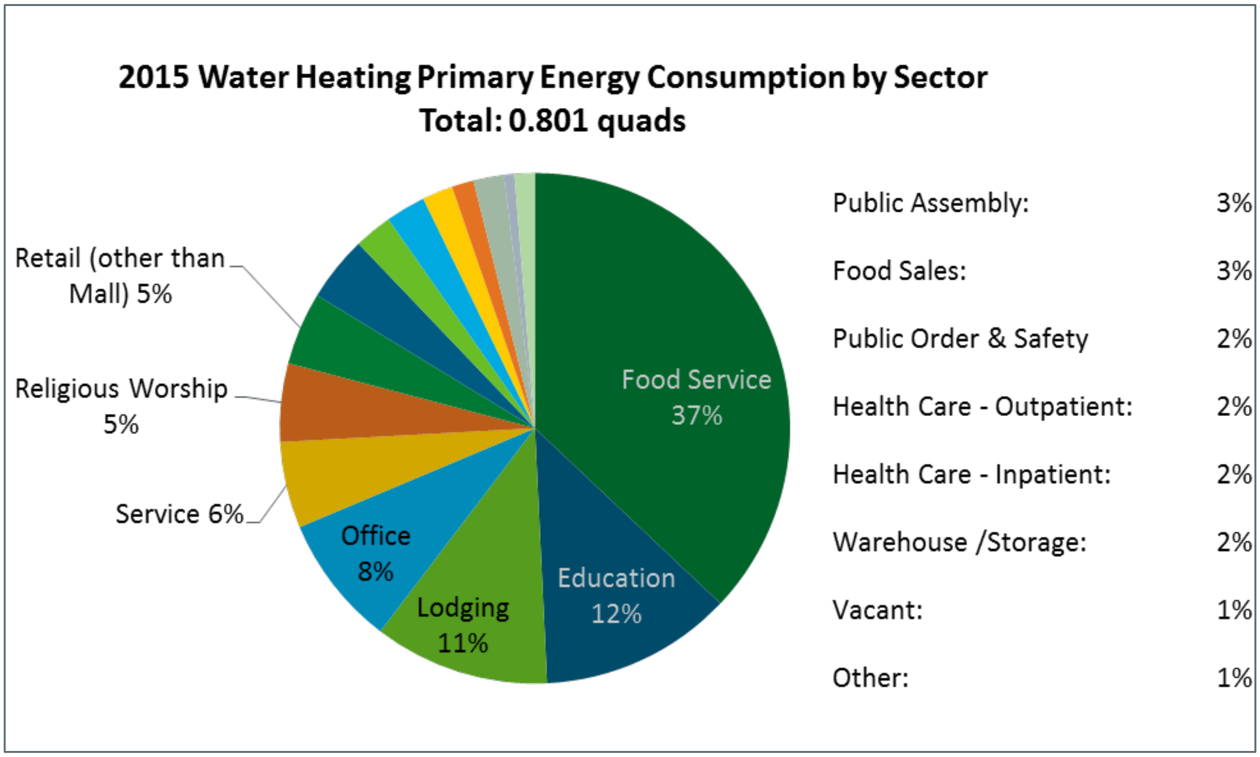
a) Annual operating hours the same estimates used by ADL. (ADL 1993)
b) Adjusted from ADL's estimated input rated capacity such that the total output capacity remains the same using a higher efficiency value of 80% versus 60% in the ADL report and 77% in the 2009 Commercial Appliances Report.
c) Our 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) UEC 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 UEC by the number of installed units from Table 6-2.
f) Assumes site-to-source conversion factors of 3.15 for electricity and 1.09 for natural gas

The commercial water heating consumption model yields a primary energy consumption of 0.801 Quads for commercial electric and gas storage water heaters summarized in Table 6-5.

Table 6-5: Estimated Primary AEC of Commercial Electric and Gas-Fired Storage Water Heaters, 2015

Fuel Type	Primary AEC [Quads/yr.]
Natural Gas	0.413
Electricity (Primary)	0.389
TOTAL	**0.801 Quads**

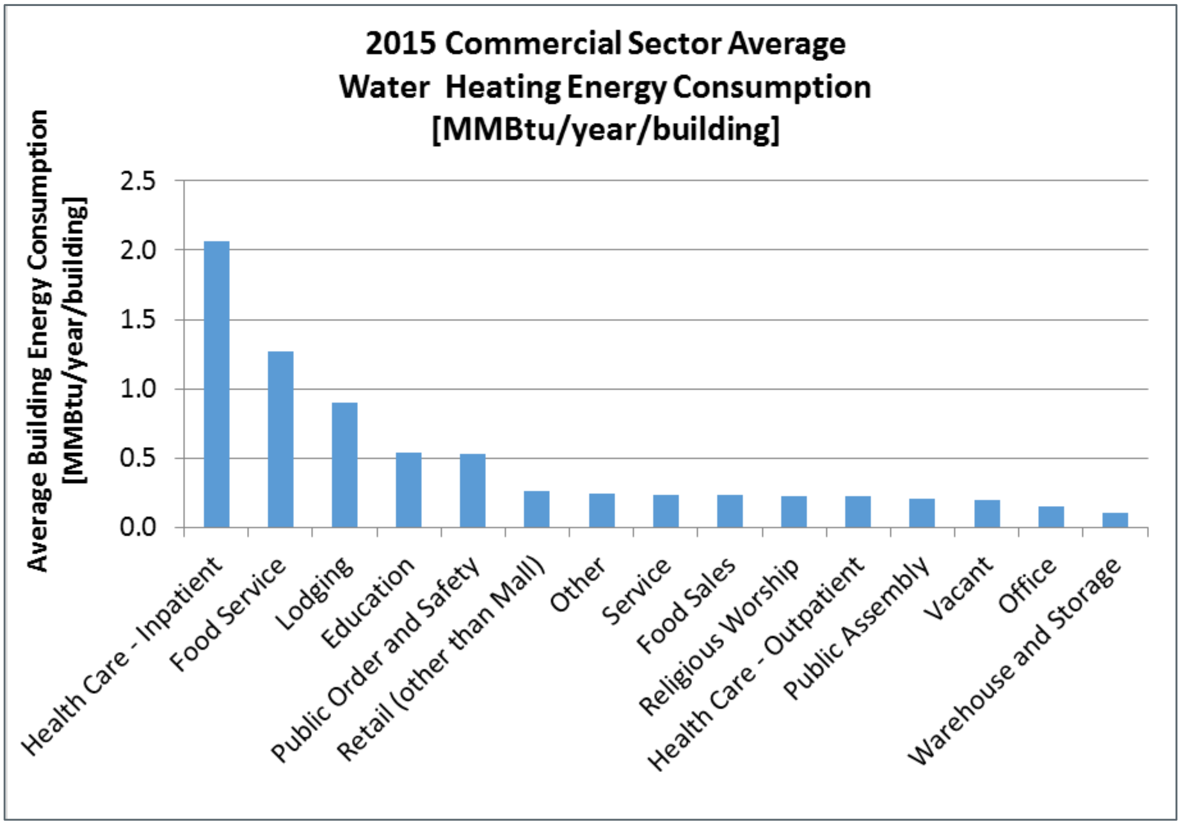
Total water heater usage among commercial building sectors varies significantly. Figure 6-6 shows the total annual water heating energy consumption by sector. Food service, education, lodging, and office buildings together account for two-thirds of the total annual water heating energy consumption.



Source: Navigant Consulting energy consumption model

Figure 6-6: Water heating primary energy consumption by sector

Evaluation of each building category's total water heating energy consumption by the number of water heaters reveals the hot water intensity of each building category, and which buildings could see the quickest payback with energy-saving technologies. Figure 6-7 below shows the average building energy consumption within each sector. 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, dish washing, and sanitation. Incorporating energy-saving technologies in these 3 sectors can have the greatest impact with attractive economics for commercial water heating consumption.



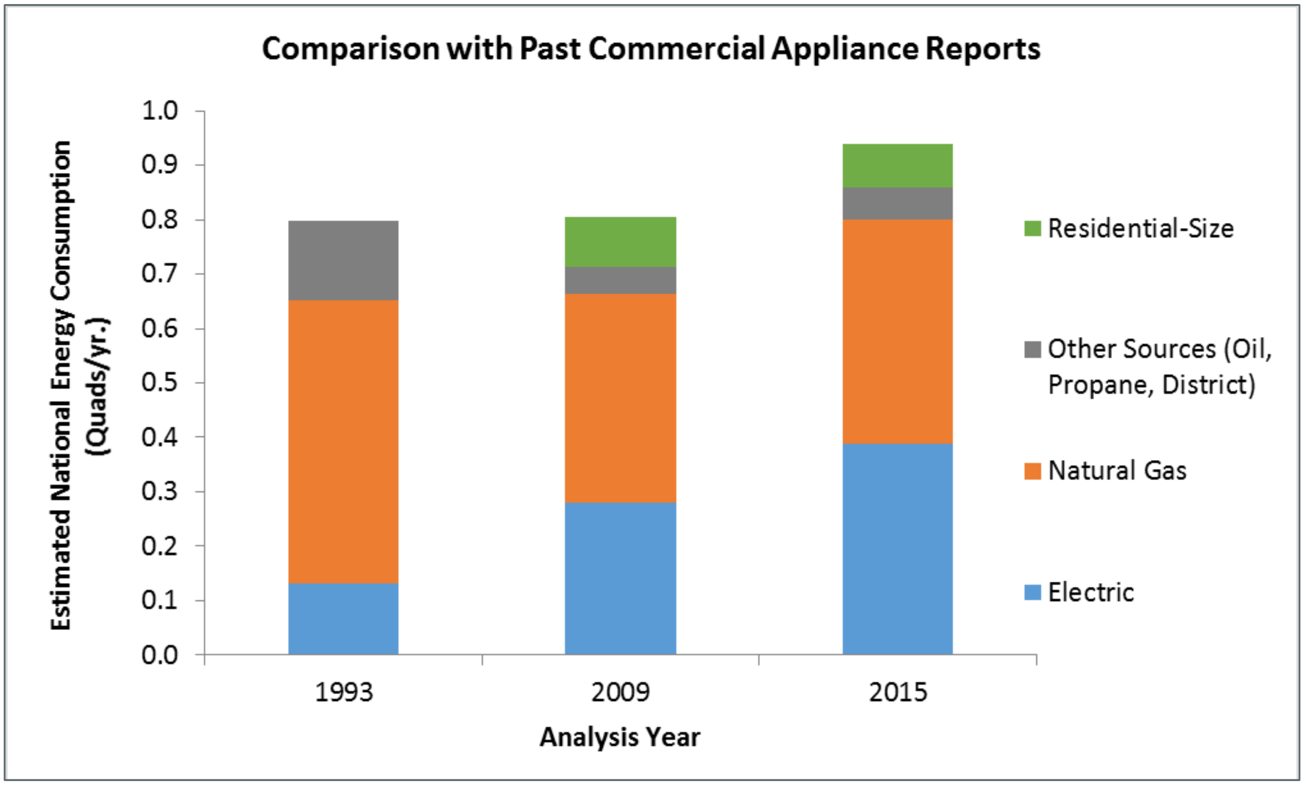
Note: Average water heating energy consumption is calculated by dividing total sector primary energy usage by number of installed water heaters in that sector

Figure 6-7: Average building water heating primary energy consumption for 2012

6.5 Comparison of Baseline Energy Consumption to Previous Studies

Figure 6-8 compares the estimated 2015 commercial storage water heater consumption and installed base with previous estimates from the 1993 ADL and 2009 Commercial Appliances Report. The figure includes an estimate for residential-size water heater energy usage in commercial buildings. Including the residential-size water heater energy consumption, we estimate commercial water heating energy usage of 0.881 Quads annually.

Two major trends underscore the increase in commercial water heating consumption in Figure 6-8. First, the increase in commercial building stock and floorspace naturally contributes to a higher national water heater energy consumption, without major advances in equipment efficiency. Secondly, the increased penetration of electric storage water heaters has a substantial effect on primary energy consumption due to the site-to-source conversion factor of 3.15. These 2 factors highlight the need for the next generation of commercial water heating technologies that can greatly improve system efficiency such as thermally activated or vapor-compression heat pump technologies (discussed in Section 6.6).



Sources: ADL 1993[146], 2009 Commercial Appliances Report[147]

Note: Includes energy usage of electric and gas commercial storage tank water heaters only. Energy usage from other sources were not considered in this report. Other sources include: propane, oil, district heating, and renewable sources.

Figure 6-8: Comparison of commercial water heating energy consumption figures

6.6 Energy Savings Opportunities

Building owners and managers have a number of energy efficiency options to reduce commercial water heater energy consumption both today and in the coming years. Modifications to existing water heating systems to recover waste heat or optimize operations can improve system efficiency with baseline equipment, and alternative water heating technologies offer significantly higher thermal efficiencies. For this report, we focus on individual technologies rather than system-wide improvements. The following sections describe technologies that improve thermal efficiency for water heaters, reduce standby heat loss, recover heat from other building technologies, and other energy-saving strategies. Table 6-6 summarizes the UES potential, applicable primary energy usage, and technical potential for each technology profiled in this section. 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.

[146] ADL. 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.

[147] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.

Table 6-6: Technical Potential of all Water Heating Technology Options

Technology	UES Potential	Applicable Fuel Types / System Designs	Applicable Primary Energy Usage (Quads/yr.)	Technical Potential (Quads/yr.)
Solar Water Heaters	35%	Gas, Electric	0.80	0.28
Vapor-Compression Heat Pump Water Heaters (HPWHs)	70%	Electric	0.39	0.27
Desuperheaters	33%	Gas, Electric	0.80	0.26
Absorption HPWHs	46%	Gas	0.41	0.19
Drain-Water Heat Recovery	20%	Gas, Electric	0.80	0.16
Instantaneous Water Heaters	15%	Gas, Electric	0.80	0.12
Smart controls	10%	Gas, Electric	0.80	0.08
Condensing Water heaters	18%	Gas	0.41	0.07
Thermoelectric HPWH	11%	Electric	0.39	0.04

6.6.1 Smart Controls

Traditional storage water heaters have relatively basic controls to maintain temperature settings within the storage tank. Advanced controllers can expand the operating capabilities of storage water heaters to provide energy efficiency, demand response, fault detection and diagnostics, and other benefits. Either factory-installed or as an add-on product, smart controllers incorporating advanced sensing and communication capabilities could offer the following functions:

- **Setback Temperature Schedules –** Water heaters typically maintain a constant tank temperature, but could reduce standby losses during unoccupied hours (e.g., nights and weekends) by decreasing the temperature setting. Smart controllers would set an hourly temperature schedule, similar to an HVAC thermostat, so that the water heater set point would decrease when the building is closed or otherwise in low occupancy periods.
- **Predictive Controls –** Depending on the building's operations, the majority of hot water consumption may occur during distinct periods of the day (e.g., lodging with morning and nighttime peak shower demands). Smart controls can learn the typical usage patterns of the building and develop a predictive schedule that adapts the recovery rate of the water heater to the expected usage schedule, temperature set point schedule, or recirculation pump operation.
- **Demand Response and Time-of-Use Rates –** Some electric water heaters already participate in demand response programs as an interruptible load and/or storage, but smart controls can extend these capabilities to adapt to time-of-use rates to avoid peak pricing periods.

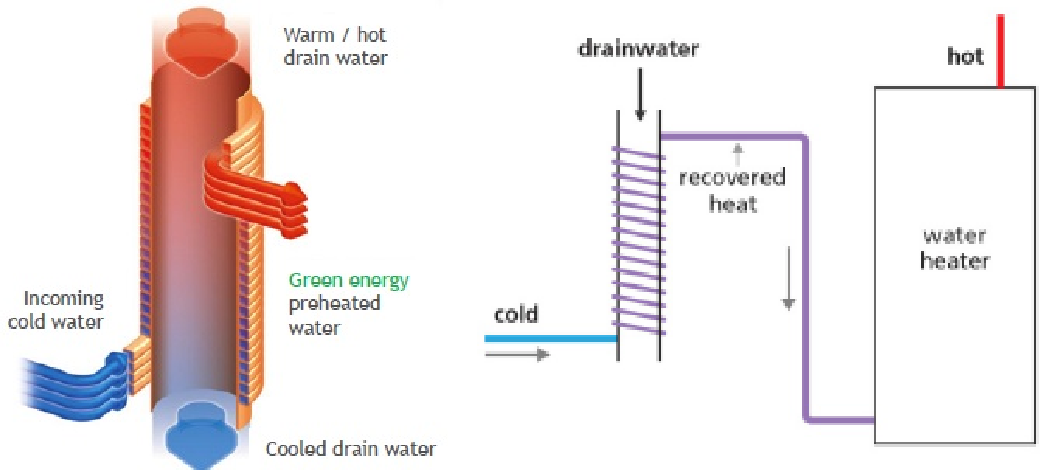
- **Fault Detection and Diagnostics –** Increasing the sensing and communication capabilities of traditional water heaters allows for greater monitoring and benchmarking of operating characteristics over time. Smart controllers would allow on-site or remote technicians to identify problems such as water leakage, efficiency degradation, unit failure, etc., so they can quickly repair and return the water heating system to normal functionality.

Several manufactures and researchers have investigated smart control technologies, but primarily for residential applications. The National Renewable Energy Laboratory has developed initial predictive control algorithms for HPWHs and estimates 2-20% energy savings based on operating conditions and temperature settings.[148] Bradford White offered several smart control technologies as part of their ICON System Accessories Packages, including leak detectors, remote fault detection and diagnostic (FDD) capabilities, and temperature setback, which showed 8-37% energy savings or greater with gas storage water heaters.[149] Several studies have shown that smart recirculation pump controls can save up to 30% on water heating costs for MF buildings.[150] Based on these findings for residential applications, we conservatively estimate a UES of 10% for commercial water heaters.

6.6.2 Drain-Water Heat Recovery

Drain-Water heat recovery systems reduce storage water heater energy consumption by preheating incoming water with thermal energy contained in wastewater. Most systems involve one or more heat exchangers that features a small copper tube spiraled along a section of the building's drainpipe. As the cool incoming water enters the spiral tube, thermal energy passes from the main drainpipe to the incoming water, increasing its temperature. Because the water enters the storage water heater at higher temperature, the water heater has to provide less energy output to reach supply temperatures. Figure 6-9 provides a simplified schematic for drain-water heat recovery systems.

[148] Jin et al. 2014. "Model Predictive Control of Heat Pump Water Heaters for Energy Efficiency." National Renewable Energy Laboratory. 2014 ACEEE Summer Study on Energy Efficiency in Buildings. August 2014.
[149] Plumbing Engineer. 2010. "Water Heater Study Reveals Significant Fuel Savings from New Programmable Setback Control." Plumbing Engineer. November 2010. Available at: http://www.bradfordwhite.com/sites/default/files/images/pdf/news/pe_brad_white_med.pdf
[150] Dentz and Ansanelli. 2015. "Energy-Efficient Controls for Multifamily Domestic Hot Water." The Levy Partnership, Inc. Building America Webinar: Central Multifamily Water Heating Systems. January 21, 2015.



Source: RenewABILITY (2011) [left][151], Cautley (2013) [right][152]

Figure 6-9: Schematic of drain-water heat recovery system

Energy savings for drain-water heat recovery systems will vary based on the building's hot water demand profiles, hydronic system design, storage water heater temperature settings, and other considerations. The manufacturer RenewABILITY estimates UES of 25-35% and greater for a variety of building types and operations.[151] In a field study at MF and commercial buildings, the Energy Center of Wisconsin found drain-water heat recovery systems provided 9-29% energy savings for storage water heaters.[152] Based on the wide range of projected savings, we conservatively estimate 20% UES for the drain-water heat recovery systems.

Several smaller manufacturers offer drain-water heat recovery systems for residential and commercial applications, but site-specific hot water demand profiles, difficulty with retrofits, and uncertain technology paybacks have limited adoption. The Energy Center of Wisconsin study had significant difficulty finding suitable sites having an accessible vertical drain line, substantial hot water loads, and close proximity of the water heater to the drain line.[153] Most products and research studies focus on residential applications, with limited available information for promising commercial buildings. Those commercial buildings with large and consistent hot water demands, such as health clubs, food service, and laundry facilities, could benefit most from this technology.

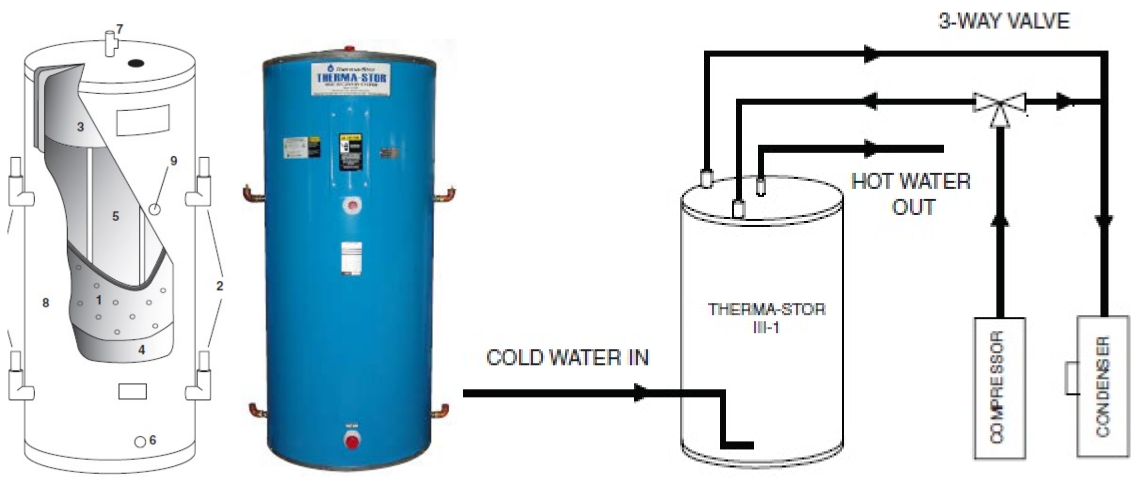
6.6.3 Desuperheaters

Desuperheaters reduce energy consumption for storage water heaters by recovering excess heat from vapor-compression HVAC and refrigeration (HVAC&R) systems to preheat incoming water. Desuperheaters use a refrigerant-to-water heat exchanger to transfer thermal energy from the high-temperature refrigerant vapor as it leaves the compressor to the cool incoming water. The pre-heated water then travels to the storage water heater tank, decreasing the amount of energy required by the water heater to reach hot water supply temperatures. Because many commercial buildings have significant HVAC&R and water heating loads (e.g., supermarket

[151] Van Decker, Gerald. 2011. "Drain Water Heat Recovery: On the Road to Becoming a Mainstream Water Heating Technology." RenewABILITY Energy Inc. 2011.
[152] Cautley, Dan. 2013. "Drain Water Heat Recovery – A Field Study of Commercial Applications." Energy Center of Wisconsin. ECW Report Number 272-1. November 27, 2013.
[153] Ibid.

compressor racks, food service walk-in freezers), desuperheaters can reduce overall site consumption by capturing usable heat from one activity to preheat hot water and potentially improve the efficiency of HVAC&R systems by reducing the condenser load.

A mature technology in many large commercial and industrial applications, desuperheaters have traditionally required complex system designs to correctly distribute water and refrigerant to the main HVAC&R and water heating components, which limited their applicability for smaller buildings. In these situations, the desuperheater consists of a remote heat exchanger or storage tank with multiple piping connections as shown in Figure 6-10. A 2010 FSTC study estimated that desuperheaters could provide 20% UES for water heating in food service applications.[154]



Source: Therma-Stor Product Brochure[155]

Figure 6-10: Desuperheater configuration with heat exchanger within storage water heater

In 2012, Rheem debuted a packaged rooftop unit with integrated refrigerant-to-water condensing system that operates as a desuperheater to preheat water with waste refrigerant heat. Figure 6-11 provides a schematic of a commercial kitchen with the H2AC rooftop unit, storage tank, and a set of instantaneous water heaters. The system raises the water temperature by 20-45°F, reducing the energy consumption of the primary water heating equipment. In an example calculation, Rheem estimates between 33-42% energy savings for baseline water heaters when including the additional fan and pump consumption.[156] At the 2016 Air-Conditioning, Heating, and Refrigerating Exposition in Orlando, FL, Rheem discussed plans for a residential model of the H2AC in a split-system configuration. We estimated a 33% UES for desuperheaters and similar refrigerant-to-water heat recovery technologies.

[154] Delagah and Fisher. 2010. “Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities.” Prepared for California Energy Commission. Report Number CEC-500-2013-050. October 2010.
[155] Therma-Stor Product Brochure Accessed August 2015. http://www.thermastor.com/Heat-Recovery-Water-Heaters/
[156] Rheem. 2013. “H2AC™ Rooftop Unit featuring eSync Integration Technology – Installation Guide.” Rheem Heating, Cooling & Water Heating. November 2013.

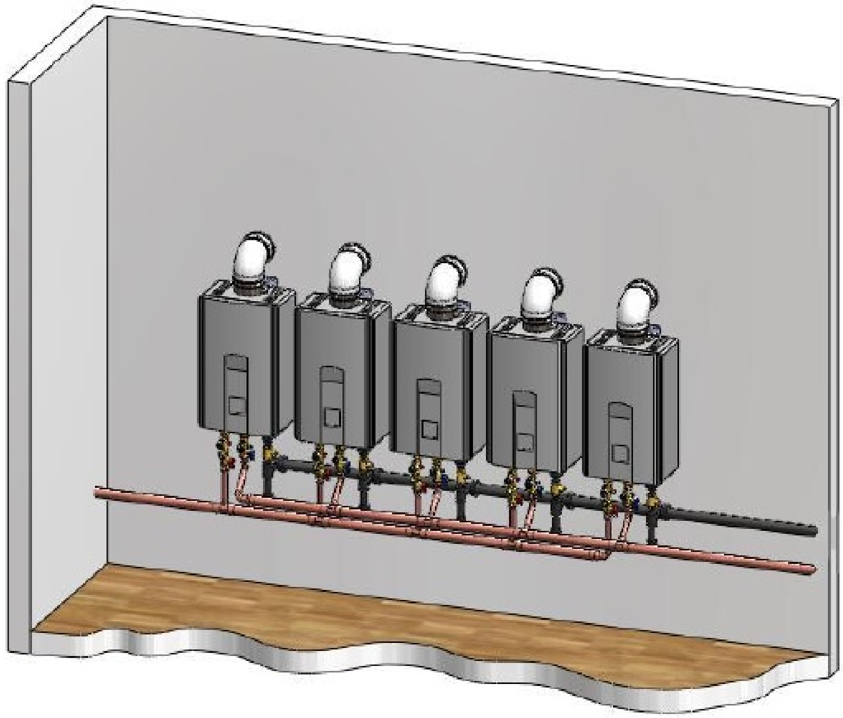
Source: Brunetto (2013)[157]

Figure 6-11: Rheem H2AC schematic

6.6.4 Instantaneous Water Heaters

Instantaneous or tankless water heaters operate without a storage tank and rapidly heat water as it passes through the unit. Predominantly gas-fired, instantaneous water heater typically require a substantially larger heating rate (kW or MMBtu/hr.), but offer the benefits of greatly reduced standby losses and seemingly “infinite” hot water capabilities. For commercial applications, system designers often install an array of instantaneous water heaters that operate in parallel via a manifold to meet the building’s hot water demands. Figure 6-12 provides a schematic for multiple instantaneous water heaters.

[157] Brunetto, Sal. 2013. “Integrated Air and Water Solutions.” Rheem Heating, Cooling & Water Heating. 2013 ACEEE Hot Water Forum. November 2013.



Source: Rinnai (2011)[158]

Figure 6-12: Schematic of multiple gas-fired instantaneous water heaters

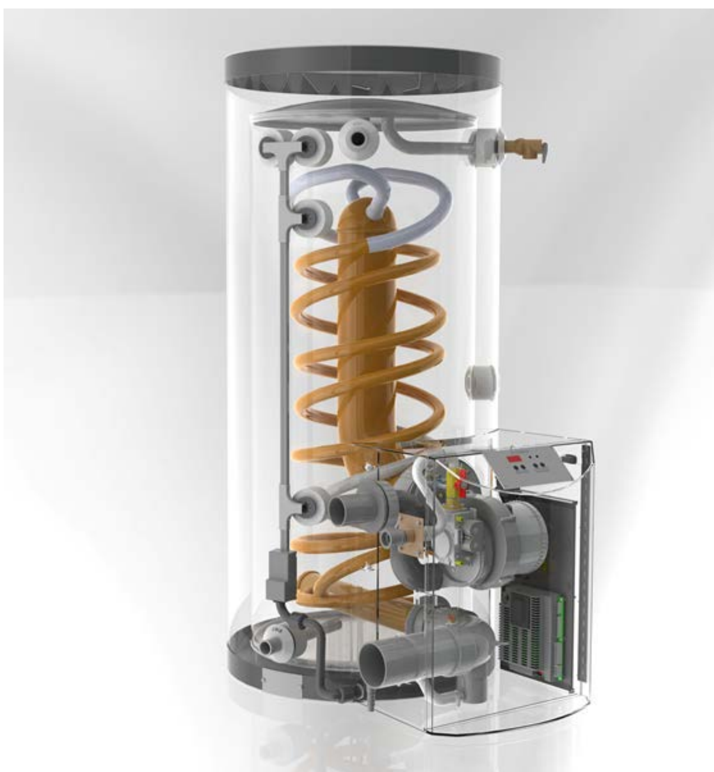
The energy savings of instantaneous water heaters for commercial buildings depends on several factors such as daily hot water usage, draw schedule, piping configuration, etc. Many studies on residential buildings show large energy savings for instantaneous water heaters due to lower standby losses, electric ignition (vs. a pilot light), and potentially higher thermal efficiencies.[159] Two field studies for the Building America program and Minnesota Office of Energy Security found savings of 33%[160] and 37%[161] respectively. Nevertheless, few studies show the energy savings potential for commercial applications. One study by the FSTC found a 9% energy savings when replacing a baseline gas storage water heater with a baseline tankless water heater for a quick service restaurant[162]. Additionally, the study found the energy savings from a condensing instantaneous water heater were less than a condensing storage water heater i.e., 17% vs. 21%, when compared to a baseline gas storage water heater. Much of the saving from using instantaneous water heaters in commercial applications comes from reducing distribution losses in large commercial buildings (e.g., schools) by eliminating large distribution systems and instead siting instantaneous water heaters very close to the point-of-use. This study does not investigate in details the savings from distribution system architectures.

158 Rinnai. 2011. "Hot Water System Design Manual." Rinnai America Corporation. August 2011.
159 Commercial water heaters use thermal efficiency (TE) rather than energy factor (EF) as an efficiency metric. EF includes consideration for standby losses, whereas TE only captures operating efficiency. On an EF basis, non-condensing instantaneous water heaters will generally have a higher EF than non-condensing storage water heaters, but on a TE basis, they will have similar ratings. AHRI requires reporting of both TE and standby losses for commercial water heating equipment.
160 Ries et al. 2013. "Assessing the Energy Savings of Tankless Water Heater Retrofits in Public Housing." Prepared for National Renewable Energy Laboratory. January 2013.
161 Bohac et al. 2010. "Actual Savings and Performance of Natural Gas Tankless Water Heaters." Prepared for Minnesota Office of Energy Security. August 2010.
162 Karas and Fisher. 2007. "Energy Efficiency Potential of Gas-Fired Water Heater Systems in a Quick Service Restaurant – An Emerging Technology Field Monitoring Study." Food Service Technology Center. October 2007.

Because of these varying projections on instantaneous water heater savings, we conservatively estimate a UES of 10% for instantaneous water heaters when replacing commercial water heaters with the same thermal efficiency. Instantaneous water heaters are widely available on the market, but carry a substantial cost premium and require additional consideration for gas-line sizing, electricity availability, and other factors. Buildings that have irregular hot water draw patterns may significantly benefit since standby losses comprise a larger percentage of water heater energy consumption. Conversely, buildings with constant water consumption may experience less energy savings, but potentially benefit from constant hot water availability compared to an existing storage water heater.

6.6.5 Condensing Water Heaters

Condensing water heaters offer thermal efficiencies up to 99% by capturing a greater amount of heat from flue gases compared to baseline gas-fired models. Offered in both instantaneous or storage configurations, condensing water heaters use one or more secondary heat exchanger to condense the water vapor in flue gases and transfer the additional heat to the heated water. Because the condensed vapor is slightly acidic, the heat exchangers, condensate drain, and flue pipe must be made from corrosion-resistant materials, such as polyvinyl chloride (PVC). For new construction, the less expensive PVC materials can offer advantages over a metal flue, but may cause issues for retrofit installations where replacing the flue is difficult. Figure 6-13 below shows a cut-away view of a typical condensing gas water heater.



Source: HTP Phoenix Gas-Fired Water Heater (2015)[163]

Figure 6-13: Condensing gas water heater

[163] HTP. 2015. "HTP Phoenix Gas Fired Water Heater." 2015. Available at: http://www.htproducts.com/phoenixwaterheater.html

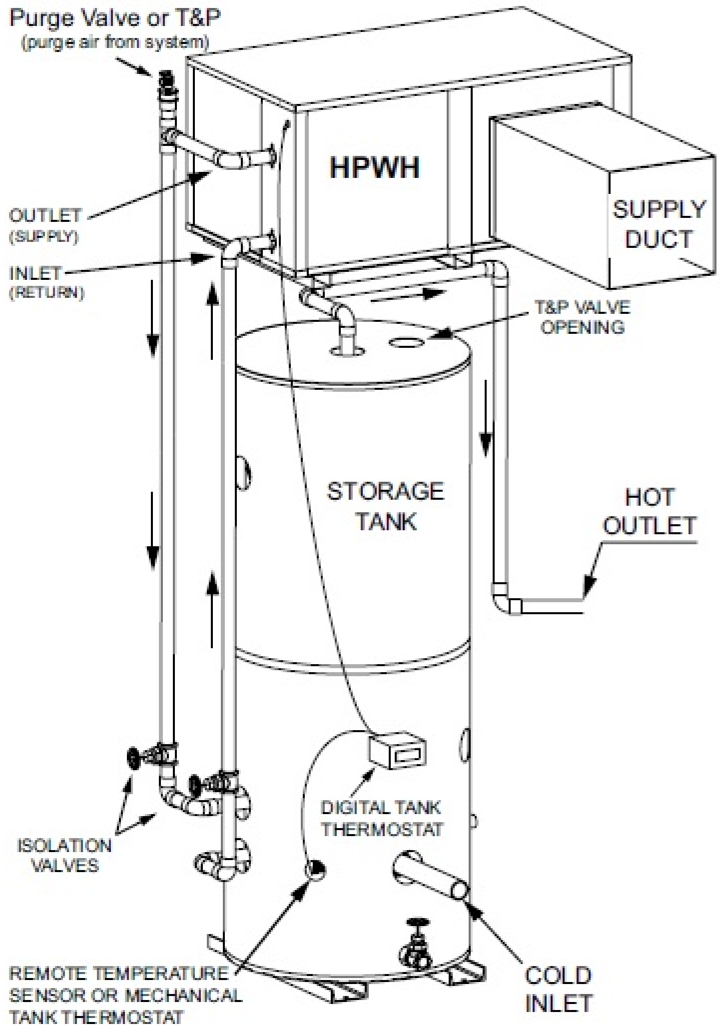
The energy savings of condensing water heaters ranges from 15-20% depending on equipment efficiencies and hot water system configuration. When comparing thermal efficiency (TE), a 94% TE condensing water heater would offer 15% savings of an 80% TE baseline water heater. A 2007 FSTC study found 17% energy savings from a condensing instantaneous water heater and 21% from a condensing storage water heater in a quick service restaurant[164]. Based on these findings and the fact that many commercial condensing storage water heaters have TEs >94%, we estimate a UES of 18% for condensing water heater technologies.

Although available on the market for several years, condensing water heaters have not achieved wider adoption due to their substantial incremental cost for the additional heat exchanger, condensate lines, pumps, etc. Additionally, the requirements for condensate removal and flue replacement pose issues for retrofit installations, especially during emergency replacement situations, which constitute a large portion of purchases.

6.6.6 Vapor-Compression HPWHs

Heat pump water heaters (HPWHs) utilize a traditional vapor-compression system to pump thermal energy from a heat source (typically air) to a storage tank to heat water. Figure 6-14 provides a schematic of a vapor-compression HPWH. Powered by an electrically driven compressor, vapor-compression HPWHs offer significant energy savings versus conventional electric storage water heaters due to COPs of 4.0 or greater. The heat pump can either integrate directly into the storage water heater, as common for residential HPWHs, or be placed remotely with hydronic piping. Because the heat pump has slower temperature recovery, most vapor-compression HPWHs use a conventional electric resistance heating element to supplement the heat pump and accelerate temperature recovery during high demand periods.

[164] Karas and Fisher. 2007. "Energy Efficiency Potential of Gas-Fired Water Heater Systems in a Quick Service Restaurant – An Emerging Technology Field Monitoring Study." Food Service Technology Center. October 2007.



Source: A.O. Smith (2014)[165]

Figure 6-14: Schematic of commercial vapor-compression HPWH

Assuming a coefficient of performance (COP) of 4.2[166], vapor-compression HPWHs would provide close to 70% UES relative to a 98% TE electric storage water heater. The actual energy savings of a vapor-compression HPWH depends on both the efficiency of the heat pump and the operating percentage of the electric resistance heater and will vary with the hot water draw profile, system sizing, operating temperatures, climate, and other factors. For example, a 2010 study on vapor-compression HPWHs in commercial buildings in the Southeast U.S. found COPs of 3.4-4.3 for some locations and 0.5-1.7 for other locations.[167] Vapor-compression HPWHs have been commercially available for over a decade for residential and commercial buildings, but have encountered barriers from high initial cost, reliability, and other factors. Recent projects

[165] A.O. Smith. 2014. "Commercial Electric Air-to-Water Heat Pump Water Heater Instruction Manual." Manual Number 318653. 2014.
[166] A.O.Smith. 2014. "Commercial Electric Heat Pump Water Heaters." February 2014.
[167] Gray, Christopher. 2010. "Energy Efficiency Potential of Heat Pump Water Heaters in Commercial Buildings." Southern Company. 2010 ACEEE Summer Study on Energy Efficiency in Buildings. August 2010.

sponsored by BTO and Sanden have developed and tested split-system CO_2 HPWHs for the U.S. market to improve operating performance[168] and cost-effectiveness.[169]

6.6.7 Solar Water Heaters

Solar water heating technologies capture solar energy to heat water either by collecting the sun's thermal energy (i.e., solar thermal) or converting sunlight into electricity to drive an electric water heater (e.g., solar photovoltaic [PV]). In either configuration, the solar water heater consists of a series of solar collectors mounted to the roof of a commercial building, a storage tank, distribution piping, and typically other components such as pumps, valves, heat exchangers, expansion tanks, controls, etc.

Commercial buildings can employ many different solar water heating technologies, each carrying its own configuration, size, layout, complexity, delivered temperatures, cost, and other aspects. The most common collector systems are evacuated-tube and flat-plate collectors, shown in Figure 6-15 and Figure 6-16 respectively.

- **Evacuated-tube collectors** use an array of heat pipes encapsulated in glass insulation tubes to collect and transfer heat to a common supply manifold that heats the hydronic fluid.

Source: HTP Solar Products (2015)[170]

Figure 6-15: Schematic of evacuated-tube solar thermal collectors

- **Flat-plate collectors** pass the hydronic fluid through a series of parallel copper pipes within a glass absorber plate to transfer thermal energy to the fluid.

[168] Miles, John. 2015. "Design and Development of Split CO_2 HPWH for North America." ACEEE Hot Water Forum. February 2015. Sanden International. Available at: http://aceee.org/sites/default/files/pdf/conferences/hwf/2015/3A-Miles.pdf
[169] Gluesenkamp, Kyle. 2014. "CO2 Heat Pump Water Heater." Oak Ridge National Laboratory. 2014 Building Technologies Office Peer Review. April 2014.
[170] HTP Solar Product. 2015. Available at: http://www.htproducts.com/solar.html

Source: HTP Solar Products (2015)[171]

Figure 6-16: Schematic of flat-plate solar thermal collectors

Solar water heater system designers incorporate these collector technologies into several common system configurations:

- **Active Solar Thermal Water Heaters –** Uses pumps to circulate thermal energy around a hydronic loop either using water (i.e., direct systems) or a water-glycol mixture (i.e., indirect systems).
- **Passive Solar Thermal Water Heaters –** Uses natural convection to circulate thermal energy around a hydronic loop either from an integral collector storage vessel (i.e., ICS or batch system) or a separate storage system located above the collector (i.e., thermosiphon).
- **Solar Thermal Heat Pumps –** Either a direct or indirect solar water heating system provides the thermal energy to drive a thermally activated heat pump (e.g., absorption, adsorption) in place of a gas-fired burner.
- **Solar PV Water Heaters –** A solar PV system provides electrical energy to either an electric storage water heater or vapor-compression HPWH. [172]

Solar water heating technologies can provide substantial energy savings for both gas and electric commercial water heaters where site conditions allow. National Renewable Energy Laboratory (NREL) estimated solar thermal water heating systems could provide 35-60% energy savings for residential homes across the U.S.[173] FSTC estimated solar thermal water heaters could provide 25% energy savings for food service buildings. The actual savings potential for each site varies and depends on: roof availability, building orientation, shading from neighboring buildings, climate and location, hot water demand profile, and other considerations. We conservatively estimate 35% UES for commercial solar water heaters. Two recent BTO reports[174,175] provide additional details on the current status, challenges, and R&D needs for solar water heating technologies.

---

[171] Ibid

[172] Solar PVT panels incorporate a solar thermal hydronic loop on the back of a solar PV panel to capture the thermal energy of the solar PV system and raise overall system efficiency.

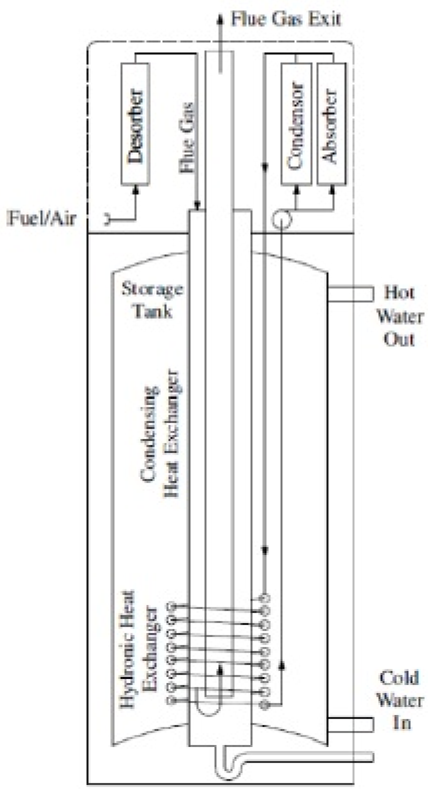
[173] Hudon et al. 2012. "Low-Cost Solar Water Heating Research and Development Roadmap." National Renewable Energy Laboratory. August 2012.

[174] Ibid

[175] Goetzler et al. 2014. "Research & Development Needs for Building-Integrated Solar Technologies." Building Technologies Office. January 2014.

6.6.8 Absorption HPWHs

Absorption HPWHs offer the potential for gas-fired water heaters with thermal efficiencies greater than 100% by utilizing a thermally activated heat pump cycle. In place of an electrically driven compressor for electric HPWHs (Section 6.6.6), absorption HPWHs operate by cyclically absorbing and desorbing a refrigerant from a secondary fluid and transferring thermal energy to a storage water heater. Most absorption HPWHs under development have similar architectures to residential vapor-compression HPWHs with the heat pump section residing on top of a storage water heater. In combined space-and-water heating system configurations, split-system architectures are more common for and are available from Robur and other manufacturers. Figure 6-17 provides a schematic for a residential absorption HPWH.



Source: Glanville, Paul (2014)[176]

Figure 6-17: Schematic of residential absorption HPWH

BTO has supported the development of absorption heat pumps for decades including 2 recent projects to develop ammonia-water (NH_3-H_2O)[177] and water-lithium bromide-water (H_2O-

[176] Glanville, Paul. 2014. "Development of Economical Gas-fired Ammonia-Water Absorption Heat Pumps for Water Heating and Space Heating Applications." Gas Technology Institute. International Gas Union Research Conference. September 17, 2014. Available at: http://members.igu.org/old/IGU%20Events/igrc/igrc-2014/presentations/wo1-3_glanville_final.pdf

[177] Garrabrant, Michael. 2013. "Development & Validation of a Gas-Fired Residential Heat Pump Water Heater." Stone Mountain Technologies, Inc. Project Number DE-EE0003985. January 21, 2013. Available at: http://www.osti.gov/scitech/servlets/purl/1060285

LiBr)[178] absorption cycles. Under support from BTO, Stone Mountain Technologies Inc. and other industry partners have developed prototype absorption HPWHs with COPs up to 1.5[179] and are conducting field testing in different U.S. climate regions.[180] Assuming a 150% TE, absorption HPWHs would provide 46% UES over an 80% TE gas-fired storage water heater.

Absorption HPWHs are attractive energy savings opportunities due to their high-efficiency and low global-warming potential (GWP) working fluids, but face many technological and market barriers including, high first costs, slow recovery times, system reliability, consumer apprehension due to chemical contents, and other issues. BTO and other research organizations are supporting absorption heat pumps and a variety of thermally activated heat pumps for HVAC and water heating applications to overcome these challenges. Other gas-fired alternatives include engine-driven heat pumps (e.g., TecoGen Inc.'s Ilios product [discussed further in Section 7.6.2])[181], adsorption heat pumps, Stirling heat pumps, thermoacoustic heat pumps, Vuilleumier heat pumps, and others. The 2014 BTO report *Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies* provides details on many of these thermally activated heat pump cycles.[182]

6.6.9 Thermoelectric HPWHs

Similar to vapor-compression HPWHs (Section 6.6.6), thermoelectric HPWHs can offer thermal efficiencies greater than 100% for electric storage water heaters. Commonly employed in electronics and portable cooling systems, solid-state thermoelectric devices create a temperature gradient across their surfaces that can act as a heat pump to deliver heat from the ambient environment into a storage water heater. Figure 6-18 provides a schematic for a thermoelectric HPWH. The system operates similar to a standard electric storage water heater, but combines the electric heating element with a set of high-efficiency thermoelectric modules to deliver hot water at suitable temperatures with a higher combined efficiency[183].

---

[178] Gluesenkamp, Kyle. 2014. "Residential Absorption Water Heater." Oak Ridge National Laboratory. 2014 Building Technologies Office Peer Review. April 2014. Available at: http://energy.gov/sites/prod/files/2014/10/f18/emt11_gluesenkamp_042414.pdf.

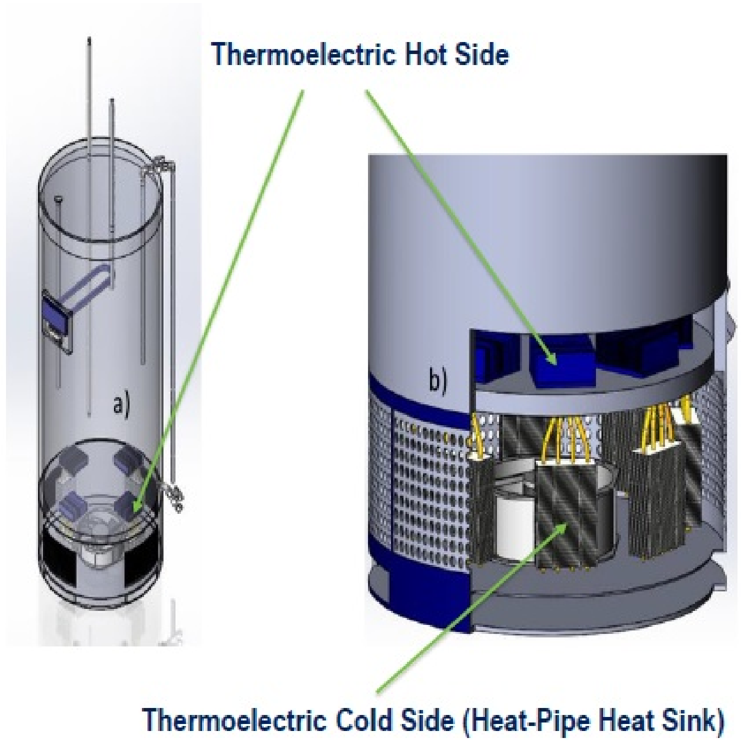
[179] Glanville, Paul. 2014. "Development of Economical Gas-fired Ammonia-Water Absorption Heat Pumps for Water Heating and Space Heating Applications." Gas Technology Institute. International Gas Union Research Conference. September 17, 2014. Available at: http://members.igu.org/old/IGU%20Events/igrc/igrc-2014/presentations/wo1-3_glanville_final.pdf

[180] Stone Mountain Technologies, Inc. http://www.stonemountaintechnologies.com/?page_id=77 Accessed August 2015.

[181] Ilios Dynamics. Accessed August 2015. Available at: http://www.iliosdynamics.com/index.htm

[182] Additional details on thermally activated heat pumps provided by Goetzler et al. 2014. "Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies." Building Technologies Office. March 2014. Available at http://energy.gov/sites/prod/files/2014/03/f12/Non-Vapor%20Compression%20HVAC%20Report.pdf.

[183] Pokharna, Himanshu. 2013. "Low Cost Heat Pump Water Heaters." Sheetak Inc. 2013 ACEEE National Conference on Energy Efficiency as a Resource. October 2013. Available at: http://aceee.org/files/pdf/conferences/hwf/2013/7A-pokharna.pdf



Source: Sheetak Inc (2015) [184]

Figure 6-18: Schematic of thermoelectric HPWH

Under support from BTO, Sheetak and their industry partners are developing a thermoelectric heat pump water heater for residential applications with a COP of 1.1 and greater[185]. Compared to a baseline electric storage water heater (98% TE), thermoelectric HPWHs at 110% TE (COP of 1.1) would offer 11% UES. While these savings are significantly less than a vapor-compression HPWH, thermoelectric models could achieve some of the energy savings benefit at a much lower incremental cost. Nevertheless, this technology requires additional R&D to improve operation and performance before commercialization.

[184] Ghoshal, Uttam. 2015. "Heat Pump Water Heater Using Solid-State Energy Converters." Sheetak Inc. 2015 Building Technologies Office Peer Review. April 2015. Available at: http://energy.gov/sites/prod/files/2015/05/f22/emt87_Ghoshal_041515.pdf

[185] Ibid

Development Status for Commercial Water Heating Technologies Table 6-7 below summarizes the development status of the alternative water heating technologies described above.

Table 6-7: Water Heating Technologies Development Status

Water Heating Technology	Development Status
Solar Water Heaters	Commercially available
Vapor-Compression HPWHs	Commercially available as integrated and add-on systems
Desuperheaters	Commercially available as integrated and add-on systems
Absorption HPWHs	Dedicated absorption water heaters are not yet commercially available. Combined heating/cooling systems are available
Drain-Water Heat Recovery	Commercially available
Instantaneous Water Heaters	Commercially available
Smart Controls	Commercially available
Condensing Water Heaters	Commercially available
Thermoelectric HPWHs	Under development

6.7 Regulated and Voluntary Efficiency Standards

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 6-8. The table omits the standards for oil-fired equipment. DOE currently has an open rulemaking for commercial water heaters.[186]

Table 6-8: 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	All	80%	$Q/800 + 100*(Vr)^{1/2}$
Gas-fired instantaneous water heaters and hot water supply boilers	< 10 gal	80%	N/A
	≥ 10 gal	80%	$Q/800 + 100*(Vr)^{1/2}$

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.
Source: DOE Commercial Water Heating Equipment Standards Webpage, Available at: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/51

[186] More information available on the rulemaking at the DOE website: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/51

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.

EPA's ENERGY STAR program offers a certification for commercial gas storage and instantaneous water heaters. In 2014, ENERGY STAR certified products comprised an estimated 42% of commercial gas water heaters shipments.[187] Table 6-9 provides key product criteria for the ENERGY STAR commercial water heating certification program.

Table 6-9: ENERGY STAR Key Product Criteria for Commercial Water Heating Equipment

Product	Product Criteria	Thermal Efficiency (TE) or Energy Factor (EF)	Maximum standby loss (Btu/hr.)[a]	Minimum Limited Manufacturer Warranty
Gas Storage	> 75,000 Btu/hr. input ≤ 140 gallons storage capacity	TE >= 0.94 or EF >= 0.93	$\leq 0.84*[Q/800 + 100*(Vr)^{1/2}]$	3 years on tank and/or heat exchanger and 1 year on parts
Gas Instantaneous	≥ 4,000 Btu/hr. per gallon of stored water		N/A	

a. Vr is the rated storage volume, in gallons. Q is the nameplate input rate in Btu/hr.

Source: EPA ENERGY STAR Commercial Water Heaters Key Product Criteria, Available at: http://www.energystar.gov/index.cfm?c=water_heat.pr_crit_comm_water_heaters

[187] ENERGY STAR. 2015. "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2014 Summary." U.S. Environmental Protection Agency. 2015. Available at: http://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.

7 Commercial Pool Heaters

Pool heaters provide thermal energy to pool water to maintain comfortable temperatures for indoor and outdoor pools. This section focuses on gas-fired pool heaters with capacities of 500,000 Btu/hr. and greater that serve indoor and outdoor pools for lodging, sports & recreation clubs, municipal parks, amusement/water parks, and education facilities. We exclude electric, oil, and propane pool heaters because the majority of commercial pools use natural gas heating equipment. Appendix A: Technology Descriptions provides detailed descriptions for commercial pool heaters.

Table 7-1 provides a summary of the UEC, installed base, and national energy consumption for U.S. commercial pool heaters. The estimated 2015 primary AEC for the 211,000 commercial water heaters is 0.21 Quads/yr.

Table 7-1: Commercial Pool Heater Energy Consumption Summary

Equipment Types	Average Site UEC (MMBtu/yr.)	Installed Base	AEC—Site Energy (TBtu/yr.)	AEC—Primary Energy (Quads/yr.)
Indoor Pool	1,498	119,000	178	0.19
Outdoor Pool	130	92,000	12	0.01
Total	**-**	**211,000**	**190**	**0.21**

Site-to-source conversion factor of 1.09 for natural gas

7.1 Market Overview

The 3 largest manufacturers of natural gas commercial pool heaters are Raypak, Pentair, and Lochnivar based on a review of retailer literature. These manufacturers offer a wide range of capacities from 500,000 Btu/hr. to 5,000,000 Btu/hr. designed for both indoor and outdoor installations and several different efficiencies. Other manufacturers such as Hayward, Zodiac, Aquacal, and others offer residential-sized pool heaters (<500,000 Btu/hr.) that are applicable for smaller commercial pools. Estimates for manufacturer market share for commercial pool heaters is unavailable.

The majority of commercial pools use natural gas heating equipment, but limited information exists on the exact breakdown for commercial pools. Without additional information, we assume all commercial pools use gas-fired pool heaters when developing energy consumption estimates.

7.2 Annual Shipments and Installed Base

7.2.1 Annual Shipments

Limited information exists for shipments of either residential or commercial pool heaters. The 2010 Residential Pool Heater Rulemaking Technical Support document provides some information on the estimated annual shipments of residential models, which we then scaled based

on the installed base of residential and commercial pools to estimate commercial pool heater shipments. As shown in Table 7-2 and
Table 7-3, the estimated annual shipments for commercial pool heaters is 4,000 units per year based on commercial pools consisting of 2.1% of U.S. pools and hot tubs. These figures are in line with estimates from industry organizations of 3,000 per year.[188]

Table 7-2: Historical Residential and Commercial Pool Heater Shipments

Year	Estimated Pool Heater Shipments	Source
2009	118,000	2010 Residential Pool Heater Technical Support Document[189]
2008	161,000	
2007	185,000	
2006	215,000	
2005	232,000	
2004	193,000	
2003	168,000	
Average	181,714	Calculation

Table 7-3: Estimated Annual Residential and Commercial Pool Heater Shipments

Metric	Value	Source
Average	181,714	Calculation
Installed Base % (Residential)	97.9%	Installed base, see Section 7.2.2
Installed Base % (Commercial)	2.1%	
Total Shipments	185,610	Calculation
Residential Shipments	181,714	Calculation
Commercial Shipments	3,895	Calculation

7.2.2 Installed Base

The installed base for commercial pools consists of a built-up analysis using building count and market data for the following commercial building types:

- Lodging (e.g., hotels, models)
- Sports and recreation facilities (e.g., gyms, health clubs)

[188] APSP. 2013. "U.S. Swimming Pool and Hot Tub Market." The Association of Pool & Spa Professionals. Available at: http://apsp.org/portals/0/images/APSP%20statistics%202013.jpg
[189] 2010 Residential Pool Heater Final Rule Technical Support Document. Chapter 3.2.6.6 Pool Heater Shipments. April 8, 2010. Available at: http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0129-0149

- Secondary and combined schools (e.g., 9^{th}-12^{th} grade or 1^{st}-12^{th} grade)
- Higher education institutions (degree granting)
- Municipal pools
- Amusement and water parks (private, no hotel)

Table 7-4 provides estimates for the number of applicable buildings and estimated number of indoor and outdoor pools. These estimates show significantly larger number of commercial pools compared to the 2009 Commercial Appliances Report. This increase is due to a combination of market growth, inclusion of additional building categories (e.g., private schools), and newly available market data showing greater numbers and increased penetration of swimming pools in specific categories (e.g., lodging). For example, the 2009 Commercial Appliances Report estimated 15% of lodging facilities had either an indoor or outdoor pool, and American Hotel & Lodging Association (AHLA) data shows 46% of lodging facilities have indoor pools and 53% have outdoor pools.[190] Section 7.5 provides further comparison between the 2009 and 2015 Commercial Appliance Reports.

Table 7-4: Estimated Installed Base of Commercial Pool Heaters

Building Type	2015 Building Stock	Estimate for Pool Location (%)		Number of Pools			Notes
		Indoor	Outdoor	Indoor	Outdoor	Total	
Lodging	158,000	46%	53%	73,000	84,000	157,000	• Count: 2012 CBECS Table B13[191] • %s: AHLA 2012 Lodging Survey[192]
Sports & Recreation Clubs	25,000	30%	0%	7,000	0	7,000	• Count: 2012 Economic Census NAICS 713940[193] • %s: Navigant Estimate
Secondary Schools & Higher Edu	47,000	80%	0%	37,000	0	37,000	• Count: 2013 Digest of Education Statistics[194] %s: Navigant Estimate
Municipal Pools	6,000	20%	80%	1,000	5,000	6,000	• Count: Density of swimming pools per population from 2015 City Parks Facts[195] • %s: Navigant Estimate

[190] AHLA. 2012. "2012 Lodging Survey." American Hotel & Lodging Association. Available at: http://www.ahla.com/uploadedFiles/AHLA/Members_Only/Property_and_Corporate/Property_-_Publications/2012%20Lodging%20Survey%20Publication.pdf
[191] CBECS 2012, Table B13. Selected principal building activity: part 2, number of buildings, 2012
[192] AHLA. 2012. "2012 Lodging Survey." American Hotel & Lodging Association. Available at: http://www.ahla.com/uploadedFiles/AHLA/Members_Only/Property_and_Corporate/Property_-_Publications/2012%20Lodging%20Survey%20Publication.pdf
[193] U.S. Census Bureau. 2012 Economic Census NAICS 713940
[194] Institute of Education Statistics. 2013. Digest of Education Statistics. Table 105.50 Available at: http://nces.ed.gov/programs/digest/d13/tables/dt13_105.50.asp
[195] Harnik et al. 2015. "2015 City Park Facts." The Trust for Public Land. April 2015. Available at: https://www.tpl.org/sites/default/files/files_upload/2015-City-Park-Facts-Report.pdf

Building Type	2015 Building Stock	Estimate for Pool Location (%)		Number of Pools			Notes
		Indoor	Outdoor	Indoor	Outdoor	Total	
Water Parks (Private, No Hotel)	300	3%	97%	100	3,000	3,000	• Count, %s: 2015 Water Park Industry Overview by Hotel and Leisure Advisors[196] • Note: Navigant estimate of 10 pools per site
Total	**236,000**	**-**	**-**	**119,000**	**92,000**	**211,000**	• Rounded to 1,000s

We believe this estimate of 211,000 commercial pools is accurate for the building categories included in this report. The Association of Pool and Spa Professionals (APSP) estimates 309,000 commercial pools in the U.S. as shown in Table 7-5, which appears to include pools in MF housing complexes (based on a review of the organization's literature). Accordingly, we only use the APSP data to estimate the annual shipments of commercial pool heaters (Section 7.2.1), but not for estimating the installed base for commercial pools.

Table 7-5: ASPS Estimated U.S. Swimming Pool and Spa Installed Base

Sector / Pool Type	Total Base 2013	% of Installed Base
Residential In-Ground	5,061,000	34.4%
Residential Above-Ground	3,531,000	24.0%
Residential Hot Tubs	5,823,000	39.5%
Total Residential	**14,415,000**	**97.9%**
Commercial	309,000	2.1%
Total	**14,724,000**	**100.0%**

Source: APSP "U.S. Swimming Pool and Hot Tub Market." [197]

Table 7-6 shows the minimum, average, and maximum lifetime estimates for residential gas-fired pool heating equipment according to the 2010 DOE rulemaking for residential direct heating products. The actual lifetime will depend on equipment operating times, cycling frequency, water pressures, water quality and chemical composition, operating temperatures, maintenance regularity, as well as exposure to wind, humidity, extreme temperatures, or other conditions.

[196] Sangree, David. 2015. "The Waterpark Wave Continues in the US." Hotel News Now. April 6, 2015. Available: http://www.hotelnewsnow.com/Article/15593/The-waterpark-wave-continues-in-the-US
[197] APSP. 2013. "U.S. Swimming Pool and Hot Tub Market." The Association of Pool & Spa Professionals. Available at: http://apsp.org/portals/0/images/APSP%20statistics%202013.jpg

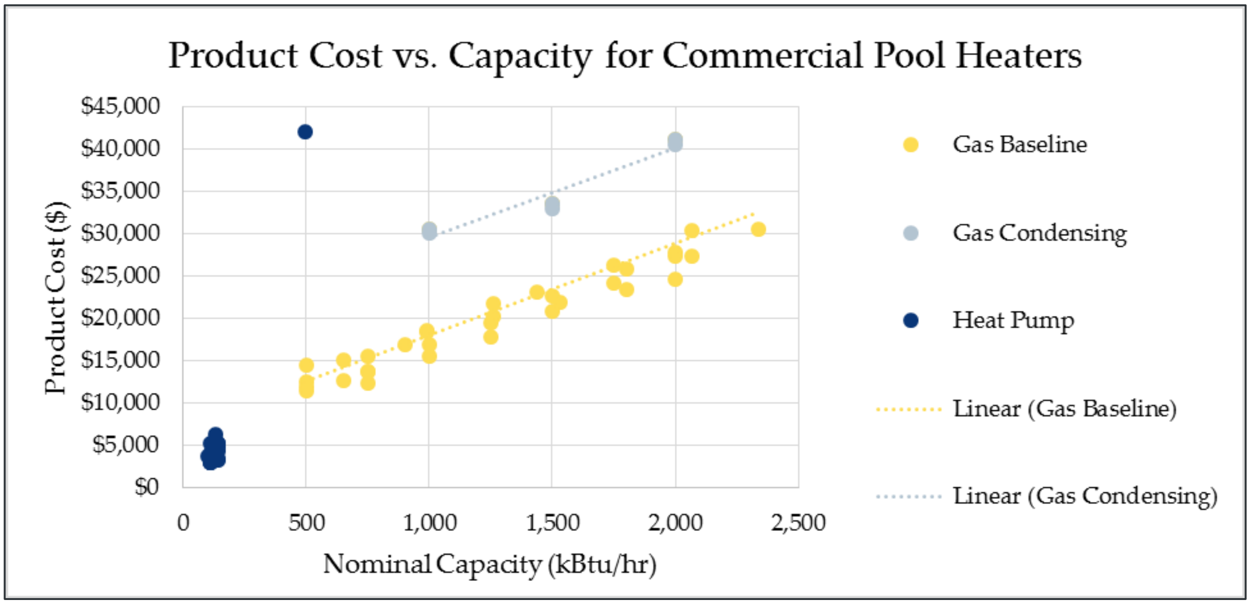
Table 7-6: Lifetime Estimates for Gas-Fired Pool Heating Equipment

Estimated Lifetime (Years)	
Minimum	3
Average	6
Maximum	20

Source: 2010 DOE Rulemaking Technical Support Document (TSD) Table 8.7.4[198]

7.3 Product Cost Breakdown

The product cost for commercial pool heaters depends on thermal efficiency, capacity, and intended installation. Figure 7-1 provides the price of commercial pool heaters as a function of capacity for different pool heating technologies. Gas-fired pool heaters show a strong linear correlation with capacity, with slightly higher costs for outdoor models and additional features. Few heat pump models are available at capacities suitable for commercial pool heating currently. Heat pump and condensing options can provide energy savings, but carry a substantial first cost premium as shown in Table 7-7.



Sources: Recreonics[199], Lincoln Aquatics[200], World Wide Pool Heaters[201], Pool Heat Pumps[202], HydroPool[203]

Figure 7-1: Product cost vs. capacity for commercial pool heaters

[198] EERE. 2010. Technical Support Document - Energy Efficiency Standards for Pool Heaters, Direct Heating Equipment and Water Heaters. U.S. Department of Energy. EE-2006-STD-0129. Table 8.7.4 April 2010.
[199] Recreonics Inc. Product Catalog. Accessed August 2015. Available at: http://www.recreonics.com/pool_heating.html
[200] Lincoln Aquatics. Product Catalog. Accessed August 2015. Available at: http://www.lincolnaquatics.com/
[201] Worldwide Pool Heaters LLC. Product Catalog. Accessed August 2015. Available at: http://www.worldwidepoolheaters.com/
[202] Poolheatpumps.com Inc. Product Catalog. Accessed August 2015. Available at: http://www.poolheatpumps.com/
[203] Hydro Pool & Spa, Inc. Accessed August 2015. Available at: http://www.hydropool.com

Table 7-7: Estimated Pool Heater Cost by Capacity (Gas Baseline vs. Gas Condensing)

Metric	Pool Heater Capacity (Btu/hr.)				Difference Over Baseline (%)
	500,000	1,000,00	1,500,000	2,000,000	
Gas Baseline	$12,642	$18,052	$23,461	$28,871	n/a
Gas Condensing	$24,259	$29,558	$34,857	$40,156	39%-92%
Heat Pump	$42,139	n/a	n/a	n/a	233%

Based on linear fit lines from Figure 7-1.

7.4 Baseline Energy Consumption

Because the energy consumption for any individual pool depends on a wide variety of weather, operational, and design factors, we followed the analysis methodology developed for ENERGY STAR's Portfolio Manager benchmarking tool to determine national commercial pool heater energy consumption.[204] The methodology estimates the heating and pumping energy use for commercial swimming pools based on building type, pool size, and placement (e.g., indoor vs. outdoor) so that a building's energy use can be separated from the pool's energy use to then benchmarking the building-related energy consumption. We used this methodology to estimate the thermal energy consumption for a representative 4,000 ft^2 indoor or outdoor pool.[205] To obtain the national baseline energy consumption, we then multiplied the representative pool consumption values by the estimated number of indoor and outdoor pools in the U.S.

Table 7-8 provides the estimated energy consumption of U.S. commercial pool heaters using the ENERGY STAR methodology. As discussed above, the analysis assumes all commercial pools use gas-fired pool heaters. These values do not account for other pool-related energy consumption sources such as pool pumps, lighting, dehumidification systems, filtration systems, and other end-use loads.

Table 7-8: Estimated Energy Consumption of Commercial Pool Heaters

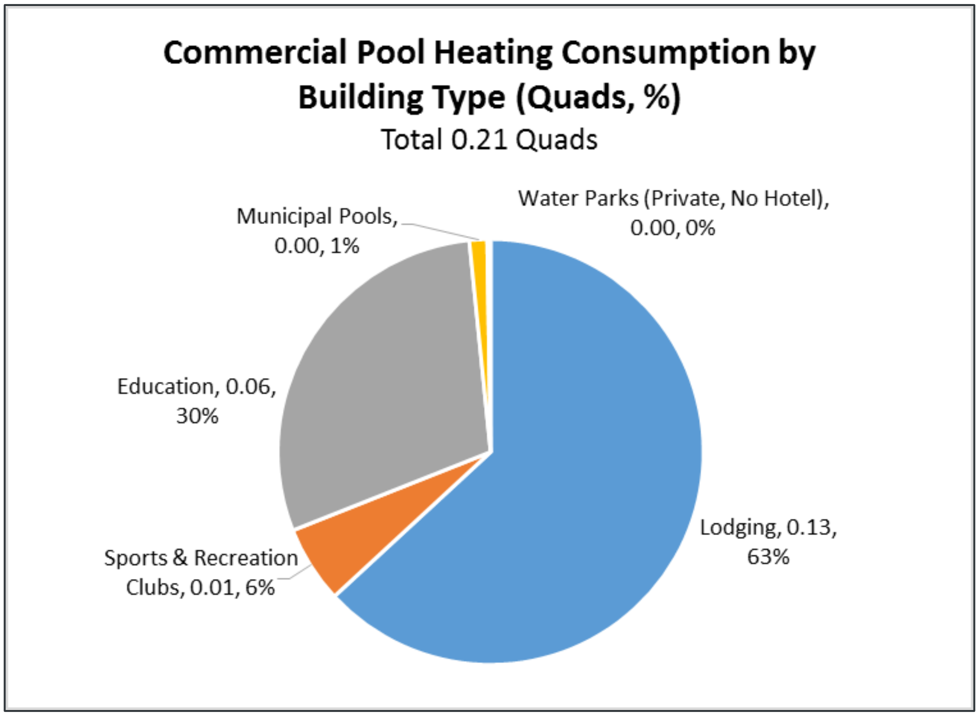
Location	No. Pools	Site UEC (MMBtu/yr.)	Primary UEC (MMBtu/yr.)	Primary AEC (Quads/yr.)
Indoor	119,000	1,498	1,633	0.19
Outdoor	92,000	130	141	0.01
TOTAL	**211,000**	**-**	**-**	**0.21**

Site-to-source conversion factor of 1.09 for natural gas

Figure 7-2 shows the total annual pool energy consumption by sector. Lodging and education account for over 90% of commercial pool heater energy consumption due to the large number of buildings with pools. As shown in

[204] EPA. 2013. "Swimming Pools and the ENERGY STAR Score in the United States and Canada – Technical Reference." U.S. Environmental Protection Agency. ENERGY STAR Portfolio Manager. July 2013.
[205] This pool size is consistent with the 2009 report.

Table 7-4, the other sectors do not account for significant percentages of overall consumption because municipal pools are primarily outdoors, only 30% of sports & recreation clubs have pools, and the included water parks do not include those facilities owned by municipalities or hotels.



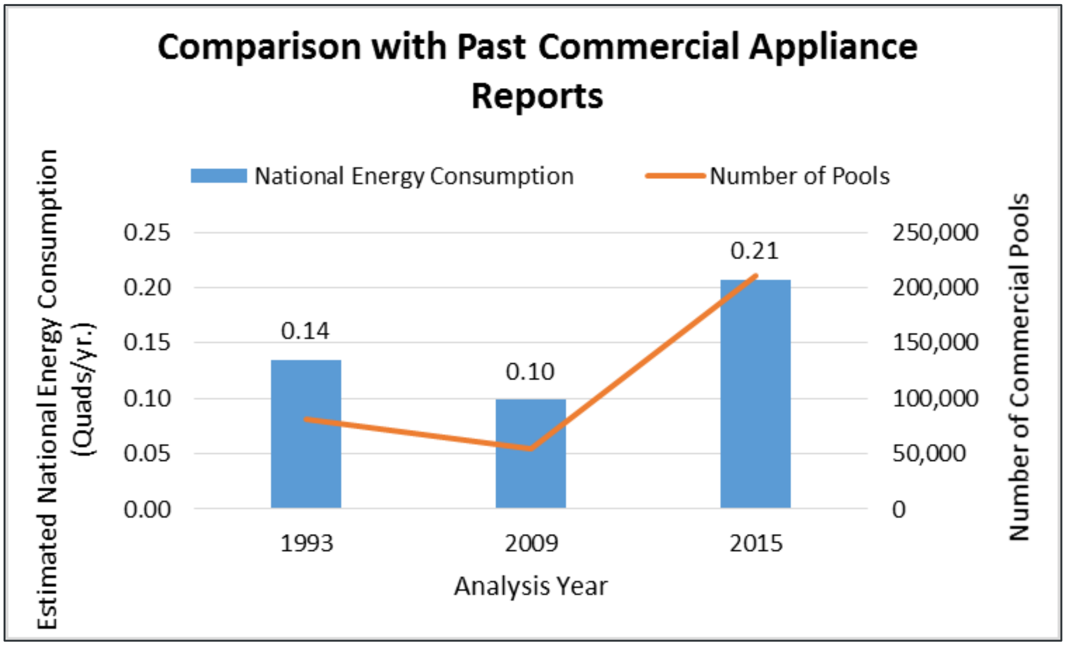
Source: Navigant Consulting energy consumption model

Figure 7-2: Commercial pool heating consumption by building type

7.5 Comparison of Baseline Energy Consumption to Previous Studies

Figure 7-3 compares the estimated 2015 pool heater consumption and installed base with previous estimates from the 1993 ADL and 2009 Commercial Appliances Report. As discussed in Section 7.2.2, newly available market data for swimming pool penetration in lodging facilities is the primary cause for the significant differences in pool heater energy consumption among the analyses. Whereas the past reports estimated 15% of lodging facilities had either an indoor or outdoor pool, a market research survey from AHLA shows 46% of lodging facilities have indoor pools and 53% have outdoor pools.[206] The AHLA survey indicates that the percentage of lodging facilities with indoor pools has increased from 33% in 2004 to 46% in 2012, which has a substantial effect on national energy consumption (0.03 Quads/yr.) due to the higher UEC of indoor pools.

[206] AHLA. 2012. "2012 Lodging Survey." American Hotel & Lodging Association. Available at: http://www.ahla.com/uploadedFiles/AHLA/Members_Only/Property_and_Corporate/Property_-_Publications/2012%20Lodging%20Survey%20Publication.pdf



Source: ADL 1993[207], 2009 Commercial Appliances Report[208]

Figure 7-3: Comparison of estimated pool heater energy consumption and installed base to past commercial appliance reports

7.6 Energy Savings Opportunities

Table 7-9 below summarizes the UES potential, applicable primary energy usage, and technical potential for each technology profiled in this section. 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 7-9: Technical Potential of Pool Heating Technology Options

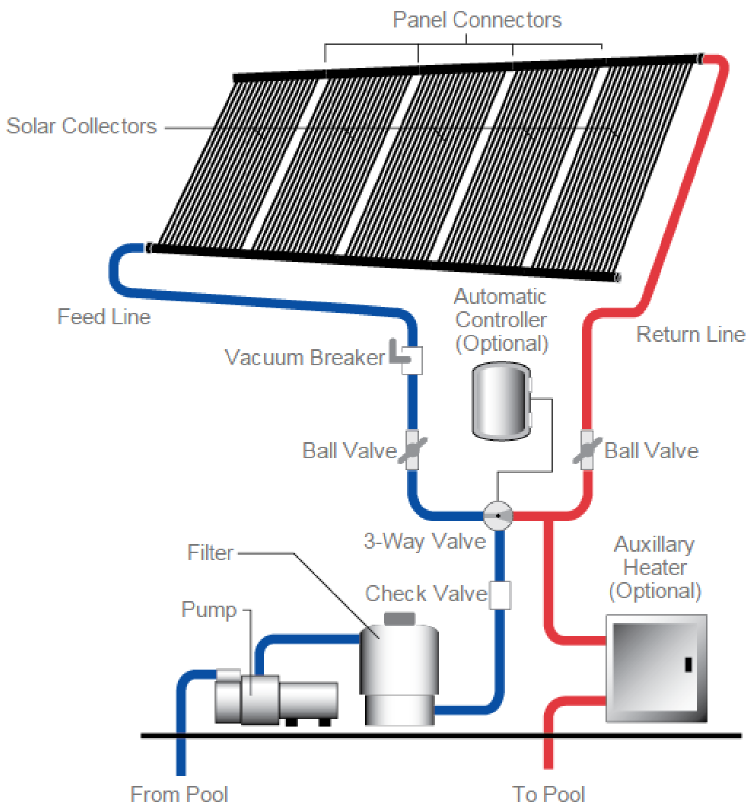
Technology	UES Potential	Applicable Fuel Types / System Designs	Applicable Primary Energy Usage (Quads/yr.)	Technical Potential (Quads/yr.)
Solar PV and Thermal	60%	All	0.21	0.12
HPWHs	60%	All	0.21	0.12
Pool Covers	50%	All	0.21	0.10
HVAC Heat Recovery Systems	36%	All	0.21	0.08
Condensing Pool Heater	15%	All	0.21	0.03

The following sections describe each technology option in more detail.

[207] ADL. 1993. “Characterization of Commercial Building Appliances.” Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.
[208] Navigant 2009Zogg et al. 2009. “Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances.” Report for DOE Building Technologies Program. November 2009.

7.6.1 Solar Pool Heaters

Solar pool heaters capture thermal energy from the sun to heat water and offset the energy consumption of conventional pool heaters. Similar to solar domestic water heating systems (Section 6.6.7), solar pool heaters consist of a set of collectors that absorb, collect, and transfer the sun's thermal energy to flowing water. Figure 7-4 shows a typical solar pool heating configuration, where a rooftop collector heats water upstream of a conventional pool heater.



Source: Heliocol[209]

Figure 7-4: Schematic of solar pool heating system

Solar pool heaters are increasingly a popular option to offset pool heater energy consumption due to their relatively low initial cost. For climates without a chance of freezing, or outdoor pools that operate only during summer months, the solar pool heating system can use unglazed rubber or plastic collectors. These collectors are less effective than glazed collectors for solar water heating, but provide sufficient heating (10-15°F) to maintain pool temperatures.

The energy savings potential for solar pool heaters depends on many characteristics, including the size of the pool, size of the collectors, the climate, the orientation of the collectors, the pool's operating hours, use of a pool cover, and many other factors. Most solar pool heating systems have a collector area 50-100% of the pool's surface area. In a 2006 design manual, the Florida Solar Energy Center estimated an optimal solar thermal system sizing to be 65-75% of the

[209] Heliocol. Accessed August 2015. Available at: http://www.heliocol.com/get-solar-smart/how-does-heliocol-work#automatic-controller

annual domestic hot water or pool heating load. This system sizing would meet an estimated 100% of the hot water demand in the summer and 50% of the hot water demand in the winter.[210] While these guidelines are Florida specific, the recommendations highlight the savings potential for a year-round pool operation. Based on these guidelines, we conservatively estimate a UES potential of 60% for solar pool heaters.

7.6.2 Heat Pump Pool Heaters

Similar to heat pump water heaters (Section 6.6.6), heat pump pool heaters use a vapor-compression heat pump cycle to pump thermal energy from a heat source (typically air) to the heated water. Most heat pump pool heaters on the market today have heating capacities for residential applications (100,000 Btu/hr. range), although at least one manufacturer offers a larger commercial model (>500,000 Btu/hr.)[211]. As shown Figure 7-5, many residential and commercial heat pump pool heaters resemble outdoor units for split HVAC systems. Most heat pump pool heaters operate without a storage tank and directly heat water traveling through the pool filtration and treatment system.

Residential (left), Commercial (right)
Source: AquaCal[212]

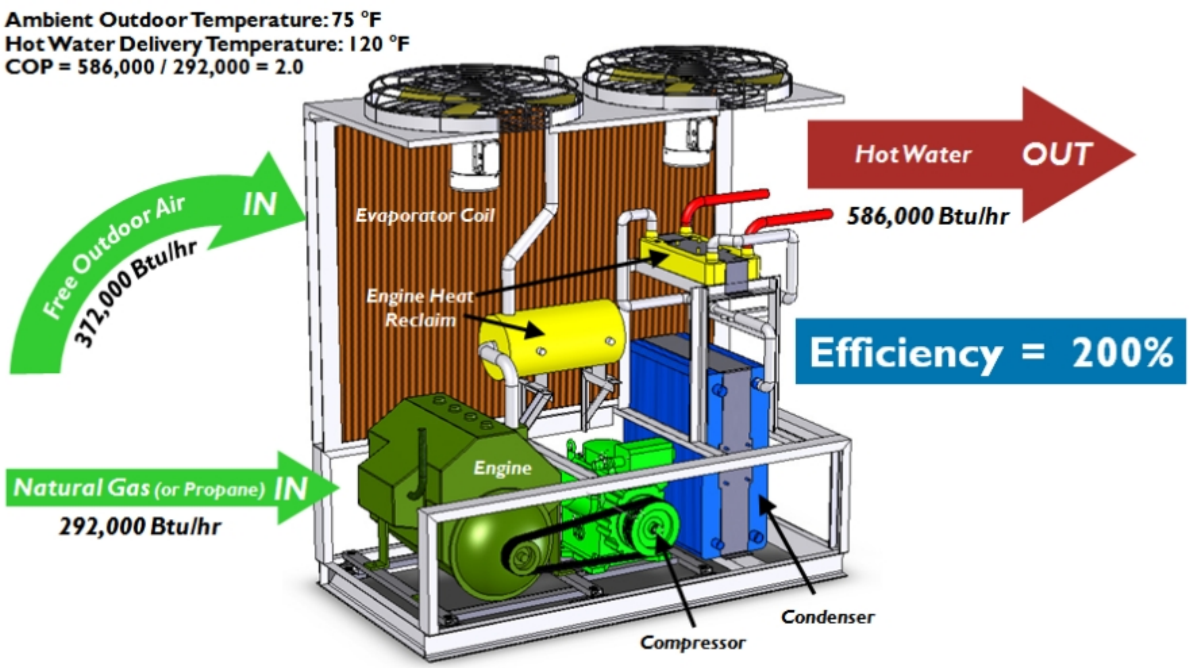
Figure 7-5: Residential and commercial heat pump pool heaters

Manufacturers offer heat pump pool heaters with COPs of 6 and greater, which offers large energy savings for commercial pools using electric pool heaters or large operators with gas pool heaters. For areas of the U.S. with lower electricity rates, heat pump pool heaters could be an attractive option for commercial pool owners but carry a substantial upfront cost premium over other options as shown in Table 7-7. As discussed previously, this investigation focuses on natural gas pool heaters, which makeup the majority of the U.S. market. As a replacement for a baseline 82% natural gas pool heater, heat pump pool heaters could provide source energy

[210] Florida Solar Energy Center. 2006. “Solar Water and Pool Heating Manual.” FSEC-IN-24. January 2006.
[211] AquaCal. 2015. “AquaCal Great Big Bopper - Commercial Sized Pool Heat Pump.” Accessed Augusr 2015, Available at: http://www.aquacal.com/great-big-bopper-commercial-pool-heat-pump
[212] Ibid

savings of 60%. Unlike many heat pump domestic water heating systems, commercial heat pump pool heaters are very rarely installed indoors and have no impact on indoor space conditioning energy consumption. Manufacturers highly discourage indoor installations due to the requirements of large airflow clearances around the units.

In addition to electrically driven models, the combined heat and power (CHP) manufacturer TecoGen has developed a heat pump water heater driven by a gas-fired engine, shown in Figure 7-6. The Ilios Dynamics water heater provides a heating output of 550,000 Btu/hr. with a source energy COP of 2.0 before accounting for auxiliary electric loads.[213] Ilios markets the product for both domestic hot water applications and pool heating. On a source basis, the UES for the engine-driven heat pump pool heater would be similar to the 60% for the electrically driven models, but could offer greater operating cost savings due to the comparatively lower cost of natural gas as the primary fuel.



Source: Ilios Dynamics[214]

Figure 7-6: Schematic of engine-driven heat pump pool heater

7.6.3 Pool Covers

Pool covers are a simple energy savings strategy to reduce the amount of thermal energy that escapes a pool during occupied hours. If left uncovered, the heated pool loses thermal energy to the surrounding environment through evaporation, radiation, and conduction to the ground, and convection to the surrounding air. Evaporation requires that operators add replacement water to maintain the desired water level and subsequently requires thermal energy to heat the replacement water to the set point. Table 7-10 outlines the DOE's estimates for energy consumption by energy-loss source.

---

[213] Ilios Dynamics. 2012. "Ilios Air-Source High Efficiency Water Heater." Accessed August 2015. Available at: http://www.iliosdynamics.com/

[214] Ibid

Table 7-10: Swimming Pool Energy-Loss Characteristics

Energy-Loss Source	Outdoor	Indoor
Evaporation	70%	70%
Radiation to Sky	20%	-
Convection to Ventilation Air	-	27%
Conduction to Ground and Other	10%	3%

Source: DOE Energy savers[215]

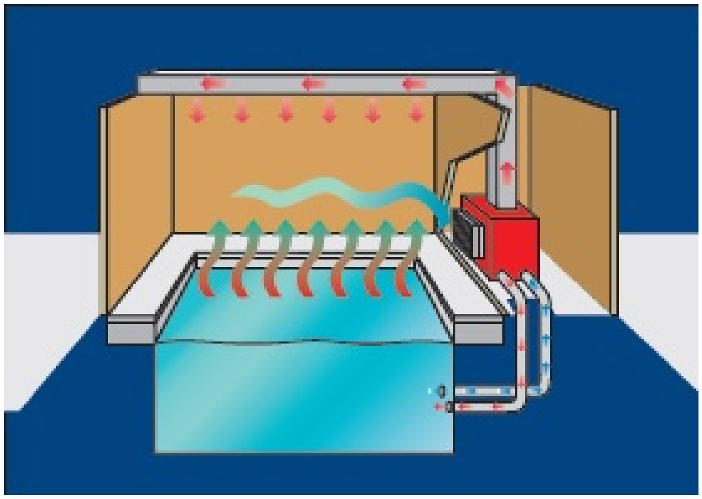
By creating a barrier between the pool and surrounding environment, more of the pool's thermal energy remains in the water. Properly employed and regularly-used pool covers can save pools between 50-70%[216], but will vary with each site. The Smart Energy Design Assistance Center (SEDAC) of Illinois found 40% energy savings for outdoor pools in Chicago.[217] Pool covers are relatively inexpensive, simple, and have been used for decades to reduce water and energy consumption. Most pool covers consist of a thin sheet of UV-resistant plastic, vinyl, or other material and can be manually or automatically deployed each night. Many building codes have started requiring pool covers during new installations, although the compliance rates, and actual practice will vary. Based on the range of adoption and practice, we conservatory estimate a UES of 50% for commercial pool covers.

Rather than a physical pool cover, several vendors offer a chemical or liquid pool cover that creates a thin layer of insulation on top of the pool water. A 2010 study of liquid pool covers at an outdoor pool in California found a 13% energy savings relative to no pool cover, but significantly less savings than a traditional plastic pool cover (approximately 50-60%).[218]

7.6.4 HVAC Heat Recovery Systems

Similar to desuperheaters for service water heating (Section 6.6.3), commercial pools can capture waste heat from HVAC, refrigeration, and other systems to offset pool heater consumption. These heat recovery systems use a refrigerant-to-water heat exchanger to transfer thermal energy from the high-temperature HVAC refrigerant to heat incoming water. These systems may operate as an add-on component or as part of a combined dehumidification/pool heating system. Indoor pools require dehumidification systems to maintain proper indoor air conditions and consequently generate significant waste heat. These systems typically do not use a storage tank, but rather provide continuous pool heating similar to solar pool heating (Section 7.6.1). Figure 7-7 provides a schematic of an indoor dehumidification system with heat recovery for pool heating.

[215] EERE. "Energy Savers – Swimming Pool Covers." Available at: http://energy.gov/energysaver/articles/swimming-pool-covers
[216] Ibid
[217]SEDAC. 2011. "Energy Smart Tips for Swimming Pools." Smart Energy Design Assistance Center. May 2011.
[218] Information & Energy Services, Inc. 2010. "Engineering Measurement & Verification Study: HeatSavr™ Liquid Swimming Pool Cover." April 13, 2010.



Source: PoolPak Product Brochure[219]

Figure 7-7: Schematic of indoor dehumidification and pool heating system

The UES from offsetting pool heater consumption with recovered HVAC energy will vary greatly based on the heating requirements of the pool, the HVAC loads of the building, whether the pool is indoors or outdoors, and other factors. PoolPak estimates 40-60% cost savings over standard HVAC and pool heating systems[220]. Assuming a 75% recovery percentage, 82% baseline efficiency, and dehumidifier COP of 5, the heat recovery system would offer approximately 36% source energy savings.

7.6.5 Condensing Pool Heaters

Similar to condensing water heaters (Section 6.6.5), condensing pool heaters use a secondary heat exchanger to capture a greater amount of heat from combustion gases. The condensing pool heater operates similar to a baseline pool heater, but condenses the water vapor in the exhaust flue, transferring additional energy to the heated water. Condensing pool heaters can offer efficiencies up to 97%, which creates a UES of 15% over baseline 82% efficient models. Because the condensed vapor is slightly acidic, the heat exchangers, condensate drain, and flue pipe must be made from corrosion-resistant materials, such as PVC. Local building codes may require condensate to be drained to the municipal sewer system rather than other on-site drainage systems which may pose an issue for pool heaters located outdoors. As shown in Table 7-7, condensing pool heaters carry a substantial cost premium of $11,000 or greater when compared to baseline models from Recreonics.

7.6.6 Development Status for Commercial Pool Heating Technologies

Table 7-11 below summarizes the development status of the alternative water heating technologies described above.

[219] PoolPak International. 2009 "ClimatePak Product Brochure." Available at: http://www.prestigeclimatisation.com/pdf/piscine/poolpack/poolpak.pdf
[220] Ibid

Table 7-11: Pool Heating Technologies Development Status

Pool Heating Technology	Development Status
Solar PV and Thermal	Commercially available
HPWHs	Commercially available as either electrically driven or gas-driven models
Pool Covers	Commercially available as integrated and add-on systems
HVAC Heat Recovery Systems	Commercially available as either an integrated dehumidification and heat recovery system or as an add-on component
Condensing Pool Heater	Commercially available

7.7 Regulated and Voluntary Efficiency Standards

There are currently no regulatory programs in place for commercial pool heaters. Energy Policy and Conservation Act (EPCA) established a minimum TE 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.

There are no ENERGY STAR or other voluntary energy efficiency standards for commercial pool heaters.

8 Commercial Laundry Equipment

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 alternative chemicals and equipment continue to rapidly emerge.

Commercial laundry equipment end-users include the following:

- **Laundromats (or coin-operated laundries) –** Traditional laundromat facilities that provide coin- or card-operated laundry equipment.
- **MF laundry facilities –** Laundry facilities located in common areas of apartment buildings, dormitories, and other MF dwellings.
- **On-premise laundries (OPLs) –** On-site laundry facilities in hotels, hospitals, assisted living facilities, universities, and prisons.
- **Dry cleaners –** Professional cleaning establishments that use organic or other solvents to launder clothing and textiles.

Please refer to Appendix A for detailed descriptions of laundry technologies.

Single-load washers, which are defined in the Energy Policy Act of 2005 as being designed for use by the occupants of a single household, and are intended to be used by individual consumers, primarily in laundromats and MF laundry facilities. Single-load washers are typically less than 4.0 cubic feet in volume - most single-load washers used in laundromats and MF housing 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.

Multi-load washers are used by OPLs and industrial laundry facilities. Multi-load washers are larger than traditional single-load washers ranging in equipment capacity, reported in terms of laundry weight, from 35 to as much as 700 pounds of laundry per load. Multi-load washers are often called “washer extractors”, if they have very high speed, moisture extracting, spin functions. Washer extractors are more robust and durable compared to single-load washers; they must withstand g-forces on the order of hundreds of g’s during extraction and endure high duty cycles.

Single-load dryers are primarily used in MF laundry and are smaller dryers in found laundromats. Similar to single-load washers, single-load dryers are intended to be used by individual consumers. They are sometimes referred to as “residential-style” dryers, but are typically more durable and may be outfitted with hardware for coin or card operations. Single-load dryer capacity is often measured by cubic feet of volume. Typical capacities range from 5.4 to 7.4 cubic feet. These dryers can usually process up to 20 pounds of laundry per load.

Multi-load dryers, also described as “tumble dryers” in the 2009 Commercial Appliances Report, are used in laundromats and in OPLs. There is no clear distinction between multi-load dryers and single-load dryers aside from increased capacity, measured by weight of laundry per load, which range from 30 to 170 pounds. Smaller sized multi-load dryers might be used in laundromats while larger multi-load dryers would be used for OPL applications with higher laundry volumes.

We use the term “industrial” or “industrial-size” to describe the largest laundry equipment, which are large off-site laundry facilities that usually serve multiple customers and often replace OPLs. Off-site laundries can use any combination of multi-load washers, multi-load tumble dryers, tunnel washers, and industrial-sized dryers. We deemed industrial laundry as out of scope for this commercial appliance report since there is very limited available data in CBECs or other sources. Where we have information, we have separately included estimates for industrial laundry energy consumption.

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. Commercial dry-cleaning facilities serve both residential (e.g. individuals and households) and commercial (e.g. uniforms, industrial clothing) customers. The traditional dry-cleaning process uses a solvent called perchloroethylene, often referred to as PCE or PERC. One major manufacturer’s PCE equipment ranges from 35 to 165 pound capacities, with most models falling between 40 and 100 pounds. [221]

Table 8-1 provides a summary of the UEC, installed base, and AEC for U.S. commercial laundry equipment. The estimated 2015 primary AEC for commercial laundry equipment is 0.42 Quads/yr.

[221] Union 2015. Accessed Dec 3, 2015. http://www.uniondc.com/index.html

Table 8-1: Commercial Laundry Energy Consumption Summary

Equipment Types	Average UEC (MMBtu/yr.) [a,b]	Installed Base (1,000s)	AEC—Primary Energy (Quads/yr.) [c]
Single-load Washers	1.3 - 3.6	1,750	0.008
Multi-load Washers	530	300	0.180
Industrial Washers [b]	-	-	0.023 [d]
Single-load Dryers	8.3 – 14	1,640	0.028
Multi-load Dryers	24 – 379	900	0.140
Industrial Dryers [b]	-	-	0.014 [d]
Dry-Cleaning Equipment	13,705	33	0.030
	Total:	**4,623**	**0.420** [e]

a. Range of UEC due to different equipment types and application uses.
b. Site kWh to Site Btu conversion of 3,412 Btu-to-kWh.
c. Site-to-source conversion factors of 3.15 for electricity and 1.09 for natural gas.
d. Industrial laundry is not in the scope of this report but we have estimated primary energy consumption based on estimated laundry volumes from TRSA[222].
e. Numbers do not sum due to rounding.

8.1 Market Overview

8.1.1 Washers

The commercial clothes washers market is segmented into single-load washers and multi-load washers.

Single-load washer technology is similar to residential clothes washers, though the total washer size is larger. Single-load washers can be either top-loading or front-loading, based on the way laundry is put in, or taken out, of the machine. For more information regarding single-load washer technology, please refer to Appendix A: Technology Descriptions.

They are used primarily by MF housing and laundromats, with an estimated split of shipments to each sector of 85% and 15% respectively. We estimate that top-loading washers represent 78% of the market, while front-loading washers constitute the remaining 22%, based on DOE historical shipments.[223]

Multi-load washers are almost exclusively used by OPL facilities, though there is a wide range of unit capacities due to the diversity in laundry loads. Motels may use smaller sized multi-load washers, while large hotels or hospitals may require significantly larger washers to accommodate high laundry throughput. We do not have shipment data for different multi-load washer capacities or types. Table 8-2 lists various manufacturers of single- and multi-load washers.

[222] TRSA 2015. "LaundryESP." TRSA – Laundry Environmental Stewardship Program. Accessed on November 2015. Available at: http://www.trsa.org/laundryesp
[223] We calculated market share of the installed base by averaging market share from the last 11 years of shipments. Source: CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Chapter 9. Dec 2014.

Table 8-2: Commercial Clothes Washer Manufacturers

Commercial Clothes Washer Equipment Type	Manufacturers
Single-load commercial washers	Alliance Laundry Systems; Whirlpool; Maytag; GE; Kenmore; LG; Wascomat (Electrolux); Dexter; Continental Girbau
Multi-load washers / Washer extractors	Alliance Laundry Systems; Jensen-GROUP; Pellerin Milnor; Milnor); LG; Wascomat; Dexter; Continental Girbau

This list is not exhaustive.
Source: Market Research

Laundromats are served primarily through local and regional distributors. Laundromats historically rely on distributors for servicing. Distributor support typically ends at point of sale, though some laundromats may rely on distributors to repair faulty or broken equipment.[224]

Large institutions with shared laundry facilities (e.g. military barracks, universities, and housing authorities) and approximately 50-90% of MF laundries are served through individual route operators. Route operators purchase laundry equipment from the manufacturer and obtain leases from the laundry facility to place the equipment in common-area laundry rooms. Route operators maintain, operate, and provide on-going support for the laundry equipment in the leased space, sharing revenue with the lessor.[225]

OPLs may purchase multi-load washers through a distributor, who also provides service support. Some OPL washers are also serviced by manufacturer route operators. [226]

8.1.2 Dryers

Commercial clothes dryers are segmented into single-load dryers for laundromat and MF housing laundries, and larger-capacity, multi-load, tumbler dryers for laundromats and OPLs. There are no major technological differences between dryer types, rather these categories illustrate the differences in capacities and physical configurations.

We estimate 16% of laundromat dryers are single-load, while 84% are multi-load, tumbler dryers. We also estimate that 80% of MF dryers are single-load capacity. [227]
Table 8-3 lists manufacturers of single- and multi-load dryers.

[224] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Chapter 3. Dec 2014.
[225] Ibid
[226] Ibid
[227] CA-IOU. 2013. "Commercial Clothes Dryers." Docket #12-AAER-2D. July 2013. Available at: http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf. Navigant estimate based on source for multi-family laundry breakdown.

Table 8-3: Commercial Clothes Dryer Manufacturers

Commercial Clothes Dryer Equipment Type	Manufacturers
Single-load and multi-load tumbler dryers	American Dryer Corporation; GE; Pellerin Milnor (Milnor); Alliance Laundry Systems; Continental Girbau; Wascomat; Whirlpool; Maytag; Dexter

This list is not exhaustive.
Source: Market research.

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 Section 8.1.1.

8.1.3 Dry-Cleaning Equipment

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 2 dry-cleaning units.[228] Refer to Appendix A: Technology Descriptions for details regarding dry-cleaning technology. We have assumed that PCE remains the baseline equipment in dry cleaners, nationwide, despite many emerging alternatives. We describe several dry-cleaning alternatives in Section 8.6.3.

Table 8-4 shows some of the manufacturers of PCE dry-cleaning equipment.

Table 8-4: Manufacturers of Commercial Clothes Washing Equipment

Equipment Type	Major Manufacturers
PCE Dry-cleaning machines	Union; Aero-tech; Columbia/ILSA; Bowe; Firbimatic

This list is not exhaustive.
Source: Market research.

The structure of the distribution chain for dry-cleaning equipment is largely similar to the distribution chain for commercial laundry equipment described above in Section 8.1.1. [229]

8.2 Annual Shipments and Installed Base

8.2.1 Annual Shipments

Annual shipments of single-load and multi-load washers are presented in Table 8-5. DOE estimates 206,000 units single-load washer shipments in the U.S. in 2013 – this is small relative

[228] 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.
[229] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.

to the U.S. residential clothes washer market. [230] We calculated multi-load washer shipments by dividing the estimated installed base by the average product life of a multi-load washer.

Table 8-5: Estimated Commercial Washer Shipments

Washer Type	Estimated Annual Shipments	Source
Single-load Washers	206,000 [a]	Commercial Clothes Washer (CCW) Rulemaking 2014[231]
Multi-load Washers	20,000 [b]	-

a. Shipments are those estimated for 2013 from source.
b. Based on estimated product life of 15 years [232]

Single-load and multi-load dryer annual shipments (Table 8-6) were calculated based on estimated installed base and product lifetime of 14 years.

Table 8-6: Estimated Dryer Shipments

Dryer Type	Estimated Annual Shipments	Source
Single-load Dryers	117,000 [a]	Estimated based on installed base and product lifetime (14 years).[233]
Multi-load Dryers	64,000 [a]	Estimated based on installed base and product lifetime (14 years).[234]

a. Calculated by dividing estimated installed base by average product lifetime.

Similar to dryers, we estimated dry-cleaning equipment annual shipments (Table 8-7) based on estimated installed base and product lifetime of 15 years.

Table 8-7: Estimated Dry-Cleaning Equipment Shipments

Equipment Type	Estimated Annual Shipments	Source
Dry-Cleaning Equipment	2,200 [a]	Estimated based on installed base and product lifetime (15 years). [235]

a. Calculated by dividing estimated installed base by average product lifetime.

[230] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Chapter 3. Dec 2014.
[231] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Chapter 3 Table 3.92. Dec 2014
[232] Navigant 2008. “Commercial Laundry Technology Market Review.” Presentation for Southern California Gas. Navigant Consulting Inc. 28 July 2008.
[233] CA-IOU. 2013. “Commercial Clothes Dryers.” Docket #12-AAER-2D. July 2013. http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf
[234] Ibid
[235] EPA. 2006. “Economic Impact Analysis of the Final Perchloroethylene Dry Cleaning Residual Risk Standard.” July 2006. http://www3.epa.gov/ttnecas1/regdata/EIAs/eiafinalpercdrycleanersresidrisk.pdf

8.2.2 *Installed Base*

Table 8-8 displays the estimated number of currently installed single- and multi-load washers as of 2015. For single-load washers, we include a breakdown of installed washers by type (top- or front-loading) and by application (MF or laundromat laundry). We calculated the existing installed base of single-load washers based on the lifetime survival rates determined in the 2014 CCW rulemaking. This methodology assumes a Weibull distribution with 11 year average lifetime (range 7 to 16 years) for MF washers, and 7 year average lifetime (range 5 to 9 years) for laundromat washers. [236]

Table 8-8: Estimated Washer Installed Base (2015)

Washer Type	Estimated Installed Base	Source
Single-load Washers		
MF, top-loading	1,200,000 [a]	CCW 2014[237]
MF, front-loading	380,000 [a]	CCW 2014
Laundromat, top-loading	130,000 [a]	CCW 2014
Laundromat, front-loading	40,000 [a]	CCW 2014
Total (Single-load Washers)	**1,750,000**	
Multi-load Washers		
Total (Multi-load Washers)	**300,000**	CBECS 2012 [238]
Total (All Washers)	**2,050,000**	

a. Number represents the number of washers remaining in service based on source's lifetime distribution analysis. Single-load washer type installed base is weighted by historical washer shipments.

Table 8-9 displays estimates for single- and multi-load dryer installed base. Dryer installed base estimates generally relied on multiplying the installed base of corresponding single- and multi-load washers by a scaling factor. We used the distribution of MF and laundromat dryers by dryer type (Section 8.1) to estimate a breakdown of installed base by application.[239]

---

[236] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. App 8-C Figure 8-C 2.2; 2.4. Dec 2014

[237] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Chapter 9 Table 9.3.1 and App 8-C Figure 8-C 2.2; 2.4. Dec 2014

[238] CBECS 2012. Microdata Public Use Data– on-premise laundry facilities "LAUNDR". June 2015.

[239] CA-IOU. 2013. "Commercial Clothes Dryers" Docket #12-AAER-2D. July 2013. http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf. Navigant estimate based on source for multi-family laundry breakdown.

Table 8-9: Estimated Dryer Installed Base (2015)

Dryer Type	Estimated Installed Base	Source
Single-load, MF	1,900,000 [a]	CA-IOU 2013[240]; ADL 1993[241]
Single-load, Laundromat	70,000 [a]	CA-IOU 2013; ADL 1993
Total (Single-load Dryers)	**1,970,000**	
Multi-load, MF	470,000 [a]	Based on single-load dryers; CA-IOU 2013
Multi-load, Laundromat	350,000 [a]	Based on single-load dryers; CA-IOU 2013
Multi-load, OPL	300,000 [b]	Based on multi-load washers
Total (Multi-load Dryers)	**1,120,000**	

a. Calculated based on single-/multi-load distribution from CA-IOU, 2013; Total number of dryers based on ratio of dryers to washers (1.3:1) from 1993 ADL report
b. Total number of dryers based on Navigant estimate of ratio of OPL dryers to washers (1:1) based on manufacturer sizing guides[242]

Dry-cleaning equipment installed base estimates were found from 2 sources and presented in Table 8-10. We assume that the vast majority of installed dry-cleaning equipment continue to be PCE dry-cleaning machines.

Table 8-10: Estimated Dry-Cleaning Equipment Installed Base

Dry-Cleaning Estimate	Estimated Installed Base	Source
Estimate 1	36,000 [a]	CARB 2006 [243]
Estimate 2	30,000 [b]	EPA 2006 [244]
Averaged	**33,000**	

a. Report presents number of dry-cleaning facilities in California. US installed base calculated by using a ratio of populations between CA and entire US (1.07 per facility).
b. Number of PCE facilities only.

8.3 Product Cost Breakdown

The average prices and installed costs for commercial washers are presented below in Table 8-11. Costs vary significantly depending on the washer capacity and the complexity of installation.

[240] CA-IOU 2013 "Commercial Clothes Dryers" Docket #12-AAER-2D. July 2013. http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf.
[241] ADL. 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.
[242] http://content.abt.com/documents/5990/OPLQuickRefGuide.pdf; http://www.dexter.com/support/knowledge-base/opl-laundry-sizing-tips-/
[243] CARB 2006. "California Dry Cleaning Industry Technical Assessment Report." CaliforniaAir Resources Board. Feb 2006. http://www.arb.ca.gov/toxics/dryclean/finaldrycleantechreport.pdf
[244] EPA 2006. "Economic Impact Analysis of the Perchloroethylene Dry Cleaning Residual Risk Standard." US-EPA. http://www3.epa.gov/ttnecas1/regdata/EIAs/eiafinalpercdrycleanersresidrisk.pdf

Table 8-11: Price and Installed Costs for Commercial Washer Equipment

Washer Type	Equipment Price ($)	Installation Cost ($)	Total Installed Cost ($)	Source
Single-load; Top-loading	1,004 [a]	225	1,229	CCW 2014[245]
Single-load; Front-loading	1,592 [a]	225	1,817	CCW 2014[246]
Washer Extractor (50 lb. capacity)	10,600 [b]	-	-	Market data [247]
Washer Extractor (400 lb. capacity)	96,000 [c]	46,000	142,000	Market data [248], ALN, 2006 [249]

a. Baseline model costs used.
b. Market data used to create line of best fit. Cost of 50 lb. capacity machine (representative of small washer extractors) calculated using best fit.
c. Based on market data obtained from 2009 Commercial Appliances Report.

Table 8-12 presents the average purchase costs for commercial dryers. Similar to washers, the purchase prices varies significantly according to drying capacity.

Table 8-12: Purchase Price for Commercial Dryer Equipment

Dryer Type	Capacity Range	Equipment Price ($)[a]	Source
Single-load, Coin-operated	<= 7.4 cu. ft.	700 – 1,100	Market data [250]
Multi-load, Coin-operated	25 lb. - 75 lb.	3,400 – 4,600	Market data[251]
Multi-load, OPL	25 lb. - 170 lb.	3,800 – 14,000	Market data[252]

a. Corresponding unit price for dryer in each size range according to source.

Table 8-13 displays the price range for PCE dry-cleaning equipment.

[245] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Ch 8 Table 8.2.8. Dec 2014.
[246] Ibid
[247] Samstores, 2015. Market data from Samstores website. Accessed Sept 2015. http://www.samstores.com/search-220-volts-commercials-washers-980.html
[248] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.
[249] ALN 2006. "Tunnel or Washer-Extractors: What's the Proper Choice? (Part 2)." American Laundry News, 2006. https://americanlaundrynews.com/articles/tunnel-or-washer-extractors-whats-proper-choice-part-2
[250] AJ Madison 2015. Market data from AJ Madison website. Accessed Sept 2015. http://www.ajmadison.com/b.php/Gas%3BCommercial%3BDryers/N~39+4294965554+4294833975
[251] Samstores 2015b. Speed Queen spec sheet from Samstores website. http://www.samstores.com/TumblerDryerCoin.pdf
[252] Samstores 2015c. Speed Queen spec sheet from Samstores website. http://www.samstores.com/SQOPLSTO2013.pdf

Table 8-13: Price Range for PCE Dry-Cleaning Equipment

Equipment Type	Capacity Range	Equipment Price ($)	Source
PCE Dry-Cleaning Machine	35 lb. - 90 lb.	38,000 – 83,000	CARB 2006 [253]

8.4 Baseline Energy Consumption

8.4.1 Unit Energy Consumption

Table 8-14 presents UEC for single- and multi-load washers, broken into 3 categories of consumption. Water heating energy, from gas or electric sources, is used in providing hot water for the wash cycle. Machine energy refers to electricity used in powering the motors, pumps, sensors, or other washer electronics when the washer is in use.

Single-load washers use either gas or electric water heating – this analysis found 25% of MF, single-load washers use electric water heaters, while the remaining washers use gas water heaters.[254] The UEC for OPL multi-load washers was back-calculated and was not used to obtain primary energy consumption.

Table 8-14: UEC - Washers

Washer Type	Gas – Water Heating (MMBtu/yr.)	Electric – Water Heating (kWh/yr.)	Electric - Machine (kWh/yr.)	Source
Single-load Washers				
MF, top-loading	1.40	116	223	CCW 2014[255]
MF, front-loading	0.77	64	103	CCW 2014
Laundromat, top-loading	2.55	0	305	CCW 2014
Laundromat, front-loading	1.40	0	140	CCW 2014
Multi-load Washers				
OPL [a]	520		3,000	Calculated

a. Total energy consumption calculated based on pounds of laundry per year, rather than UEC. UEC presented here is an estimate based on multi-load washer installed base.

Table 8-15 presents UEC for single- and multi-load dryers. We separated out single-load dryers that use electric elements (used for drying wet laundry) from those that use natural gas. Machine electricity refers to the electricity required to operate the motors, fans, sensors, and other electronic equipment used while the dryer is on.

[253] CARB 2006. “California Dry Cleaning Industry Technical Assessment Report.” Air Resources Board Feb 2006. http://www.arb.ca.gov/toxics/dryclean/finaldrycleantechreport.pdf

[254] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Ch 7 pp 7-8. Dec 2014.

[255] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Ch 7. Dec 2014.

Table 8-15: UEC - Dryers

Dryer Type	Gas – Heating (MMBtu/yr.)	Electric – Heating (kWh/yr.)	Electric - Machine (kWh/yr.)	Source
Single-load Dryers				
MF Dryers - Electric	-	2,300	130	2009 Commercial Appliances Report[256]
MF Dryers - Gas	10	-	130	CAL-IOU 2013[257]
Laundromat Dryers	13	-	170	CAL-IOU 2013
Multi-load Dryers				
MF, Tumbler Dryer	21	-	240	Market Data
Laundromat, Tumbler Dryer	41	-	320	Market Data
OPL, Tumbler Dryer [a]	336	-	3,570	Calculated

a. Total energy consumption calculated based on pounds of laundry per year, rather than UEC. UEC presented here is an estimate based on multi-load dryer installed base. 150 lb. load; ratio 1.5:1 for multi-load dryer size vs multi-load washer size

For all single-load dryers, UEC is based on cycles per day, which we derived from the number of single-load washer cycles multiplied by the installed base ratio of dryers to washers (1.3:1).[258] For gas single-load dryers, we assumed a 20 lb. washer capacity and average gas input rate of 11,500 Btu/cycle to estimate energy consumed per cycle.[259] For electric-heating, MF dryers, we assumed the same capacity and an electric consumption of 2.8 kWh/cycle.[260]

We assumed all multi-load tumbler dryers will use gas heating.[261] For MF and laundromat multi-load dryers, we assumed the same number of cycles per day as single-load dryers. The MF/laundromat dryer average gas input rate was extracted from a linear fit of tumbler dryer gas input rates taken from market data. For OPL multi-load dryers, we calculated total energy consumption based on pounds of annual OPL-related laundry by estimating that multi-load dryers have 1.5 times the capacity of multi-load washers (150 lbs. per load).[262] The UEC presented for OPL dryers is calculated by dividing total energy consumption by the estimated installed base. Table 8-16 displays estimated UEC for PCE-type dry-cleaning equipment.

[256] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.
[257] CA-IOU. 2013. "Commercial Clothes Dryers." Docket #12-AAER-2D. July 2013. http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf
[258] ADL. 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.
[259] Estimated from average annual gas consumption of a 20 lb dryer, divided by estimated yearly cycles. Source: CAL-IOU, 2013.
[260] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.
[261] Ibid
[262] Recommendations by laundry manufacturers. http://www.dexter.com/support/knowledge-base/opl-laundry-sizing-tips-/; http://content.abt.com/documents/5990/OPLQuickRefGuide.pdf

Table 8-16: UEC - Dry-Cleaning Equipment

Dry-Cleaning Equipment Type	Gas – Steam/ Heating (MMBtu/yr.)	Electric - Machine (kWh/yr.)	Source
PCE Dry-Cleaning Equipment [a]	13,703	618	SCE, 2009[263]

a. Total energy consumption calculated based on pounds of dry-cleaning laundry per year, rather than energy per unit

8.4.2 Primary Energy Consumption

Table 8-17 presents total primary energy consumption for all commercial (and industrial) applications. Gas (87%) and electricity (13%) consumption for all commercial laundry add up to approximately 0.42 Quads of total primary energy consumption. Water heating for washing accounts for approximately 52% of total energy consumption.

[263] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008. http://stpp.ucla.edu/sites/default/files/Garment%20Care%20Energy%20Report.pdf

Table 8-17: Primary AEC of Commercial Laundry Equipment

Laundry Equipment Type	Water Heating (Quads/yr.)		Drying (Quads/yr.)		Electric - Machine (Quads/yr.)	Total (by type)
	Gas	Electric	Gas	Electric		
Single-load Washers [a]	0.003	0.002			0.004	**0.008 (2%)**
Multi-load Washers [b]	0.170				0.010	**0.18 (43%)**
Industrial Washers [c]	0.02				0.003	**0.023 (5%)**
Single-load Dryers [d]			0.010	0.015	0.002	**0.028 (7%)**
Multi-load Dryers [e]			0.13		0.013	**0.14 (34%)**
Industrial Dryers [c]			0.01		0.002	**0.014 (3%)**
Dry-Cleaning [f]	0.02				0.005	**0.03 (7%)**
Total [g]	**0.213 (51%)**	**0.002 (0.5%)**	**0.15 (36%)**	**0.015 (4%)**	**0.038 (9%)**	**0.42**

a. Source: CCW 2014[264]
b. Sources: CBECS 2012[265]; Riesenberger 2006[266]
c. Sources: TRSA 2009[267]; Navigant 2008[268]
d. Sources: CAL-IOU 2013[269]; market data; Single-load washers analysis
e. Sources: Single-load and Multi-load washers analysis; market data
f. Sources: SCE 2009[270]; 2009 Commercial Appliances Report[271]
g. Numbers do not sum due to rounding

Of the 0.42 Quads, OPL applications account for 75% of total primary energy consumption (Figure 8-1). Of the remaining applications, MF dryers and industrial laundry represent the next largest energy consumers at 9% each.

[264] CCW 2014. 2014 Commercial Clothes Washer Rulemaking. Final Rule. Technical Support Document. Dec 2014.
[265] CBECS 2012. Commercial Buildings Energy Consumption Survey 2012 – Microdata. Energy Information Agency (EIA). Released June 2015. http://www.eia.gov/consumption/commercial/data/2012/index.cfm?view=microdata
[266] Reisenberger 2006. "PBMP – Commercial Laundry Facilities; IV. On-Premise Laundry Facilities." Koeller and Company, 2006. http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/non_residential/laundry/PBMP-Report-On-Premise-Laundry.pdf
[267] TRSA. 2009. "Laundry Environmental Stewardship Program (ESP)." TRSA. Study completed 2009; accessed Sept 2015. http://www.trsa.org/page/water
[268] Navigant. 2008. "Commercial Laundry Technology Market Review." Presentation for Southern California Gas. Navigant Consulting Inc. 28 July 2008.
[269] CA-IOU. 2013 "Commercial Clothes Dryers" Docket #12-AAER-2D. July 2013. http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf
[270] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies" http://stpp.ucla.edu/sites/default/files/Garment%20Care%20Energy%20Report.pdf
[271] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.

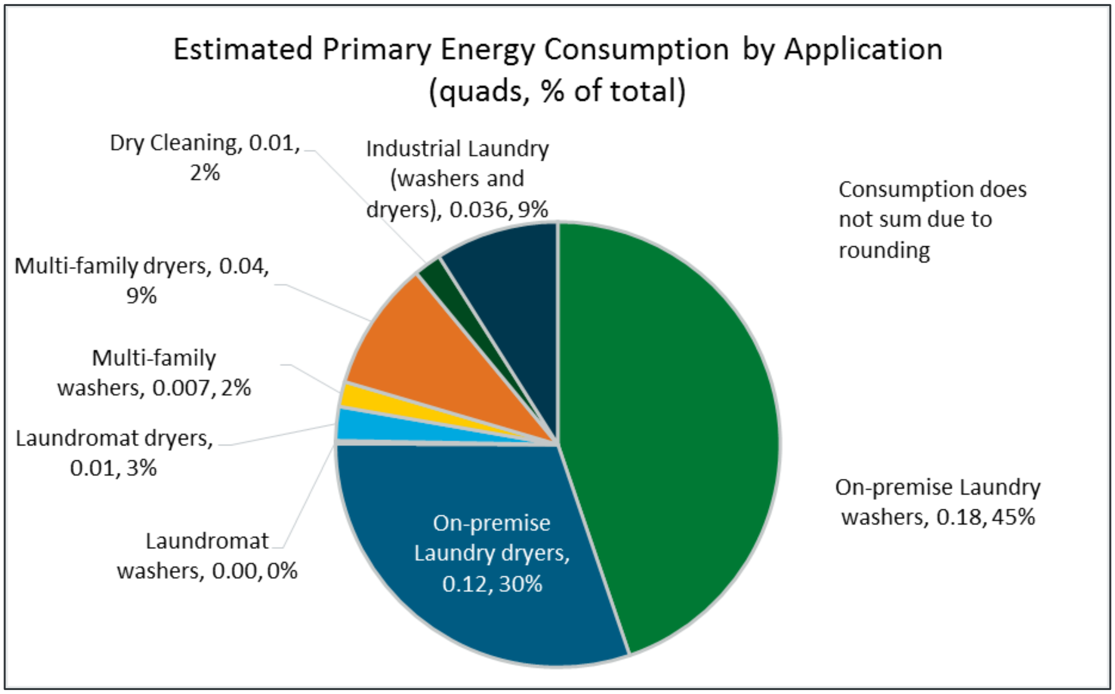


Figure 8-1: Primary Energy Consumption by Application

8.5 Comparison of Baseline Energy Consumption to Previous Studies

8.5.1 Installed Base Comparison

Our estimate of 1,750,000 installed single-load washer units is approximately 66% of the installed base estimate from the 2009 Commercial Appliances Report. This can be attributed to a different method of calculation for installed base. Our method uses lifetime survival rates (for both laundromat and MF washers) determined in the 2014 CCW rulemaking, while the 2009 Commercial Appliances Report estimated installed base by multiplying unit shipments in 2009 by an average unit lifetime. We believe the 2015 estimate more accurately reflects the installed base because it accounts for different survival rates between MF and laundromats.

Our multi-load washer installed base estimate (300,000, approximately 42% higher than 2009 Commercial Appliances Report) was based on new CBECS data and other sources from which we calculated total OPL yearly laundry volume (approximately 85 billion pounds).[272, 273] The 2009 Commercial Appliances Report estimated significantly less total OPL laundry volume, as national data was not available at the time.

Single-load dryer installed base is based on single-load washer estimates, thus is the dryer installed base difference is affected by the aforementioned washer differences. We also used

[272] CBECS 2012. Commercial Buildings Energy Consumption Survey 2012 – Microdata. Energy Information Agency (EIA). Released June 2015. http://www.eia.gov/consumption/commercial/data/2012/index.cfm?view=microdata

[273] Reisenberger. 2006. "PBMP – Commercial Laundry Facilities; IV. On-Premise Laundry Facilities." Koeller and Company, 2006. http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/non_residential/laundry/PBMP-Report-On-Premise-Laundry.pdf

recent California sources, which allowed us to revise the installations of MF single-load dryers as compared to MF multi-load dryers.[274] We estimate 80% of MF washers are single-load dryers, compared to 50% in the 2009 Commercial Appliances Report. Because of this change in estimates, we report 13% higher single-load dryer installed base (1,640,000) than the 2009 report (1,450,000).

Multi-load dryer installed base estimates were 45% of the 2009 Commercial Appliances Report, impacted by the shift in MF dryer estimates as described in the previous paragraph. By total installed base, we estimate 2,450,000 installed dryers (single- and multi-load), which is 74% of the 2009 report's total.

Our estimate for dry-cleaning equipment largely relied on the 2009 Commercial Appliances Report in the absence of more recent sources. We averaged the estimated installed base from the 2009 report with a report by EPA in 2006. Our estimate is 92% of the 2009 reports installed base.

8.5.2 Energy Consumption Comparison

The 2009 Commercial Appliances Report breaks up commercial washing by equipment type (e.g. washer extractors, tunnel washers, etc.). Thus, it is more difficult to estimate the energy consumption by a specific application that uses multiple types of laundry equipment, such as industrial laundry. In this current report, where possible, we broke energy consumption down by specific laundry uses and applications – single-load washers refers to laundromat and MF applications, multi-load washers refers to OPL applications, and industrial washers refers to industrial laundry applications regardless of washing equipment. Categorizing energy consumption by laundry application/end-use provides better understanding potential energy savings - energy savings technologies and strategies might be more effective when marketed towards to specific applications (e.g. OPLs) rather than to individual technology types.

Therefore, a direct comparison between the 2015 Commercial Appliances Report and the 2009 Commercial Appliances Report is not suitable for all applications or equipment types. We have aggregated the energy consumption of multi-load and industrial washers and dryers from the 2015 report and presented the comparison in Figure 8-2.

[274] CA-IOU. 2013 "Commercial Clothes Dryers" Docket #12-AAER-2D. July 2013. http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf

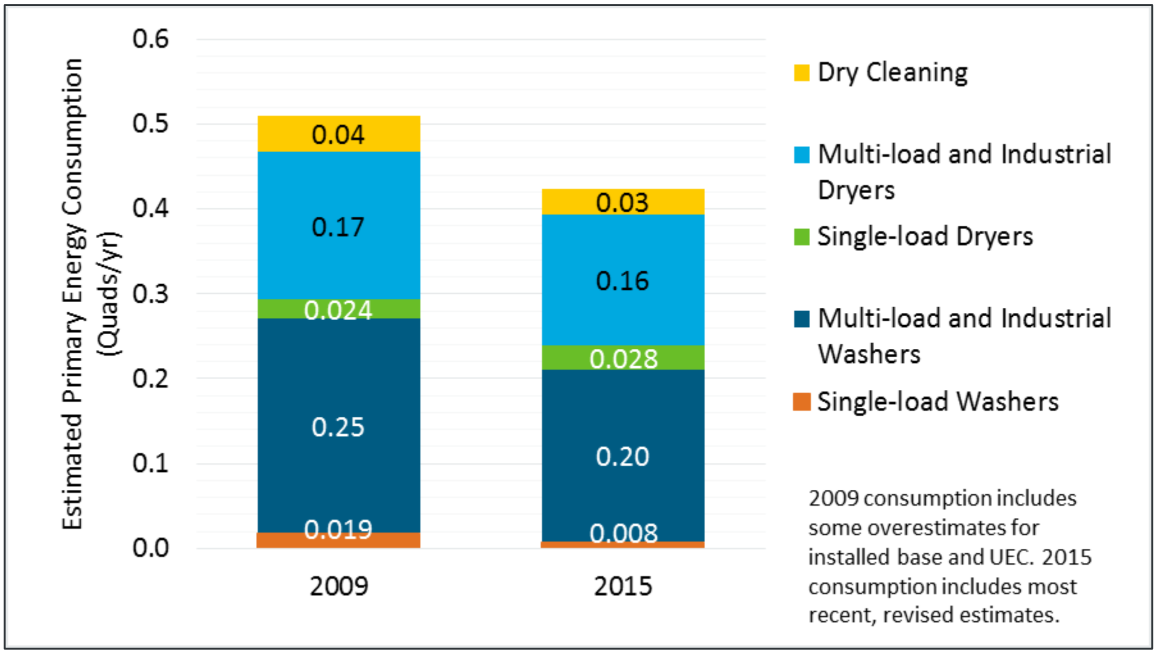


Figure 8-2: Comparison of primary energy consumption with the previous commercial appliances report

We revised single-load washers, a DOE regulated product, with newest data regarding average UEC and installed base. An improved installed base estimate (described in Section 8.5.1), along with efficiency improvements across the industry has led to a 50% reduction in estimated energy consumption.

The multi-load washer energy consumption estimate was reduced in this report due to improved and more accurate installed base data from the recent CBECS. We also used a revised methodology which estimates energy consumption based on total volume of laundry for each OPL facility (i.e. hospitals, nursing homes, hotels, motels). We also found better sources relating to national industrial laundry volumes – by using these laundry volumes, we found that the 2009 report overestimated the energy consumption of industrial washers (washer extractors and tunnel washers) and industrial dryers.

Despite the differences in methodology, the overall laundry segment appears to be improving in efficiency. DOE regulations appear to be effective in reducing commercial single-load washer energy consumption as units now are more efficient compared to 2009. Despite relatively long lifetimes for multi-load and industrial-sized washers, we estimate new models are approximately 9% more efficient than those evaluated in 2009.[275]

For commercial dryers of all sizes, the main differences between 2015 and 2009 Commercial Appliances Reports are due to revisions in installed base estimates. In the absence of more accurate data, we used rated gas input rates to estimate UEC – these input rates are roughly the same as those found in 2009.

[275] Estimated based on efficiency improvements made by industrial laundry equipment 1997-2009. 2009 Appliances Report used efficiency estimates from the Reisenberger report from 2006.

For dry-cleaning equipment, we used a newer source which provided more updated UEC estimates – overall, this represents minor energy efficiency gains in the dry-cleaning.

8.6 Energy Savings Opportunities

8.6.1 Commercial Washer Energy Savings Opportunities

Table 8-18 presents several energy savings opportunities which could significantly reduce national primary energy consumption of commercial washers.

Table 8-18: Technical Potential of Washer Technology Options

Technology	UES	Applications	Impacted energy consumption	Applicable Primary Energy Use (Quads/yr.)	Technical Potential (Quads/yr.)	Sources
Single-load washers						
Max tech for res-style washers	25%	MF; Laundromats	Hot water & machine electricity	0.008	0.0019	CCW TSD 2014[276]
Multi-load washers						
Wastewater recycling	19% [a]	OPLs	Hot water	0.17	0.033	DOE 2014a[277]
Low-temperature detergent	47%	OPLs	Hot water	0.17	0.080	Navigant 2008[278]
Liquid CO_2	49% [b]	Hospital or Nursing home OPLs	Hot water; Drying	0.05	0.02	CEC 2014[279]
Ozone	65%	OPLs	Hot water	0.17	0.11	DOE 2014b[280]
Polymer beads	100% [b]	OPLs	Hot water	0.17	0.17	Liberty 2014[281]

a. Based on estimated 4 therms/1000 lbs. (gas WH savings) ; 6.9 kWh/1000 lbs. (electricity consumption increase)
b. Based on case study with clean room laundry. Dryer energy savings included in 49% savings estimate.
c. Elimination of all hot water consumption; impact on electricity consumption not known

[276] CCW TSD 2014. Available at: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/46
[277] DOE. 2014. "Demonstration of Advanced Technologies for Multi-load Washers in Hospitality and Healthcare - Wastewater Recycling Technology." PNNL. Published August 2014. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23535.pdf
[278] Navigant. 2008. "Commercial Laundry Technology Market Review." Presentation for Southern California Gas. Navigant Consulting Inc. July 28, 2008.
[279] CEC. 2014. "CO2-based Cleaning of Commercial Textiles." Prepared by CO2 Nexus Inc for California Energy Commission. Published March 2014. http://www.energy.ca.gov/2014publications/CEC-500-2014-083/CEC-500-2014-083.pdf
[280] DOE. 2014. "Demonstration of Advanced Technologies for Multi-load Washers in Hospitality and Healthcare – Ozone Based Laundry Systems." PNNL. Published August 2014. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23536.pdf
[281] Liberty Utilities. 2014. "Xeros Laundry Technical Assessment Study". Liberty Utilities. Feb 11, 2014. http://www.libertyutilities.com/east/gas/my_business/documents/Xeros_Study_for_LibertyUtilities.pdf

8.6.1.1 Highest Efficiency Single-Load Washers (Max Tech)

Single-load washers are covered by DOE minimum efficiency standards and thus subject to regulations. Energy savings opportunities for single-load washers are generally incremental changes to reduce water and energy usage. We did not identify any breakthrough single-load washer technologies, but found many minor options to improve efficiency. We estimate the maximum technical potential for single-load washers to be equivalent to upgrading the current installed base to the maximum technology level from the DOE rulemaking.

In the new CCW Rulemaking TSD, the highest efficiency (max tech) top-loaders primarily derived energy savings from reducing machine energy consumption.[282] This is possible through an improvement to the washer cycle control or an increase in motor (or other machine-related) efficiency. They also are able to significantly improve their overall energy consumption by better removing the remaining moisture from the laundry.[283] Max tech single-load front-loaders derive energy savings from a reduction of hot water and machine energy consumption.

Max tech technology washers would often include several washer technology options:

- Adaptive water fill control with improved flow controls, allowing the washer to use only as much water as necessary for each load of laundry
- Modified control schemes, which could reduce water consumption and drying energy required after the cycle
- Spray rinse, which reduces the amount of water used in rinsing laundry
- Low-profile agitator design, which is designed to agitate clothing while requiring less water than a traditional agitator
- Improved motor efficiency or direct drive motors, which reduces machine-related electricity consumption.

Max tech washers could reduce total single-load washer consumption by 25%, though would require high costs to the customer.[284]

8.6.1.2 Wastewater Recycling

Wastewater recycling systems are a retrofit technology which recycles and reuses wash water from previous wash cycles to decrease the amount of new hot water required. Generally this retrofit technology is compatible with all multi-load washers. Wastewater recycling is commercially available but with low overall market penetration.

Laundry wastewater recycling (Figure 8-3) cleans wastewater discharge from the laundry system through a series of filtration steps designed primarily for removing solids, followed by several stages of disinfection. The water is kept in a holding tank and is continually disinfected until it is needed for the next wash cycle. After the initial installation and startup period, systems typically require little maintenance apart from filter replacements. Generally, recycled wastewater has little to no impact on wash quality, and can be used in all commercial facility types.

---

[282] CCW TSD 2014. Available at: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/46
[283] For this study, we do not consider the energy related to drying laundry as part of clothes washer energy consumption.
[284] CCW TSD 2014. Available at: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/46

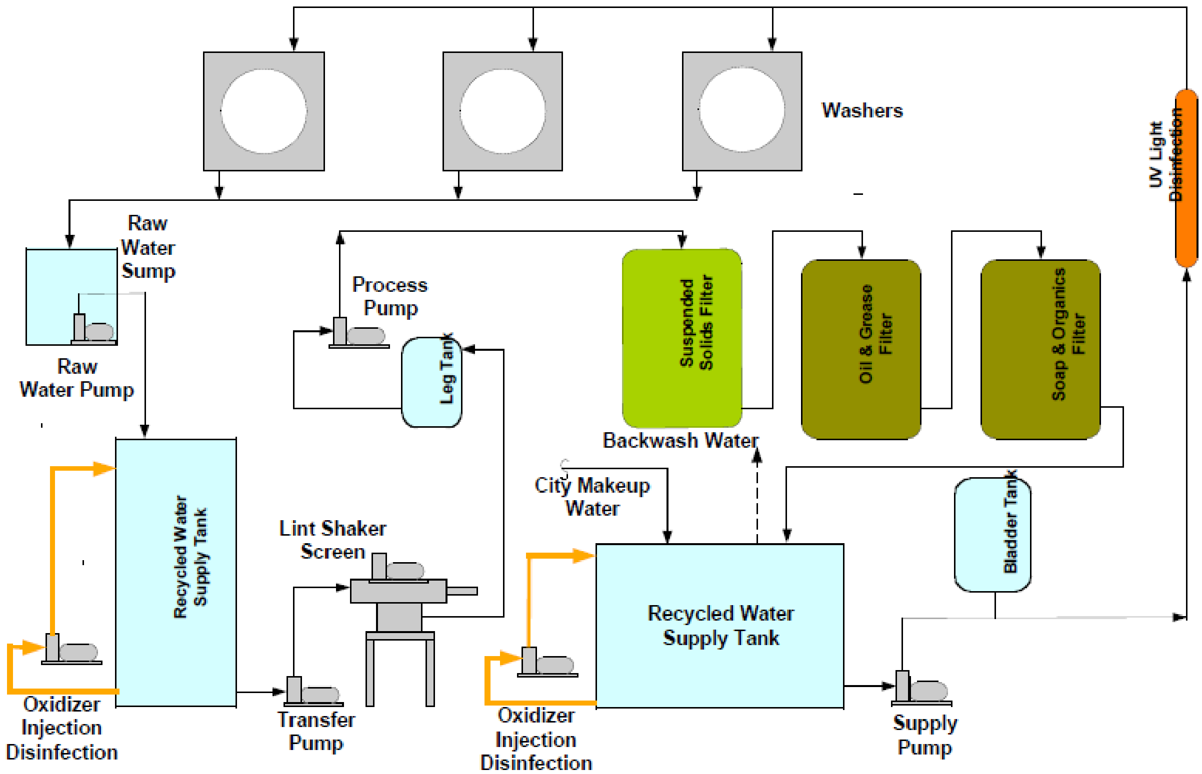


Diagram source: DOE 2014a[285]

Figure 8-3: Schematic of an AquaRecycle Wastewater Recycling System

Wastewater recycling savings estimates (4 therms/klb gas savings; 6.9 kWh/klb electricity increase) were derived from savings measured during a wastewater system retrofit field study.[286] These UES were then applied to the total annual OPL volume (86.5 billion pounds) to calculate technical potential. The total percent savings was estimated at 18%.

8.6.1.3 Low-Temperature Detergent

Low-temperature detergent is an energy savings opportunity which allows existing installed washers to decrease the amount of hot water needed for each wash cycle. The detergents works by using enzymes to remove stains and enables operation at 120°F compared to the standard 170°F. These detergents are commercially available, with at least 2 known companies that offer them (Ecolab Inc., and Norchem).

Some commercial laundry facilities may be good retrofit candidates, though low-temperature detergents may not be suitable for facilities which require high wash temperatures to destroy bacteria or pathogens. Low-temperature detergents are priced comparably to traditional detergents and typically work without any modifications to existing multi-load washers. [287]

---

[285] DOE. 2014. "Demonstration of Advanced Technologies for Multi-load Washers in Hospitality and Healthcare - Wastewater Recycling Technology." PNNL. Published August 2014. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23535.pdf

[286] Ibid

[287] PNNL. 2013. "Scoping Report: Advanced Technologies for Multi-Load Washers in Hospitality and Healthcare." Pacific Northwest National Laboratory. March 2013. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22310.pdf

8.6.1.4 Ozone

An ozone laundry system creates ozone from ambient air using a separate wall-mounted ozone generator. The ozone is mixed or injected into the wash water where it then reacts with soils and stains on the laundry. The soils are separated from the fabric through mechanical action of the machine. Ozone also acts as a natural disinfectant, which allows it to sanitize laundry at low water temperatures. Ozone laundry technology is typically installed as a retrofit for existing washers.

Ozone laundry technology saves energy by allowing users to use unheated wash water for lightly to moderately soiled laundry, and lower water temperatures for heavily soiled laundry. Since fewer chemicals are used, rinse time is also minimized, reducing total cycle time and water consumption. Ozone systems can generally be used in all commercial facility types, due to its sanitizing capabilities.[288]

Several ozone laundry vendors exist on the market, including Ozone Laundry Systems, Ecowash, ClearWater Tech and Total Ozone Solutions.

UES estimates of 65% represent the energy savings of a hotel facility from an ozone retrofit field study.[289] To estimate technical savings potential in Table 8-18, we assumed that the unit savings only applied to the energy consumed for hot water heating.

8.6.1.5 Liquid Carbon Dioxide

Liquid CO_2 cleaning uses pressurized CO_2 as a solvent and does not use any water to wash laundry – as such, it is also considered a dry-cleaning technology. Beyond dry-cleaning, liquid CO_2 cleaning could also be used for some specialized industrial and OPL applications.

Liquid CO_2 is introduced to a load of laundry at high pressure and dissolves dirt or soil from the laundry. 99% of the CO_2 is typically recovered and reused for following wash cycles. The clean laundry, when removed from the washer, is already dry, thus saving overall cycle time. For more information regarding the liquid CO_2 cleaning process, please refer to Section 8.6.3.2.

A California Energy Commission case study assessed the energy consumption of a prototype CO_2 system that can be used for cleanroom applications. The study found the Nexus CO_2 system obtained 46% gas-related energy savings, which could be attributed to water heating and drying purposes.[290] We are unable to determine the amount of gas used exclusively for water heating during clothes washing, and thus have assumed the entirety of the gas savings to water heating. As cleanroom laundry hot water consumption is approximately double that of standard industrial laundry, the energy savings found in this case study may be higher than typical OPLs.

The report also finds the Nexus system saves over 60% of operating electricity costs. Since we believe the majority of this electricity consumption could be attributed to cleanroom specific

[288] Ibid

[289] DOE. 2014. "Demonstration of Advanced Technologies for Multi-load Washers in Hospitality and Healthcare – Ozone Based Laundry Systems." PNNL. Published August 2014. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23536.pdf

[290] CEC. 2014. "CO2-BASED CLEANING OF COMMERCIAL TEXTILES." Prepared by CO2 Nexus Inc for California Energy Commission. Published March 2014. http://www.energy.ca.gov/2014publications/CEC-500-2014-083/CEC-500-2014-083.pdf

equipment, we did not include these savings in our calculated savings potential. The report notes that the costs for the cleanroom Nexus is between approximately $400,000, though the costs of other liquid CO_2 systems not used for clean room applications is likely much lower.

8.6.1.6 Polymer Beads

Polymer bead cleaning uses the absorbent properties of nylon polymer beads to clean clothes. The nylon beads are added to the wash drum with a small amount of water and detergent to loosen the dirt or stains on the clothing. The clothes are tumbled with the polymer beads for around 45 minutes. The polarity of the nylon polymer attracts stains from the clothing. Under humid conditions, the polymer becomes absorbent. Dirt is attracted to the surface and then absorbed into the center of the bead. At the end of the cycle, the polymer beads are separated from the clothing through an inner drum/outer drum rotation process.

Xeros Ltd. in the United Kingdom originally developed this technology; they now sell the systems in the U.S. Prior research conducted by Xeros demonstrated up to 90% water savings, and demonstrated 40% total laundry energy savings, along with reduced detergent consumption.[291] A recent case study by Liberty Utilities showed that the Xeros Laundry technology was able to completely eliminate hot water consumption altogether, though it did not measure any differences in electricity consumption between baseline and polymer washers.[292] Assuming the Liberty Utilities study can be generalized to all cleaning applications, we have displayed a technical potential savings of 0.17 Quads, which represents the elimination of all hot water energy consumption from the OPL sector.

From the Liberty Utilities study, we found that the Xeros polymer bead unit required approximately $34,000 more in incremental installed cost over a baseline OPL washer. [293]

8.6.2 Commercial Dryer Energy Savings Opportunities

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.[294] Therefore, the greatest opportunities for improving dryer energy efficiency focus on decreasing the amount of heat input per pound of laundry and maximizing the moisture removal achieved for that heat input. Even so, average dryer gas input rates have not changed significantly between this report and the 2009 Commercial Appliances Report. Table 8-19 lists relevant energy savings opportunities for single-load dryers and the technical potential for each opportunity.

A subset of the energy-saving features that apply to smaller single-load dryers could be applied to larger-capacity, multi-load, tumble dryers. Nearly all large-capacity tumbler dryers are gas-fired and thus the greatest opportunities for improving dryer energy efficiency focus on maximizing efficacy of the gas heat input. We estimated the same percent energy savings between single- and multi-load dryer units. Table 8-19 lists those technologies that could be implemented in multi-load dryers and presents a technical potential estimate.

[291] Xeros-Bead Cleaning. Website cited by PNNL 2013. http://www.xeroscleaning.com/
[292] Liberty Utilities. 2014. "Xeros Laundry Technical Assessment Study". Liberty Utilities. Feb 11, 2014. http://www.libertyutilities.com/east/gas/my_business/documents/Xeros_Study_for_LibertyUtilities.pdf
[293] Ibid
[294] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.

Table 8-19: Technical Potential of Dryer Technology Options

Technology	UES Potential	Applications	Impacted energy consumption;	Applicable Primary Energy Usage (Quads/yr.)	Technical Potential (Quads/yr.)	Sources
Single-load Dryers						
Automatic cycle termination	17%	MF; Laundromats	Heating and machine electricity	0.028	0.0048	Ecova 2014[295]
Gas modulation	15%	MF; Laundromats	Gas heating	0.01	0.0015	TIAX 2005[296]
Heat pump dryer technology	50%	MF	Electric heating	0.015	0.0077	TIAX 2005
Heat recovery; Inlet air preheat	17%	MF; Laundromats	Gas heating	0.01	0.0017	Ecova 2014
Multi-load Dryers						
Automatic cycle termination	17%	OPLs	Heating and machine electricity	0.14	0.024	Ecova 2014
Gas modulation	15%	OPLs	Gas heating	0.13	0.019	TIAX 2005
Heat recovery; Inlet air preheat	17%	OPLs	Gas heating	0.13	0.022	Ecova 2014

8.6.2.1 *Automatic Cycle Termination*

Many commercial single- and multi-load dryers tend to over-dry laundry because the default drying cycle is longer than is necessary to adequately dry the load. Manufacturers can retrofit moisture sensors inside the dryer to control the length of the drying cycle, eliminating the heating and motor energy consumed during over-drying.

Sources from GE Global Research and ACEEE have estimated a UES between 15%[297] and 17%[298] - we used 17% for our technical savings potential estimates.

8.6.2.2 *Gas Modulation*

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. As laundry dries during the cycle, the moisture removal rate slows down regardless of the heat input – thus towards the end of the cycle, excess heat is wasted since

---

[295] Ecova. 2014. "The Time is Ripe for Paying Attention to Clothes Drying Technology and Policy in Relation to Efficiency and Drying Time." Report for ACEEE by Ecova. 2014. http://aceee.org/files/proceedings/2014/data/papers/9-501.pdf
[296] TIAX. 2005. "High Efficiency, High Performance Clothes Dryer." TIAX LLC. Report. 31 March 2005.
[297] GE. 2004. Energy Efficient Laundry Process. Report. GE Global Research, Dec. 2004.
[298] Ecova. 2014. "The Time is Ripe for Paying Attention to Clothes Drying Technology and Policy in Relation to Efficiency and Drying Time." Report for ACEEE by Ecova. 2014. http://aceee.org/files/proceedings/2014/data/papers/9-501.pdf

it does not affect drying time. Modulating gas dryers have the ability to detect when the clothes are becoming dry and can reduce the heat input rate 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. Despite the relative maturity of this technology, there are no gas modulating dryers currently available on the market.[299]

The TIAX study determined a savings in dry cycle time ranging from 20% to 40%, and a savings in energy from 13% to 23%.[300] Nicor Gas found a gas savings of 12.4-13.8% in the results of pilot testing a modulating gas valve retrofit which can convert a non-modulating gas dryer to a modulating dryer.[301] We used a UES of 15% in our calculations of national primary energy savings potential.

8.6.2.3 Heat Recovery and Inlet Air Preheat

An air-to-air heat exchanger is capable of recovering exhausted waste air and preheating incoming air. This preheating allows the dryer to use less energy in heating the drying air.

The 2011 DOE Residential Dryers rulemaking (based on a 1977 NIST document) and a 1984 study by LBNL have estimated the UES of this technology to be 14%[302] to 26%[303]. More recently, in 2014 lab tests, Ecova found a dryer savings of 17% by using a heat recovery ventilator as the heat exchanger.[304] We used the most recent lab testing savings estimates to calculate technical potential for this technology.

8.6.2.4 Heat Pump Dryers

Electric heat pump dryers are a replacement technology for traditional electric clothes dryers, which make up a small portion of the commercial dryer market. Several heat pump dryers have been available for years in Europe, and there are limited models of residential and commercial 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.[305] Current market share of commercial heat pump dryers in the US market is not known.

---

[299] CA-IOU. 2013. “Commercial Clothes Dryers” Docket #12-AAER-2D. July 2013. http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2D_Commercial_Clothes_Dryers/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Commercial_Clothes_Dryers_2013-07-30_TN-71757.pdf

[300] TIAX. 2005. “High Efficiency, High Performance Clothes Dryer.” TIAX LLC. Report. 31 March 2005.

[301] Nicor. 2014. “Nicor Gas Emerging Technology Program – 1036: Commercial Dryer Modulation Retrofit.” Nicor Gas. Sept. 16, 2014. http://nicorgasrebates.com/-/media/Files/NGR/PDFs/ETP/1036%20Non-Modulating%20Dryer%20Retrofit%20FINAL%20APPROVED%20Public%20Project%20Report%20to%20Nicor%20Gas%209-16-14

[302] 2011 Residential Dryers Rulemaking. Final Rule. Technical Support Document. Chapter 3.

[303] LBNL. 1984. Hekmat, D. & W.J. Fisk. 1984. Improving the Energy Performance of Residential Clothes Dryers, Presented at the 25th Annual International Appliance Technical Conference, Ohio State University, May 15-16.

[304] Ecova. 2014. “The Time is Ripe for Paying Attention to Clothes Drying Technology and Policy in Relation to Efficiency and Drying Time.” Report for ACEEE by Ecova. 2014. http://aceee.org/files/proceedings/2014/data/papers/9-501.pdf

[305] LBNL. 2009. “Technical Note: Heat Pump Clothes Dryers.” Lawrence Berkeley National Laboratory. Report. 18 February 2009.

Most of the European models have longer drying times and are much more expensive than a typical European tumbler dryer.[306] Ecova performed recent testing on commercially available unvented heat pump dryers and found cycle times of 75 minutes or more.[307] The drying time would be considered significant market barriers for any commercial dryer within the U.S. Ecova noted that some "hybrid" products include an electric resistance element or variable compressor speeds, which would reduce drying time – however, this reduced time results in a "hybrid" dryer efficiency much closer to conventional dryer efficiency.[308]

The 2009 Commercial Appliances Report estimated a 50% UES was possible for heat pump dryers, based on the TIAX prototype that was in development.[309] This prototype is a vented heat pump dryer, which boosts efficiency and reduces drying time but requires outdoor venting. Other sources, as reported in the 2011 DOE Residential Dryers rulemaking, found that heat pump dryers consumed about 50% less electricity when compared to conventional residential dryers.[310] We used a 50% UES estimate on electric commercial dryers used only in MF applications.

The Ecova report also suggests that a gas-driven heat pump dryer may also be technologically and economically feasible. However, it did not note any current developments for the technology. This technology does offer more potential for commercial dryer applications, as most commercial dryers already rely on natural gas heating.

8.6.3 Dry-Cleaning Alternatives and Energy Savings Opportunities

A number of alternatives to PCE have emerged in the dry-cleaning equipment market. The most popular alternatives are the following, though we note several more alternatives in Section 8.6.3.3:

- Professional wet cleaning
- Carbon-dioxide dry-cleaning
- Hydrocarbon dry-cleaning
- Silicone dry-cleaning

The 2 leading environmentally preferable technologies available today are CO_2 dry-cleaning and professional wet cleaning – a 2009 study by Sinsheimer et al. has found that hydrocarbon and silicone dry-cleaning do not save energy compared to PCE.[311] The study consisted of field

[306] Ibid
[307] Ecova 2014. "The Time is Ripe for Paying Attention to Clothes Drying Technology and Policy in Relation to Efficiency and Drying Time." Report for ACEEE by Ecova. 2014. http://aceee.org/files/proceedings/2014/data/papers/9-501.pdf
[307] CA-IOU. 2013. "Commercial Clothes Dryers" Docket #12-AAER-2D. July 2013.
[308] Ecova 2014. "The Time is Ripe for Paying Attention to Clothes Drying Technology and Policy in Relation to Efficiency and Drying Time." Report for ACEEE by Ecova. 2014. http://aceee.org/files/proceedings/2014/data/papers/9-501.pdf
[309] TIAX. 2005. "High Efficiency, High Performance Clothes Dryer." TIAX LLC. Report. 31 March 2005.
[310] E. Bush and J. Nipkow. 2006. Tests and Promotion of Energy-Efficient Heat Pump Dryers. Report Prepared for International Energy Efficiency in Domestic Appliances & Lighting Conference '06.
[311] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008.

studies conducted on each of the above 4 alternative dry-cleaning technologies to measure gas and electricity consumption.[312]

An older study by Sinsheimer et al. formed the basis for dry-cleaning technology consumption for the 2009 Commercial Appliances Report.[313] We found significant variability of ± 50% in experimentally measured energy consumption presented by the older and newer sources. Both sources are case studies of PCE dry cleaners switching to an alternative technology – thus experimental error and low study sample size could explain the unit consumption differences.

Despite the uncertainty in energy consumption, increasingly stringent environmental regulations will likely push the dry-cleaning industry towards a cleaner alternative. Further study is required to assess the current alternatives and provide guidance on selecting the most energy efficient, yet environmentally benign, technology.

We considered CO_2 dry-cleaning and professional wet cleaning for our technical potential estimates. Table 8-20 summarizes the technical savings potential these technologies. Other dry-cleaning alternatives such as hydrocarbon and silicone dry-cleaning, which may not save energy, are discussed in Section 8.6.3.3

Table 8-20: Technical Potential of Dry-Cleaning Alternatives

Technology	UES Potential	Impacted energy consumption	Applicable Primary Energy Usage (Quads/yr.)	Technical Potential (Quads/yr.)	Sources
Dry-Cleaning Equipment Alternatives					
Wet Cleaning	29%	Gas heating and electricity	0.03	0.009	SCE 2009 [314]
Liquid CO_2	5% [a]	Gas heating and electricity	0.03	0.002	SCE 2009

a. Savings calculated by averaging 2 test facilities. Further research would be warranted to improve data quality.

8.6.3.1 *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

[312] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008. http://stpp.ucla.edu/sites/default/files/Garment%20Care%20Energy%20Report.pdf

[313] Sinsheimer, Peter, and Cyrus Grout. 2004. "Evaluating Energy Efficiency in the Garment Care Industry: A Comparison of Five Garment Care Technologies." Rep. UEPI Papers, 2004. Print.

[314] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008. http://stpp.ucla.edu/sites/default/files/Garment%20Care%20Energy%20Report.pdf

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.[315] Figure 8-4 shows the process flow diagram for professional wet cleaning.

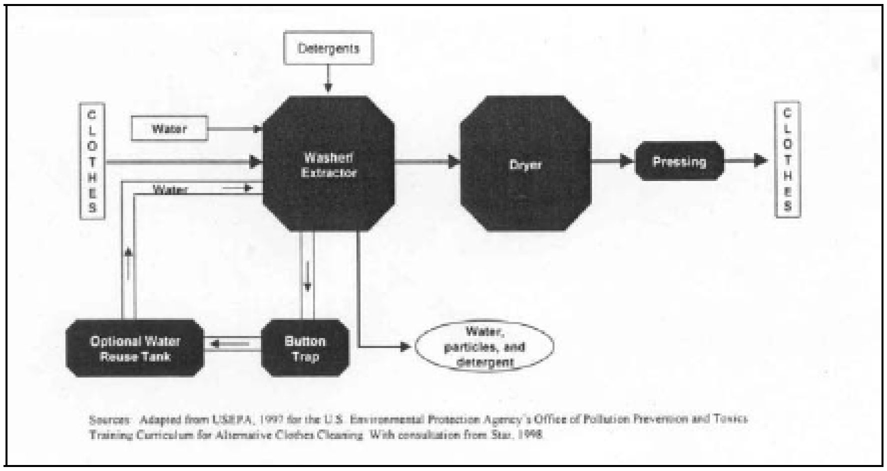


Diagram source: Sinsheimer 2004[316]

Figure 8-4: Process flow diagram for professional wet cleaning

As displayed in Table 8-20, professional wet cleaning saves approximately 30% gas and electricity consumption as compared to PCE, with a technical savings potential of almost 0.01 quad. According to analysis by Massachusetts Office of Energy and Environmental Affairs, the capital cost of wet cleaning equipment is about 10% less than PCE equipment.[317]

8.6.3.2 *Carbon-Dioxide Dry-Cleaning*

The CO_2 process is a liquid carbon-dioxide-based garment cleaning process for commercial and retail dry cleaning. 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.[318] Figure 8-5 displays a process flow diagram of an example CO_2 dry-cleaning.

[315] UEPI. 2009. "Garment Care." UEPI. Website accessed on Sept. 7, 2009. http://departments.oxy.edu/uepi/ppc/projects.htm.
[316] Sinsheimer, Peter, and Cyrus Grout. 2004. “Evaluating Energy Efficiency in the Garment Care Industry: A Comparison of Five Garment Care Technologies.” Rep. UEPI Papers, 2004. Print.
[317] Massachusetts Office of Energy and Environmental Affairs. 2013. “Dry Cleaners Environmental Certification Comparative Analysis.” Aug 2013. http://www.mass.gov/eea/agencies/massdep/service/approvals/dry-cleaner-forms.html
[318] UEPI. 2009. "Garment Care." UEPI. Website accessed on Sept. 7, 2009. http://departments.oxy.edu/uepi/ppc/projects.htm.

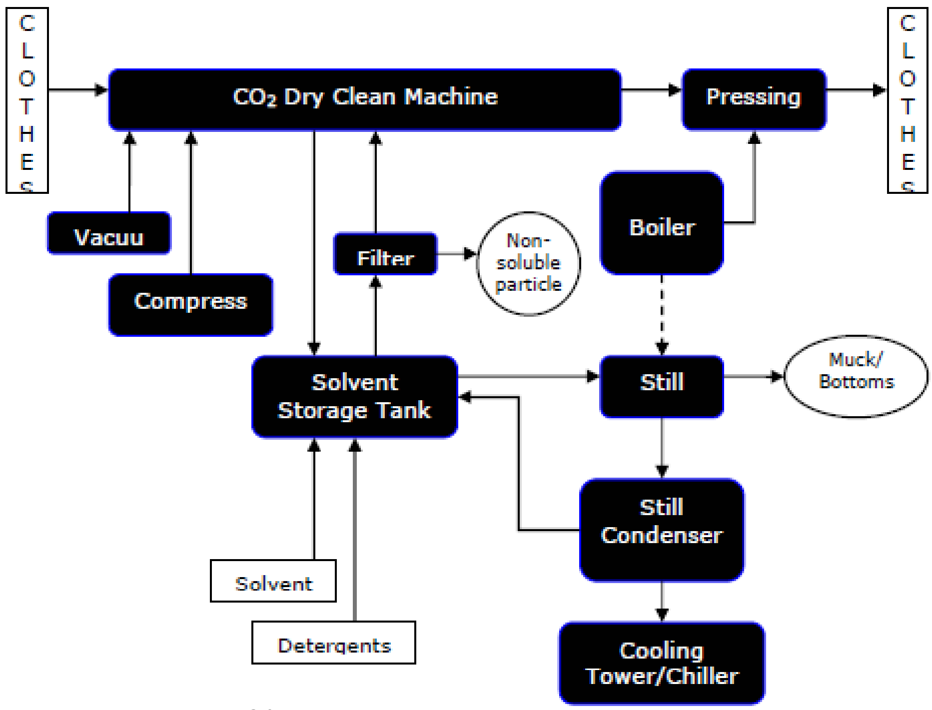


Diagram Source: SCE 2009[319]

Figure 8-5: CO_2 Dry-Cleaning Process Flow Diagram

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. 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 during a distillation process which uses either steam from a boiler or electric-heating coils – depending on the machine, distillation energy will be either gas or electricity consumption. The machine uses boiler steam to press the garments after the cleaning cycle. The entire cleaning cycle lasts about 20 to 30 minutes and the cleaned laundry does not need to be further dried.

Equipment costs for CO_2 dry-cleaning systems are substantially higher than PCE dry-cleaning machines.[320]

8.6.3.3 Other Dry-Cleaning Alternatives

Other popular dry-cleaning alternatives include using hydrocarbon and silicone solvent instead of PCE. While these alternatives offer climate and air quality benefits over PCE, they do not provide electricity or gas savings over the PCE method. Table 8-21 shows our estimate for both alternatives, which would result in a net increase of primary energy consumption.

---

[319] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008. http://stpp.ucla.edu/sites/default/files/Garment%20Care%20Energy%20Report.pdf

[320] Sinsheimer, Peter, and Cyrus Grout. 2004. "Evaluating Energy Efficiency in the Garment Care Industry: A Comparison of Five Garment Care Technologies." Rep. UEPI Papers, 2004. Print.

Table 8-21: Hydrocarbon and Silicone Dry-Cleaning Alternatives

Technology	UES Potential	Impacted energy consumption	Applicable Primary Energy Usage (Quads/yr.)	Technical Potential (Quads/yr.)	Sources
Dry-Cleaning Equipment Alternatives					
Hydrocarbon	-12% [a]	Gas heating and electricity	0.03	-0.004	SCE 2009[321]
Silicone	-25% [a]	Gas heating and electricity	0.03	-0.008	SCE 2009

a. These dry-cleaning alternative technologies offer climate change and air quality benefits over traditional PERC technology. However, according to SCE 2009, they do not save gas or electric energy.

- **Hydrocarbon Dry-Cleaning –** Hydrocarbon solvent (also referred to as 'petroleum') is the most widely used alternative to PCE. Hydrocarbon dry clean machines must be equipped with solvent-recovering pollution control devices similar to those found on PCE equipment. While technically not classified as hazardous, hydrocarbon dry-cleaning does emit volatile organic compounds and generates hazardous waste. Hydrocarbon solvents are highly flammable, and fire codes often require the construction of firewalls between the machine and the rest of the facility.[322] These restrictions are barriers that limit the desirability of hydrocarbon dry cleaning as an alternative to PCE.

  Previous studies have found that equipment costs are slightly higher than PCE dry-cleaning machines.[323] The Massachusetts analysis found that capital costs for hydrocarbon dry-cleaning equipment could range from 10% less to 10% more than PCE equipment. [324]

- **Silicone Dry-Cleaning –** Silicone solvent is becoming increasingly popular, and has been marketed as a non-toxic alternative to PCE. The solvent used is known as "Green Earth" 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 hydrocarbon and silicone solvents. Although silicone is less flammable than hydrocarbon solvents, it is subject to the same fire codes and regulations. [325]

---

[321] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008.
[322] Sinsheimer, Peter, and Cyrus Grout. 2004. "Evaluating Energy Efficiency in the Garment Care Industry: A Comparison of Five Garment Care Technologies." Rep. UEPI Papers, 2004. Print.
[323] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008.
[324] Massachusetts Office of Energy and Environmental Affairs. 2013. "Dry Cleaners Environmental Certification Comparative Analysis." Aug 2013. http://www.mass.gov/eea/agencies/massdep/service/approvals/dry-cleaner-forms.html
[325] Sinsheimer, Peter, and Cyrus Grout. 2004. "Evaluating Energy Efficiency in the Garment Care Industry: A Comparison of Five Garment Care Technologies." Rep. UEPI Papers, 2004. Print.

Capital costs for silicone dry-cleaning equipment range from slightly higher to 20-25% less than the cost of PCE equipment.[326, 327]

- **Other Solvents –** Dry-cleaning solvents continue to be an active area of R&D. In addition to those previously described, we have identified several new dry-cleaning alternatives:
  - SolvonK4 (formaldehyde dibutyl acetal)
  - iPura HCS
  - Rynex (Propylene Glycol Ether)
  - DrySolv (1-Bromopropane (n-propyl bromide))
  - Solvair (dipropylene glycol normal butyl ether / CO_2)

  None of these solvents require "breakthrough" dry-cleaning technology. We did not perform any further research in the above solvents for energy savings potential.

8.7 Regulated and Voluntary Efficiency Standards

8.7.1 Regulated Efficiency Standards

DOE has mandated efficiency standards for single-load commercial clothes washers, as Table 8-22 shows. Separate standards apply for top-loading and front-loading product classes. These standards specify a minimum modified energy factor, expressed in cubic feet of washer capacity per kilowatt-hour; and maximum water factor, expressed in gallons per cubic foot of washer capacity.

Table 8-22: DOE Energy Conservation Standards for Commercial Clothes Washers

Product Class	Modified Energy Factor	Water Factor
Top-loading	1.60	8.5
Front-loading	2.00	5.5

DOE has not established any minimum efficiency standards for multi-load (or industrial) commercial clothes washers.

DOE has not established standards for single-load or multi-load commercial clothes dryers, though a residential clothes dryer standard exists. As of early 2015, the California Energy

[326] SCE. 2009. "Comparison of Electricity and Natural Gas Use of Five Garment Care Technologies." Prepared for California utilities by Pollution Prevention Center. ET 05.0, Dec 10, 2008.
[327] Massachusetts Office of Energy and Environmental Affairs. 2013. "Dry Cleaners Environmental Certification Comparative Analysis." Aug 2013. http://www.mass.gov/eea/agencies/massdep/service/approvals/dry-cleaner-forms.html

Commission and California Investor-Owned Utilities are currently engaged in developing a test procedure and standard for commercial clothes dryers. [328]

DOE has not established any minimum energy efficiency standards for dry-cleaning equipment. EPA, however, established air emission standards for PCE in 2008, thus impacting all PCE-type dry-cleaning facilities. There is currently a regulatory program in California mandating the phase-out of PCE-type dry-cleaning by 2023.

8.7.2 *Voluntary Efficiency Standards*

There are several voluntary programs promoting energy-efficient, single-load commercial clothes washers, described in following sections. We found no voluntary programs for multi-load washers, clothes dryers, and dry-cleaning equipment.

8.7.2.1 *ENERGY STAR*

ENERGY STAR provides a high efficiency specification for single-load commercial clothes washers with capacities greater than 1.6 cubic feet. These criteria are stricter than the federal minimum efficiency standards, and do not distinguish between single-load commercial clothes washer product classes.

Table 8-23: ENERGY STAR Specification for Commercial Clothes Washers

Equipment Type	Modified Energy Factor	Water Factor
Commercial Clothes Washers [a]	≥ 2.2	≤ 4.5

Source: CCW 2014[329]

a. Standards are effective February 1, 2013.

8.7.2.2 *Consortium for Energy Efficiency*

The Consortium for Energy Efficiency (CEE) develops initiatives to promote the manufacture and purchase of energy-efficient products and services. CEE has historically maintained a commercial clothes washer specification that provides tiers of efficient CCW products for washers than exceed federal standards, and a qualified product list for available washers within each tier. The "Commercial Family Sized Clothes Washer Specification" is not currently active, due to changes to federal and Energy Start standards for single-load commercial washers.

[328] CA-IOU. 2015. "Commercial Clothes Dryers – Additional Market Data and Standard Proposal Refinement." Prepared by California Investor Owned Utilities for California Energy Commission. Published Jan 2015. http://www.energy.ca.gov/appliances/2014-AAER-01/prerulemaking/documents/comments_water_topics/Refinement_to_Commercial_Clothes_Dryer_CASE_Study_2015-01-21_TN-74379.pdf

[329] CCW. 2014. "Commercial Clothes Washer Rulemaking. Final Rule." Technical Support Document. Chapter 3. Dec 2014.

9 Miscellaneous End-Use Services and Equipment

Commercial buildings include a variety of "other," "plug load," or "miscellaneous equipment" that have relatively small UEC values, but collectively can contribute to a significant portion of a building's AEC. In this report, the miscellaneous end-use services and equipment category ("miscellaneous equipment") includes medical imaging equipment, vertical-lift technologies, coffee makers, non-refrigerated vending machines, ATMs, POS terminals, distribution transformers. Appendix A: Technology Descriptions provides detailed descriptions of each end-use service or equipment.

Table 9-1 provides a summary of the UEC, installed base, and AEC for U.S. commercial miscellaneous equipment. The estimated 2015 primary AEC for miscellaneous end-use services and equipment is 0.70 Quads/yr.

Table 9-1: Miscellaneous End-Use Services and Equipment Energy Consumption Summary

End-Use Technologies	Average UEC (kWh/yr.)	Installed Base (1,000s)	AEC—Site Energy (TWh/yr.)	AEC—Primary Energy (Quads/yr.)
X-Ray	9,500	81	0.77	0.008
Magnetic Resonance Imaging (MRI)	111,000	12	1.39	0.015
Computed Tomography (CT) Scan	41,000	14	0.55	0.006
Ultrasound	760	78	0.06	0.001
Elevators	7,600	805	6.12	0.066
Escalators	22,850	35	0.81	0.009
Non-Refrigerated Vending	570	5,005	2.86	0.031
Automated Teller Machine	2,900	414	1.20	0.013
Point-of-Service (POS) Terminals	320	8,742	2.80	0.030
Distribution Transformers	7,900	5,700	45.00	0.484
Coffee Makers	905	5,565	3.20	0.035
Total			**64.80**	**0.698**

Site kWh to Site Btu conversion of 3,412 Btu-to-kWh; site-to-source conversion factors: Electricity: 3.15 and natural gas: 1.09.

9.1 Market Overview

9.1.1 Medical Imaging Equipment

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 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.

Reliability, non-energy performance, and first cost are the most important decision-making criteria for medical imaging equipment. Energy efficiency is rarely considered during the purchase decision of a machine.

9.1.2 Vertical-Lift Technologies

In addition to a large number of specialist firms, there are 4 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.

9.1.3 Coffee Makers

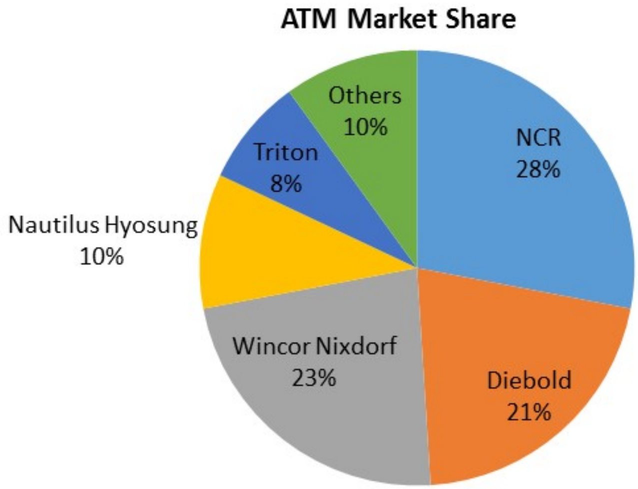
The majority of energy used by coffee makers goes into heating the water through a resistive heating element. The most common type is a coiled wire. The heat from the wire is then transferred to an aluminum water tube to boil the water and in some instances, also heats a warming plate to keep the coffee pot warm.

9.1.4 Non-Refrigerated Vending Machines

Most sites have a contract spanning several years with a vender operator, who is responsible for providing drinks, snacks, and other vending services. Generally the operator owns the vending machines but you may have some opportunities to work with them to get energy-efficient machines that will cost you less to operate.

9.1.5 Automated Teller Machines

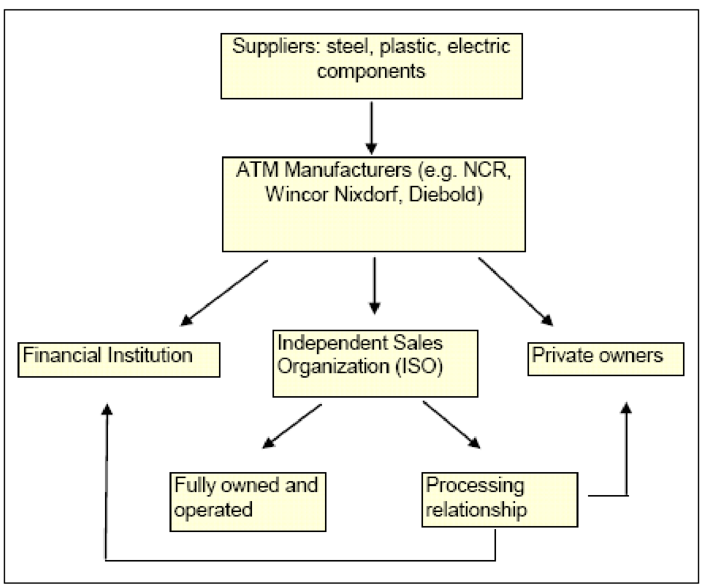
While only a few companies are responsible for the majority of ATM manufacturing, the ownership and operation of these machines are the responsibility of a large and diverse number of organizations. Figure 9-1 depicts some of the leading ATM manufacturers, with NCR Corporation, Diebold, and Wincor Nixdorf accounting for 75% of the world market share. The top 5 owners of ATMs in the United States account for just 17% of the total installed base.



Source: Lehman Brothers, 2008 [330]

Figure 9-1: Global ATM manufacturer market share as of 2007

Several options for ownership and operation of ATM machines exist, as depicted by the value chain in Figure 9-2.



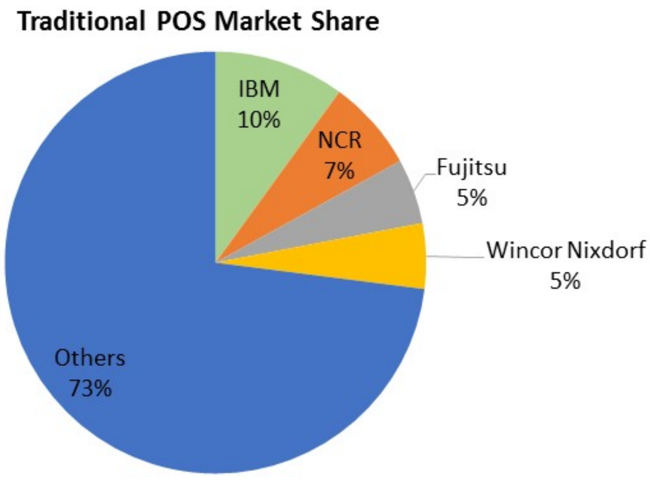
Source: Lehman Brothers, 2008 [331]

Figure 9-2: Overview of the ATM industry value chain

[330] Lehman Brothers. 2008. "NCR Corporation Profile." May 2008.
[331] Ibid.

9.1.6 Point-of-Service Terminals

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 9-3).



Source: Lehman Brothers, 2008 [332]

Figure 9-3: Global POS manufacturer market share as of 2007

9.1.7 Distribution Transformers

Distribution transformers were not included in the 2009 Commercial Appliance Report. We decided to include them in this report because of their large energy consumption compared to other miscellaneous end-use services and equipment. Distribution transformers are devices that transform electric utility power distribution line voltages (4-35 kilovolts) to lower secondary voltages (120-480 volts) suitable for customer equipment. This voltage transformation can occur in multiple stages, depending on application, but all electrical energy used in the U.S. passes through at least one distribution transformer before being used in end-use equipment. Generally speaking, distribution transformers are reliable and efficient devices, with no moving parts and average life spans of more than 30 years.

Liquid-immersed transformers rely on oil or other liquid circulating around the coils for cooling. Dry-type transformers on the other hand only use natural convection of air for insulation and cooling. Liquid-immersed transformers are generally more efficient than dry-type due to more effective heat transfer in liquid cooled systems. Medium-voltage, dry-type transformers are only applicable for industrial processes, and liquid-filled transformers are all medium voltage. 90% of liquid-filled transformers serve utilities and the remainder serve industrial processes.

Distribution transformers can be located outside of or inside commercial buildings. For this report, we are only considering those transformers located inside commercial buildings. Low-voltage dry-type distribution transformers are the most common type of transformer for commercial buildings.

[332] Ibid

Medium-voltage, dry-type distribution transformers are suited for larger industrial sites, and liquid-immersed distribution transformers are commonly used for utility applications.

9.2 Annual Shipments and Installed Base

Limited information exists on the annual shipments for most miscellaneous equipment types.

We used a variety of sources to develop installed base estimates for miscellaneous end-use services and equipment. To develop 2015 installed base estimates for medical imaging equipment, we used the 2011 installed base numbers presented in a 2013 report by the EIA, and assumed a 1% annual growth in installed base.[333] Table 9-2 shows the 2015 installed base of medical imaging equipment.

Table 9-2: Installed Base of Medical Imaging Equipment

Type	Installed Base [a]
MRI	12,000
CT Scan	14,000
X-Ray	81,000
Ultrasound	78,000

[a] Assumed 1% annual growth from the 2011 annual base presented in the EIA Analysis and Representation of Miscellaneous Electric Loads in NEMS[334]

To develop the 2015 installed base of vertical-lift technologies, we created a scaling factor using the number of elevators and escalators in CBECS 2003 and CBECS 2012. We then applied this scaling factor to the installed base in CBECS 2012 to develop the 2015 installed base, shown in Table 9-3.

Table 9-3: Installed Base of Vertical-Lift Technologies

Type	Installed Base [a]	Source
Elevator	589,000	CBECS (2003)
Escalator	26,000	
Elevator	751,000	CBECS (2012)
Escalator	33,000	
Elevator	1.07	Scaling Factor
Escalator	1.07	
Elevator	805,000	Estimated 2015
Escalator	35,000	

[a] From CBECS (2003) and CBECS (2012) microdata

[333] EIA. 2013. "Analysis and Representation of Miscellaneous Electric Loads in NEMS." Prepared for EIA by Navigant Consulting and SAIC. May 22, 2013. http://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf
[334] Ibid.

To develop the installed base of non-refrigerated vending machines, ATMs, POS terminals, and coffee makers, we used a combination of 2008 installed base data from 2 different reports and total commercial floor space from CBECS reports. Using the total commercial square footage in CBECS 2003 and CBECS 2012, we created a scaling factor from 2008 to 2015 and applied that to the 2008 installed base estimate to obtain the 2015 installed base. We used the 2008 installed base estimates from a 2010 TIAX report and the 2009 Commercial Appliance Report.[335, 336] The results of the scaling analysis and 2015 installed base are shown in Table 9-4 and Table 9-5.

Table 9-4: Scaling Factor for Miscellaneous End-Use Services and Equipment

Total Commercial Floor Space (million square feet)	Source
72,000	CBECS (2003)
87,000	CBECS (2012)
80,000	Estimated 2008
92,000	Estimated 2015
1.15	Scaling Factor [a]

[a] Estimated floor space 2015 ÷ Estimated floor space 2008

Table 9-5: Installed Base of Non-Refrigerated Vending Machines, ATMs, POS, and Coffee Makers

Equipment	2008 TIAX Installed Base [a]	2008 Navigant Installed Base [b]	2015 Installed Base [c]
Non-Refrigerated Vending Machines	4,355,000	-	5,005,000
Automated Teller Machines	360,000	-	414,000
POS Terminals	-	7,607,000	8,742,000
Coffee Makers	-	3,102,000	3,565,000

[a] TIAX 2010 [337]
[b] Navigant 2009 [338]
[c] 2008 Installed Base x scaling factor from Table 9-4, above.

To develop the 2015 installed base of distribution transformers, we used the same approach that was done for medical imaging equipment. We took the 2011 installed base numbers presented in

---

[335] McKenney et al. 2010. "Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type." TIAX LLC for US Department of Energy. 2010.
[336] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009. http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf
[337] McKenney et al. 2010. "Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type." TIAX LLC for US Department of Energy. 2010.
[338] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009. http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf

a 2013 report by the EIA, and assumed a 1% annual growth in installed base. The results are shown in Table 9-6.

Table 9-6: Installed Base of Distribution Transformers

Installed Base [a]	Source
5,470,000	2011 EIA Installed Base
5,700,000	Estimated 2015 Installed Base
[a] Assumed 1% annual growth from the 2011 annual base presented in the EIA Analysis and Representation of Miscellaneous Electric Loads in NEMS[339]	

9.3 Product Cost Breakdown

Limited information exists for the cost of most miscellaneous equipment types.

9.4 Baseline Energy Consumption

When possible, we used new industry reports from TIAX and EIA to update the AEC. When new data was not available, we used the UEC presented in the 2009 Commercial Appliance Report and the updated 2015 installed base to develop an updated AEC.

Table 9-7 through Table 9-10 show the use characteristics and UEC for medical imaging equipment.

Table 9-7: MRI Use Characteristics, 2015

Value Type	Mode	Estimate [a]
Power Draw (W)	Active	21,000
	Idle/Ready	14,000
	Sleep/Standby	9,000
	Off	0
Annual Usage (Hours)	Active	1,460
	Idle/Ready	2,920
	Sleep/Standby	43,80
	Off	0
UEC (kWh/yr)	**-**	**111,000**
[a] Source: EIA 2013, Analysis and Representation of Miscellaneous Electric Loads in NEMS [340]		

[339] EIA 2013. "Analysis and Representation of Miscellaneous Electric Loads in NEMS." Prepared for EIA by Navigant Consulting and SAIC. May 22, 2013. http://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf
[340] Ibid.

Table 9-8: CT Scan Use Characteristics, 2015

Value Type	Mode	EIA Estimate [a]
Power Draw (W)	Exposure	17,000
	Partial	5,000
	Standby	4,600
	Idle	4,600
Annual Usage (Hours)	Exposure	90
	Partial	77
	Standby	977
	Idle	7,616
UEC (kWh/yr)	**-**	**41,000**

[a] Source: EIA 2013, Analysis and Representation of Miscellaneous Electric Loads in NEMS [341]

Table 9-9: X-Ray Use Characteristics, 2015

Value Type	Mode	EIA Estimate [a]
Power Draw (W)	Exposure	57,000
	Partial	3,500
	Idle	2,500
	Off	0
Annual Usage (Hours)	Exposure	4
	Partial	206
	Idle	3,403
	Off	5,147
UEC (kWh/yr)	**-**	**9,500**

[a] Source: EIA 2013, Analysis and Representation of Miscellaneous Electric Loads in NEMS [342]

[341] Ibid.
[342] Ibid

Table 9-10: Ultrasound Use Characteristics, 2015

Value Type	Mode	EIA Estimate [a]
Power Draw (W)	On	340
	Standby	150
	Off	0
Annual Usage (Hours)	On	1,560
	Standby	1,560
	Off	5,640
UEC (kWh/yr)	**-**	**760**

[a] Source: EIA 2013, Analysis and Representation of Miscellaneous Electric Loads in NEMS [343]

Using the UEC presented in Table 9-7 through Table 9-10 and various industry reports from 2010 to 2013, we developed the AEC for miscellaneous end-use services and equipment, as shown in Table 9-11.

[343] Ibid.

Table 9-11: Miscellaneous End-Use Services and Equipment UEC and US AEC, 2015

End-Use Category	Equipment	2015 Inventory	Annual Electric UEC (kWh/yr.)	US AEC – Site (TWh/yr.) [c]	US AEC – Primary (TWh/yr.) [d]
Medical Imaging Equipment	MRI	12,000 [a]	111,000 [b]	1.39	4.37
	CT Scan	14,000 [a]	41,000 [b]	0.55	1.75
	X-Ray	81,000 [a]	9,500 [b]	0.77	2.43
	Ultrasound	78,000 [a]	760 [b]	0.06	0.19
Vertical-Lift Technologies	Elevator	805,000 [e]	7,600 [f]	6.12	19.3
	Escalator	35,000 [e]	22,850 [f]	0.81	2.6
Vending Machines	Non-Refrigerated Vending Machine	5,005,000 [g]	570 [h]	2.86	9.0
Automated Teller Machines	Automated Teller Machine	414,000 [g]	2,900 [h]	1.2	3.8
POS Terminals	POS Terminal	8,742,000 [g]	320 [i]	2.8	8.8
Distribution Transformers	Distribution Transformer	5,700,000 [j]	7,900 [k]	45	142
Coffee Makers	Coffee Maker	5,565,000 [g]	905 [i]	3.2	10.2

[a] Source: Table 9-2
[b] Source: Table 9-7 through Table 9-10
[c] Equal to the Annual UEC x 2015 Inventory
[d] Site-to-source conversion factor of 3.15 for electricity
[e] Source: Table 9-3
[f] ACEEE 2013 [344]
[g] Source: Table 9-5
[h] TIAX 2010 [345]
[i] 2009 Commercial Appliances Report[346]
[j] Source: Table 9-6
[k] EIA 2013, Analysis and Representation of Miscellaneous Electric Loads in NEMS [347]

Figure 9-4 displays summary data on the energy consumption of all miscellaneous end-use services and equipment types covered in this report.

[344] Kwatra et al. 2013. “Miscellaneous Energy Loads in Buildings.” ACEEE. June 2013.
[345] McKenney et al. 2010. “Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type.” TIAX LLC for US Department of Energy.
[346] Zogg et al. 2009. “Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances.” Report for DOE Building Technologies Program. November 2009. http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf
[347] EIA 2013. "Analysis and Representation of Miscellaneous Electric Loads in NEMS." Prepared for EIA by Navigant Consulting and SAIC. May 22, 2013. http://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf

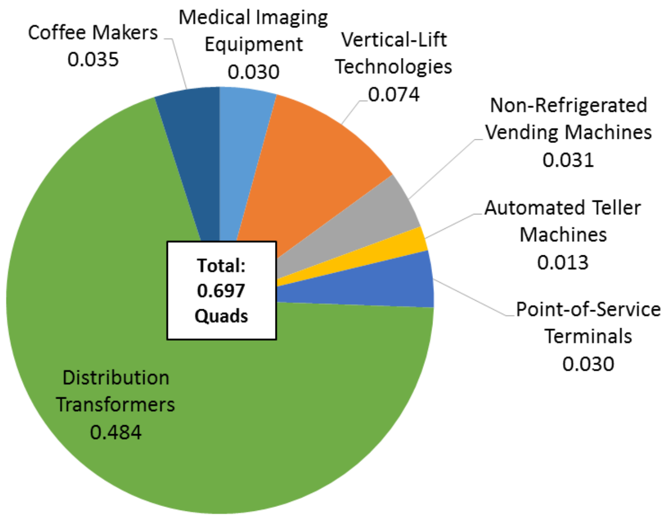


Figure 9-4: Summary of miscellaneous end-use services and equipment consumption (Quads) by equipment type

9.5 Comparison of Baseline Energy Consumption to Previous Studies

We compared our estimate of AEC to estimates from several other sources; these include ADL (1993) and the 2009 Commercial Appliance Report. Table 9-12 and Figure 9-5 illustrate the comparison. Please note the major differences in AEC in Figure 9-5 is primarily due to the fact that the 2008 and 2015 estimates include additional end-use technologies, as seen in Table 9-12.

Table 9-12: AEC Estimate Comparison

End-Use Technology	1993 ADL AEC (Quads/yr) [a]	2008 Navigant Estimate AEC (Quads/yr) [b]	2015 Navigant Estimate AEC (Quads/yr) [c]	Percent Difference [d]
X-Ray	0.007	0.050	0.008	-83%
MRI	0.001	0.009	0.015	66%
CT Scan	0.002	0.012	0.006	-50%
Ultrasound	No Estimate	No Estimate	0.001	NA
Elevators	No Estimate	0.055	0.066	20%
Escalators	No Estimate	0.008	0.009	9%
Non-Refrigerated Vending	No Estimate	0.022	0.031	40%
Automated Teller Machine	0.008	0.013	0.013	-1%
POS Terminals	0.017	0.025	0.030	20%
Distribution Transformers	No Estimate	No Estimate	0.484	NA
Coffee Makers	No Estimate	0.029	0.035	20%

[a] ADL (1993)[348]
[b] 2009 Commercial Appliance Report[349]
[c] Source: Table 9-11
[d] Calculated: (Navigant 2015 – Navigant 2008) / Navigant 2008

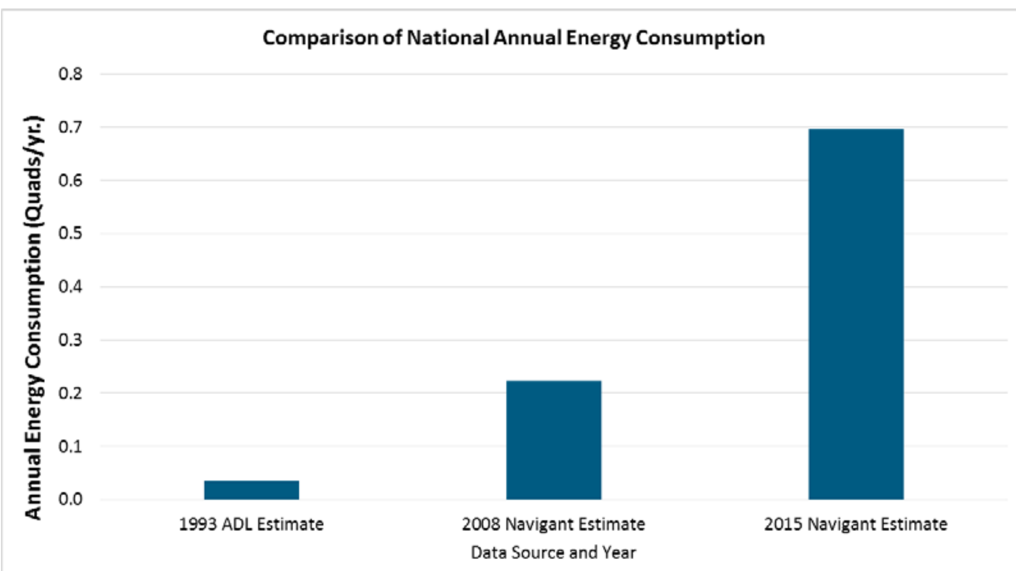


Figure 9-5: Estimated national energy consumption for miscellaneous end-use services and equipment by various sources

---

[348] ADL 1993. "Characterization of Commercial Building Appliances." Arthur D. Little. Report for DOE Office of Building Technologies, Building Energy Division. June 1993.
[349] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report for DOE Building Technologies Program. November 2009.
http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf

The variances in percent difference in the medical imaging equipment exist due to the different source we used compared to the source used in the 2008 estimate. The 2008 estimate came from a 2006 TIAX report.[350] For this report we used medical imaging equipment data from a 2013 EIA report. We believe this data will yield the most accurate AEC estimates for medical imaging equipment. The variances in percent difference for the other end-use technologies exist from using updated UEC data and increased growth in installed base.

9.6 Energy Savings Opportunities

9.6.1 Vertical-Lift Technologies

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. Savings in elevators are possible in the motor and drive combinations as well as controls: [351]

1. ***Variable-voltage, variable-frequency (VVVF) drives***

   VVVF drives and gearless permanent-magnet motors are more efficient than typical AC induction motors or DC shunt field motors.

2. ***Regenerative drives***

   There is energy absorbed during acceleration that must be removed during deceleration (braking). If this energy is not recovered, it is wasted as heat. Regenerative drives can recover excess braking energy from the elevator and feed it to the building's power grid. There are industry claims of recovering 25% of the total energy used by the elevator.

3. ***Efficient lighting***

   Use of efficient lighting and controls for fans, lights, and signaling lights can provide additional savings.

4. ***Controls***

   Controls to turn off or slow down the escalator when inactive are employed in many escalators. Modern building codes such as ASHRAE 90.1 specifications also require the use of such controls in compliant buildings.

Overall, estimates suggest energy savings of about 25% are possible by upgrading existing elevators and escalators to the most efficient available.

9.6.2 Distribution Transformers

Distribution transformers have a high efficiency, typically ranging from 97% to 99.5%. However, because all electricity passes through one or more distribution transformers, even a

[350] TIAX. 2006. "Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030." Tech. no. D0366. 2006.
[351] Kwatra et al. 2013. "Miscellaneous Energy Loads in Buildings." ACEEE. June 2013.

slight improvement in efficiency has a significant commutative effect on energy savings. Changes to transformer design, core or winding material, and type and amount of insulation in the transformer can affect energy losses. Other possible efficiency gains include:

- Hexaformer distribution transformers utilize an atypical geometry that can reduce losses by 30%.
- Coupling hexaformer transformers with an intelligent control system, and replacing a single large transformer with several smaller ones, can reduce losses by around 50%.
- Amorphous core materials offer the potential to reduce energy losses significantly.

9.7 Regulated and Voluntary Efficiency Standards

9.7.1 Medical Imaging Equipment

There are currently no regulatory programs in place for medical imaging equipment.

There are no ENEGY STAR or other voluntary energy efficiency standards for medical imaging equipment.

9.7.2 Vertical-Lift Technologies

There are currently no regulatory programs or ENERGY STAR efficiency standards in place for vertical-lift technologies.

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.[352]

ASHRAE 90.1 requires the escalators to automatically slow to the minimum permitted speed in accordance with ASME A17.1/CSA B44 or applicable local code when not conveying passengers.[353]

9.7.3 Coffee Makers

There are currently no regulatory programs in place for coffee makers.

There are no ENEGY STAR or other voluntary energy efficiency standards for coffee makers.

9.7.4 Non-Refrigerated Vending Machines

DOE has minimum energy efficiency standards for refrigerated vending machines, but not for non-refrigerated vending machines.

[352] USGBC. Accessed December 2015. Available at: http://www.usgbc.org/resources/540ea13eap-min-energydefault-elevator-energy-use-mwh-yr-elevator.

[353] ASHRAE. 2012. "Addenda, 2012 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010. *Energy Standard for Buildings Except Low-Rise Residential Buildings."*

Additionally, an ENERGY STAR specification exists for refrigerated vending machines, but not for non-refrigerated vending machines.

9.7.5 Automated Teller Machines

There are currently no regulatory programs in place for ATMs.

There are no ENEGY STAR or other voluntary energy efficiency standards for ATMs.

9.7.6 Point-of-Service Terminals

There are currently no regulatory programs in place for POS.

There are no ENEGY STAR or other voluntary energy efficiency standards for POS.

9.7.7 Distribution Transformers

DOE published amended minimum energy efficiency standards on April 18, 2013 for distribution transformers, shown in Table 9-13 and Table 9-14.[354] The compliance date with the amended standards is January 1, 2016. Please note that liquid-immersed distribution transformers are not shown because they are not used in commercial buildings.

Table 9-13: Energy Conservation Standards for Low-Voltage Dry-Type Distribution Transformers

Single Phase		Three Phase	
kVa	Efficiency (%)	kVa	Efficiency (%)
15	97.70	15	97.89
25	98.00	30	98.23
37.5	98.20	45	98.40
50	98.30	75	98.60
75	98.50	112.5	98.74
100	98.6	150	98.83
167	98.70	225	98.94
250	98.80	300	99.02
333	98.90	500	99.14
		750	99.23
		1,000	99.28

[354] DOE Distribution Transformers Standards Webpage. Accessed December 2015. Available at: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/66#standards

Table 9-14: Energy Conservation Standards for Medium-Voltage, Dry-Type Distribution Transformers

Single Phase				Three Phase			
BIL kVa [a]	20–45 kV efficiency (%)	46–95 kV efficiency (%)	≥96 kV efficiency (%)	BIL kVa [a]	20–45 kV efficiency (%)	46–95 kV efficiency (%)	≥96 kV efficiency (%)
15	98.10	97.86	-	15	97.50	97.18	-
25	98.33	98.12	-	30	97.90	97.63	-
37.5	98.49	98.30	-	45	98.10	97.86	-
50	98.60	98.42	-	75	98.33	98.13	-
75	98.73	98.57	98.53	112.5	98.52	98.36	-
100	98.82	98.67	98.63	150	98.65	98.51	-
167	98.96	98.83	98.80	225	98.82	98.69	98.57
250	99.07	98.95	98.91	300	98.93	98.81	98.69
333	99.14	99.03	98.99	500	99.09	98.99	98.89
500	99.22	99.12	99.09	750	99.21	99.12	99.02
667	99.27	99.18	99.15	1,000	99.28	99.20	99.11
833	99.31	99.23	99.20	1,500	99.37	99.30	99.21
				2,000	99.43	99.36	99.28
				2,500	99.47	99.41	99.33

[a] BIL (basic impulse insulation level)

In addition to the DOE minimum energy efficiency standard, the National Electrical Manufacturers Associated (NEMA) has developed and published a voluntary industry standard, test method, and labeling standard for distribution transformers.[355] The NEMA premium efficiency specification is shown in Table 9-15. Note – the most recent federal standards meet or exceed the efficiency of NEMA Premium in many transformer classes.

[355] NEMA. 2012. "NEMA Premium Efficiency Transformer Program Guidelines." Accessed from: http://www.nema.org/Policy/Energy/Efficiency/Documents/NEMA_Premium_Efficiency_Transformer_Product_Specifications.pdf

Table 9-15: NEMA Premium Efficiency Specification for Low-Voltage Dry-Type Distribution Transformers

Single Phase		Three Phase	
kVa	Efficiency (%)	kVa	Efficiency (%)
15	98.39	15	97.90
25	98.60	30	98.25
37.5	98.74	45	98.39
50	98.81	75	98.60
75	98.95	112.5	98.74
100	99.02	150	98.81
167	99.09	225	98.95
250	99.16	300	99.02
333	99.23	500	99.09
		750	99.16
		1,000	99.23

10 Appendix A: Technology Descriptions

This section provides brief descriptions for major appliance types in each end-use category discussed in this report. We based these condensed descriptions on those contained in the 2009 Navigant report and updated where necessary. Please refer to the 2009 Commercial Appliances Report for additional details.[356]

10.1 Commercial Cooking Appliances

Commercial cooking appliances include the following subcategories: fryers, broilers, griddles, ovens, ranges, steamers, and microwave ovens.

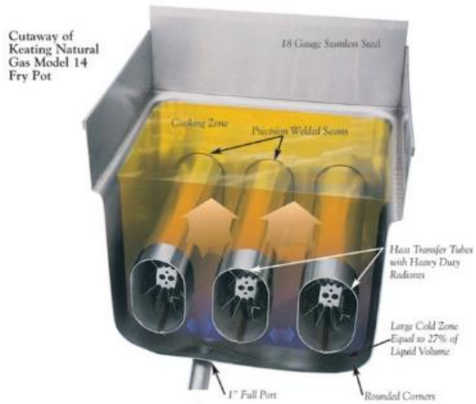
10.1.1 Fryers

Fryers immerse food in oil heated to about 350°F to cook food. 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.

The majority of energy used by fryers is used by the burners or heating elements to maintain oil temperature. Fryers are available in gas and electric models and differ by how they heat oil:

- **Gas fryers –** "Fire tubes" are sealed metallic tubes immersed in the oil at the bottom of the kettle or along the side walls that separate the flame from the oil and act as a heat exchanger to the oil.
- **Electric fryers –** Electric-heating elements located at the bottom of the kettle heat oil directly. These elements differ from oven heating elements in that they are designed to prevent oil from burning.

[356] Zogg et al. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances." Report by Navigant Consulting, Inc., for U.S. Department of Energy. December 2009. Available: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf



a) Fire Tubes (Keating of Chicago 2015[357])

b) Resistance Heaters (FSTC 2007[358])

Figure 10-1: Fire tubes in a gas-fired fryer and electric resistance heaters in an electric fryer

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.

Fryers are usually sized based on their oil capacity, ranging from 15-200 lbs. of oil, to serve the specific needs of the kitchen. 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.

The 3 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 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.
- **Countertop fryers –** Countertop fryers 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.

[357] Keating of Chicago. 2013. “Instant Recovery Fryers.” Available at: http://www.keatingofchicago.com/media/broc/IRfryers_2013.pdf. Accessed December 2015.
[358] FSTC. 2007. “Paloma PF-12SGas Fryer Performance Test.” May 2007.

- **Pressure fryers** – Pressure fryers come in either floor-mounted or countertop models. Pressure fryers 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.

10.1.1.1 Fryer Energy Efficiency

Table 10-1 summarizes the energy efficiency range and other metrics (such as oil capacity and idle energy rate) for the fryers described above.

Table 10-1: 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	15-40a	unknown	unknown	unknown
	Electric	15-30	15-40a	18-60	unknown	unknown

Source: FSTC 2002[359] (Unless otherwise noted)
Source: Survey of available models from manufacturer websites
Efficiency range for currently available models as defined by ASTM testing methods (FSTC 2002)
There is limited test data on the energy consumption of countertop fryers.
Energy consumption rate during the idle mode (maintaining oil at the temperature required for frying)

10.1.2 Broilers

Commercial kitchens commonly use broilers to cook meat and seafood, brown foods, reheat plated food, and melt cheese. Figure 10-2 shows a standard underfired broiler is used to "grill" foods, it gives meats their stripped "grill marks". Broilers are available in gas and electric models and the majority of energy used in broilers is by the burners or heating elements. 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.

[359] FSTC. 2002. "Commercial Kitchen Appliance Assessment Report." Food Service Technology Center. 2002

Source: FSTC 2002[360]

Figure 10-2: Typical underfired broiler

Three main types of broilers are underfired, overfired, and salamander broilers:

- **Underfired broilers –** Underfired broilers, also known as charbroilers, have the highest production capacity of all broilers and are the most versatile. 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. 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.
- **Overfired broilers –** Overfired broilers 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.
- **Salamander broilers –** Salamander broilers 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.

10.1.2.1 Broiler Energy Efficiency

Table 10-2 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, 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

[360] Ibid.

(resulting in higher efficiencies as defined by ASTM testing methods) as the heating elements are in the grate.

Table 10-2: Broiler Input Rate and Efficiencies

Type	Fuel	Rated Input – Site Energy (kBtu/hr.)	Baseline Efficiency Range [a]	Source [b]
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.
b. FSTC Appliance Technology Assessments [361]

10.1.3 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. 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 (Figure 10-3) 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 10-3) 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 2 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.

[361] FSTC – Appliance Technology Assessments. Accessed 2015. Available at: http://www.fishnick.com/equipment/techassessment/

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

Source: Garland 2009[362]

Figure 10-3: Typical standard and double-sided griddles

Other griddle types include sandwich grills and hot dog grills, 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 using heated, rolling metal tubes and are normally found in convenience stores and concession stands.

10.1.3.1 Griddle Energy Efficiency

Table 10-3 summarizes the energy efficiency range and rated input of the above-described griddles and grills.

Table 10-3: 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.

10.1.4 Ovens

Ovens are the most versatile of all cooking appliances and are, therefore the most widely used cooking device for commercial cooking applications. 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. Most standard gas ovens have a standing pilot light.

There are many types of ovens in use, utilizing all 3 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. Major oven types include:

[362] Garland. 2015. http://www.garland-group.com. Accessed December 2015.

- **Convection oven –** Convection ovens (Figure 10-4) use a fan to force convection instead of relying on natural convection alone to cook foods.[363] 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 2 sizes: "full" and "half" size. Full-size can accept larger (18" x 26") baking pans; half-size accepts smaller (18" x 13") baking pans.

Source: Garland 2009[364]

Figure 10-4: Convection oven (Garland MCO)

- **Deck oven –** Deck ovens (Figure 10-5) 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 3 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.

Source: Garland 2009[365]

Figure 10-5: Deck oven (Garland G2000)

[363] While all ovens rely on convection to cook, this refers to forced convection ovens.
[364] Garland, 2015. http://www.garland-group.com. Accessed December 2015.
[365] Ibid.

- **Combination oven –** A combination oven, also known as a “combi-oven” (Figure 10-6), 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. Initially, electric comb-ovens dominated the market, but now most manufacturers also offer gas combi-ovens. These ovens use energy to power heating elements and to control the injection of steam.

Source: FSTC 2002[366]

Figure 10-6: Typical combination oven

- **Rack and rotating rack ovens –** Rack ovens (Figure 10-7) 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.

Source: FSTC 2002[367]

Figure 10-7: Typical rotating rack oven

[366] FSTC. 2002. “Commercial Kitchen Appliance Assessment Report.” Food Service Technology Center. 2002
[367] Ibid.

- **Cook-and-hold ovens –** Cook-and-hold ovens (Figure 10-8) 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.

Source: FSTC 2002[368]

Figure 10-8: Typical cook-and-hold oven

- **Conveyor oven –** Conveyor ovens (Figure 10-9) 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 4 heating processes:
  - Infrared
  - Natural convection with a ceramic baking hearth
  - Forced convection (also known as air impingement)
  - 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.

Source: Middleby 2015[369]

Figure 10-9: Conveyor oven (Blodgett B2136)

[368] FSTC. 2002. "Commercial Kitchen Appliance Assessment Report." Food Service Technology Center. 2002
[369] Middleby UK. Blodgett Conveyer Ovens. http://www.middlebyuk.co.uk/blodgett/4585495520. Accessed December 2015.

10.1.4.1 Oven Energy Efficiency

Table 10-4 summarizes the energy efficiency range and rated input of the ovens described above.

Table 10-4: 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
b. Efficiencies of gas and electric models should not be compared without accounting for electricity generation and transmission losses.

10.1.5 Ranges

Commercial ranges typically consist of 6 open burners or heating elements with a standard oven incorporated underneath (Figure 10-10). 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.”

Source: Garland 2009[370]

Figure 10-10: Six-burner range (Garland C836)

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

Ranges are classified as light/medium duty or heavy duty based on their heating capacity and durability. 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 10-5 summarizes the energy efficiency and rated input of ranges.

Table 10-5: Typical Range Input Rate and Efficiencies, 2008

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

10.1.6 Steamers

Steamers (Figure 10-11) cook food primarily using steam either generated from separate boilers (boiler-based steamers) or self-generated steam (connectionless steamers). Hot steam condenses on the surface of the food, transferring heat from the vapor to the food. 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. Steamers are available with gas and electric configurations for both basic categories of steamers, pressure-less (atmospheric) and pressurized (low and high):

[370] Garland. 2015. http://www.garland-group.com. Accessed December 2015.

- **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 and may use a fan or direct jets to improve cooking times.
- **Pressure steamers**- Pressure steamers employ a closed system to allow the steam to build pressure inside the cooking compartment using heavy sealed doors to maintain pressure. 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.

Source: FSTC 2002[371]

Figure 10-11: Typical steamer

10.1.6.1 Steamer Energy Efficiency

Table 10-6 summarizes the energy efficiency and rated input of steamers described above.

Table 10-6: 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[372]
b. Source: EPA 2015.[373] 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

[371] FSTC. 2002. "Commercial Kitchen Appliance Assessment Report.". Food Service Technology Center. 2002
[372] Ibid.
[373] "Commercial Kitchen Equipment Savings Calculator," EPA, last updated February 2015; available: http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx

10.1.7 Microwave Ovens

Commercial microwave ovens are larger and higher in power output c than residential models. 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 6 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 10-7 details power draw of a baseline unit.

Table 10-7: Power Draw Characteristics of Commercial Microwaves

Metric	Value	Source Comments
Rated (Operational) Power Draw Range	1,000 – 3,200 watts[a]	Survey of current models available on manufacturer websites
Average of Operational Range Above	2,100 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

10.2 Commercial Food Preparation

Commercial kitchens contain a variety of electric appliances that aid in the preparation, storage, and serving of cooked food. Manufacturers typically design each appliance type to perform one or more specific functions including: mixing, slicing, cutting, peeling, grinding, juicing, and food processing. In addition to mechanical food preparation equipment, several other equipment categories keep food at proper temperatures before serving, during transport, and other time periods between cooking and serving. Equipment types such as hot food holding cabinets, holding carts, steam tables, heat lamps, and other warming elements do not provide substantial cooking, browning, or other processes besides maintaining prepared food at proper serving temperatures. Examples of these appliances are pictured in Figure 10-12.

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

Source: Hobart 2015[374]

Figure 10-12: Food preparation equipment

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.

10.3 Commercial Dishwashers

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 10-13.

There are 2 washing strategies and 4 main types of dishwashers used in commercial buildings: washing strategy (low-temperature and high-temperature) and dishwasher type (undercounter, door-type, conveyor-type, and flight-type).

[374] Hobart. 2015. http://www.hobartcorp.com/. Accessed December 2015.

Source: Carlisle 2015[375]

Figure 10-13: Typical dish racks

10.3.1 Washing Strategies

The 2 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.

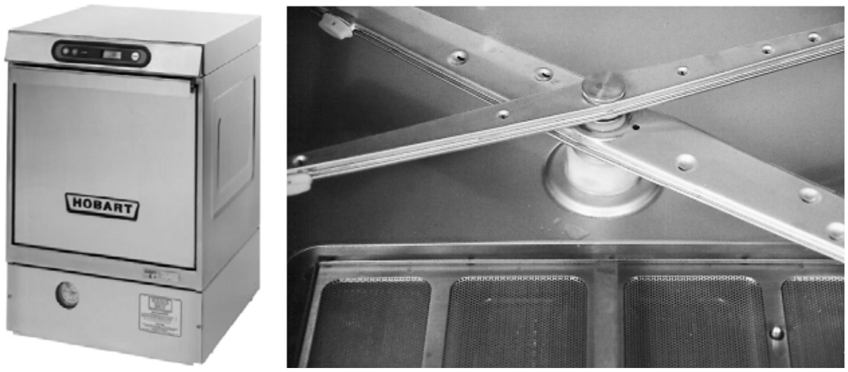
Fresh water does not continually flow to the dishwasher during the wash process. A tank or sump holds a water-detergent mixture that is sprayed onto the dishes, this water flows back to the tank to form a continuous loop recycling wash water. However, fresh water is used for the final rinse cycle. Both 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.

10.3.2 Dishwasher Types

Undercounter dishwashers are the smallest commercial dishwashers available, are placed underneath counters, and have a door that opens downwards with dish racks that pull out. Similar in design to residential models, these machines have a much shorter cycle time than their residential counterparts; the total wash time ranges from 2-5 minutes. These machines to not dry dishes. Undercounter dishwashers are used in smaller establishments that serve less than 100 meals per hour. A revolving arm (Figure 10-14) 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.

---

[375] Carlisle. 2015. http://catalog.carlislefsp.com/warewashing.html. Accessed December 2015.

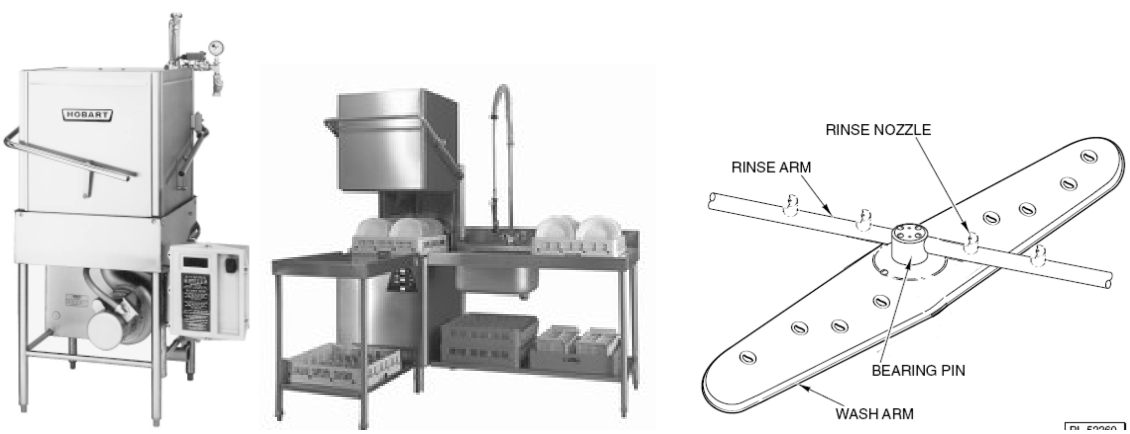


a) Undercounter Dishwasher b) Sprayer Arms

Source: Hobart 2015[376]

Figure 10-14: Undercounter dishwasher (Hobart LX Series)

Door-type dishwashers are machines that have one or several doors that slide vertically for loading and unloading racks of dishes (see Figure 10-15). Their design allows for faster and easier loading and unloading compared undercounter dishwashers and are typically part of a washing “assembly line”. These are used in establishments that serve between 100 and 500 meals per hour. These machines have a single tank for water and detergent and 2 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. Water is constantly added to it during the rinse cycle displacing some of the existing wash water, such that 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 2 in the market.



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

Sources: Hobart 2015[377]

Figure 10-15: Door-type dishwasher (Hobart AM14)

Conveyor dishwashers (Figure 10-16) use a motor driven conveyor belt to move rack-loaded dishes through the machine. These dishwashers have separate wash and rinse compartments

[376] Hobart. 2015. “LX Dishwasher Series Instruction Manual.” Available at: www.hobartcorp.com. Accessed December 2015.
[377] Hobart. 2015. “Model AM14 and AM14C Dishwasher Instruction Manual.” Available at: www.hobartcorp.com. December 2015.

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. 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. 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.

Source: Dishwashers Direct Ltd. 2015[378]

Figure 10-16: Conveyor dishwasher (Elframo ETE 20)

Flight-type dishwashers are the highest capacity dishwashers available. Similar to conveyor machines, flight-type dishwashers use a conveyor belt to move dishes through the machine, but dishes are loaded directly onto the conveyor belt (outfitted with dish-holding prongs) instead of being loading into racks (see Figure 10-17). These dishwashers are used in establishments that serve over 2,000 meals per hour and are custom built to fit a facility's needs and layout.

Source: Blakeslee 2015[379]

Figure 10-17: Flight-type dishwasher (Blakeslee F-Series)

[378] Dishwashers Direct Ltd. 2015. https://www.dishwashers-direct.com/. Accessed December 2015.
[379] Blakeslee. 2015. http://www.blakesleeinc.com/Flight-type-dishwasher/. Accessed December 2015.

10.4 IT and Office Equipment

IT and office equipment includes a wide variety of electrical devices that support business activities through communication, imagining, data storage and other functions. Many types of IT and office equipment have both residential and commercial applications. For many products, the same equipment can serve both sectors (e.g., desktop monitors), while other categories differ on their capacity (e.g., large office printer vs. small home printer), with higher-capacity products designed for commercial applications.

Table 10-8 provides a brief description for major equipment types and subcategories.

Table 10-8: IT/Office Equipment Technology Types and Subcategories

Major Equipment Types	Equipment Subcategories
Personal Computers	Desktop and laptop computers
Desktop Monitors	Primary and secondary monitors
Imaging Equipment	Printers, MFDs, fax machines, document scanners
Server Computers	Enterprise/corporate, small/medium data centers, hyperscale cloud data centers
Network Equipment	Switching products, enterprise routers, enterprise WLAN, security applications
Uninterruptable Power Supply	Enterprise and data centers

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.

10.4.1 Personal Computers

PCs are computers intended for direct operation by an individual end-user. In commercial buildings, PCs come in 2 forms, desktop PCs, which are designed for regular use at a single location and laptop PCs, which are designed for mobile use. A typical desktop PC today comes either in a stand-alone design that then connects with a keyboard and monitor or an integrated design where the computer is directly connected to the monitor display. A typical laptop includes the major PC components with an integrated display and keyboard. In this report, we consider the energy consumption characteristics of these auxiliary monitor display units separately.

10.4.2 Desktop Monitors

A computer monitor is a peripheral visual display unit for a PC. 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 report, we consider stand-alone desktop monitor displays intended to be used as peripheral equipment, and do not include the built-in monitors for laptop PCs.

10.4.3 Server Computers

Server computers provide computing, storage, and other services for communication networks located either on-site within an office building or off-site in large data centers. Typical services include running multiple software applications and hosting shared information within the network.

10.4.4 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. Commercial imagining equipment category includes printers, MFDs, fax machines, and document scanners.

All laser printers and most MFDs – 2 equipment types that account for over 80% of the total imaging equipment energy consumption combined – employ electrostatic or xerographic imaging to put an image onto paper. 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^{o} 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, contributing to higher energy consumption.

10.4.5 Uninterruptible Power Supply

Uninterruptible power supplies (UPS) improve the reliability for PCs, servers, and other devices by providing backup power immediately to reduce interruptions caused by momentary power fluctuations (e.g., voltage surges, voltage sags, and sudden outages).

There are 3 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.
- 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. 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.

10.4.6 Network Equipment

The network equipment category includes several different device types that support communication between computer systems and other devices. This category includes the following technologies:[380]

- **Switching Products:** A network device that filters, forwards, and floods frames (i.e., data packets) based on the destination address of each frame.
- **Enterprise Router:** A network device that determines the optimal path along which network traffic should be forwarded.
- **Enterprise WLAN Controller:** A network device whose primary function is to manage WLAN traffic through one or more wireless access point devices.
- **Security Appliance:** A stand-alone network device whose primary function is to protect the network from unwanted traffic.

10.5 Water Heaters

Traditional commercial water heating equipment includes storage tank heaters, booster heaters, and instantaneous (tankless). The vast majority of commercial water heaters use natural gas or electricity, although some use propane/LPG, oil or solar thermal (typically with a secondary backup source). Water heaters are classified by their energy source, storage volume (as applicable), and energy input capacity, which is reported either as MMBtu/hr. for natural gas heaters and kW for electric heaters. Major equipment categories include storage water heaters, instantaneous water heaters, booster heaters, and stand-alone water heaters.

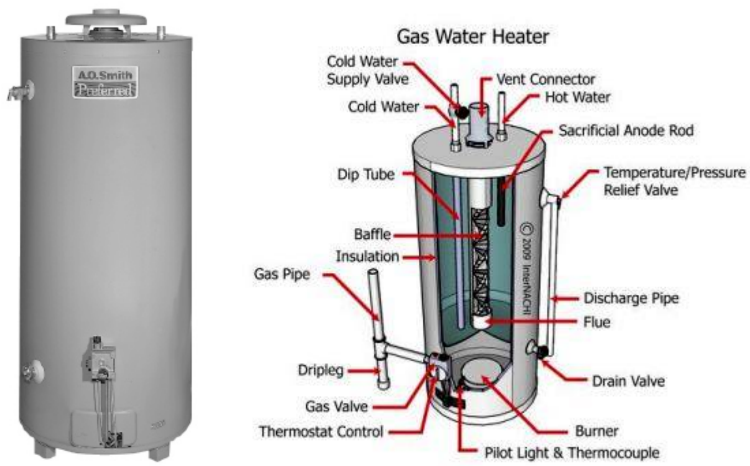
10.5.1 Storage Water Heaters

10.5.1.1 Natural Gas Storage Water Heaters

Natural gas storage water heaters are the most common type of water heaters for commercial applications. Figure 10-18 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

[380] Denkenberger et al. 2014. "Network Equipment." Codes and Standards Enhancement (CASE) Initiative For PY 2013: Title 20 Standards Development. May 15, 2014. Available at: http://www.energy.ca.gov/appliances/2013rulemaking/documents/comments/12-AAER-2A_Consumer_Electronics/12-AAER-2A_CA_IOUs_Response_to_CEC_Data_Request_Network_Equipment_2014-05-15_TN-73026.pdf

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.



Sources: Left: A.O. Smith (AOSmith 2015[381]); Right: International Association of Certified Home Inspectors (NACHI 2015[382])

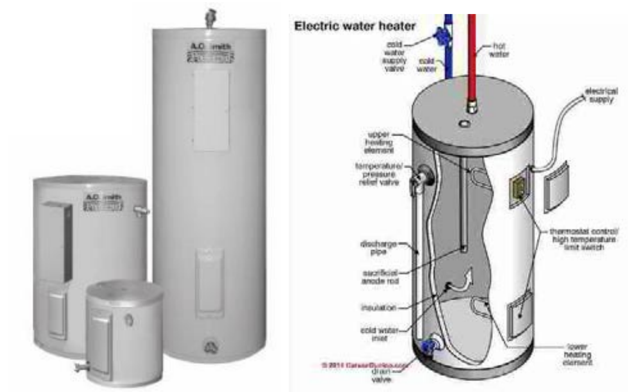
Figure 10-18: Natural gas storage water heater design

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.

10.5.1.2 Electric Storage 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 10-19 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 2 heating elements, while the highest capacity units may have up to 200 individual heating elements.

[381] A.O. Smith Water Heaters. 2015. http://www.hotwater.com/. Accessed December 2015.
[382] NACHI. 2015. International Association of Certified Home Inspectors. http://www.nachi.org/lifespan-water-heater.htm. Accessed December 2015.



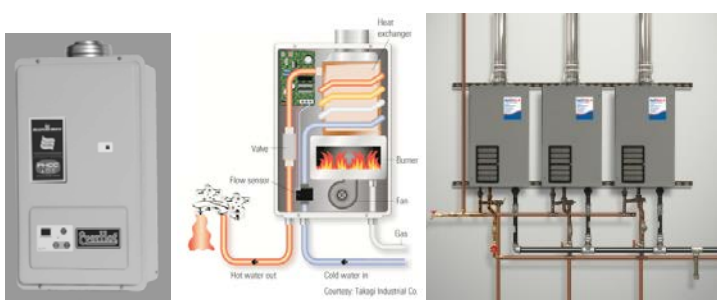
Sources: A.O. Smith (AOSmith 2015[383]); Right: Inspectapedia (Inspectapedia 2015[384])

Figure 10-19: Electric storage tank water heater design

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.

10.5.2 Instantaneous Water 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 10-20 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.



Sources: Left: Bradford White (Bradford 2015[385]); Center: Takagi Industrial Co. (Takagi 2015[386]); Right: Low Energy Systems, Inc. (LES 2015[387])

Figure 10-20: Natural gas instantaneous water heaters

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.

[383] A.O. Smith Water Heaters. 2015. http://www.hotwater.com/. Accessed December 2015.
[384] Inspectapedia. 2015. http://inspectapedia.com/plumbing/Hot_Water_Heater_Cylinder.php. Accessed December 2015.
[385] Bradford White. 2015. www.bradfordwhite.com. Accessed December 2015.
[386] Takagi Industrial Co. 2015. www.takagi.com. Accessed December 2015.
[387] Low Energy Systems Inc. 2015. www.palomawaterheaters.com. Accessed December 2015.

10.5.3 Booster Heaters

Some commercial buildings also use booster water heaters for high-temperature applications. Figure 10-21 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°F 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°Fusing 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.

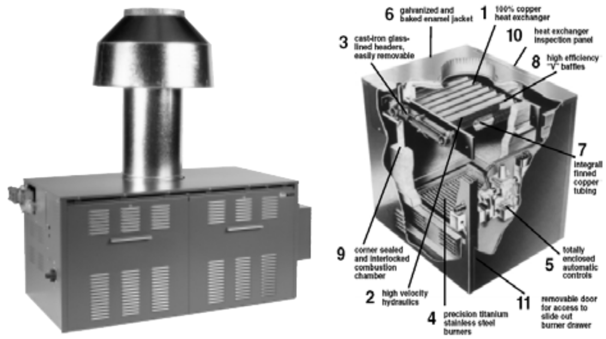
Sources: Left: Energy Solutions Center (ESC 2015[388]); Right: PrecisionTemp (Precision 2015[389])

Figure 10-21: Booster water heaters

10.5.4 Stand-Alone Water Heaters

For certain applications, the water heater may function as a stand-alone heating unit attached to a separate insulated water storage tank. Figure 10-22 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.

[388] Energy Solutions Center. 2015. www.energysolutionscenter.org. Accessed December 2015.
[389] PrecisionTemp. 2015. www.precisiontemp.com. Accessed December 2015.



Source: Rheem (Rheem 2015[390])

Figure 10-22: Stand-alone high capacity natural gas heater

10.6 Pool Heaters

Pool heaters provide thermal energy to pool water to maintain comfortable temperatures for indoor and outdoor pools. This section focuses on gas-fired pool heaters with capacities of 500,000 Btu/hr. and greater that serve indoor and outdoor pools for lodging, sports & recreation clubs, municipal parks, amusement/water parks, and education facilities. We exclude electric, oil, and propane pool heaters because the majority of commercial pools use natural gas heating equipment. Figure 10-23 shows a typical natural gas-fired commercial pool heater.

Source: Raypak website (Raypak 2015[391])

Figure 10-23: Natural gas-fired commercial pool heater

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.

[390] Rheem Manufacturing Co. 2015. www.rheem.com. Accessed December 2015.
[391] Raypack 2015. "Commercial Heating and Hot Water Products." http://www.raypak.com/commframe.htm. Accessed December 2015.

10.7 Commercial Laundry

Commercial laundry consists of a variety of equipment including washers, dryers, dry-cleaning machines, and other large laundry equipment such as presses, flatwork ironers, sorters, feeders, folders, and finishers. This report focuses on 3 major laundry equipment: commercial washers, commercial dryers, and dry-cleaning equipment.

Commercial Clothes Washers

Commercial clothes washers clean clothing, bedding, linens, and other textiles for use in residential, commercial, or industrial applications. Commercial clothes washers can be classified by their capacities and design: single-load clothes washers (top-loading, front-loading), multi-load washers and washer extractors.

10.7.1 Single-Load Commercial Washers

Single-load commercial washers are designed for use in applications in which the occupants of more than one household will be using the clothes washer, such as MF housing common areas or coin laundries.

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.

10.7.1.1 Top-Loading Washers

Top-loading single-load commercial washers resemble traditional consumer clothes washers. An example is shown in Figure 10-24.

Source: AJMadison 2015[392]

Figure 10-24: Single-load commercial top-loading washer

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 front-loading multi-load capacity washers similar to those used in OPLs and industrial laundries. Multi-housing laundries are expected to continue to use smaller, single-load soft-mounting washers (AWE 2009).

10.7.1.2 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 10-25 shows an example of a typical single-load commercial front-loading clothes washer.

[392] AJ Madison. 2015. AJ Madison website. Whirlpool CAE2743BQ pictured. Accessed Dec 3, 2015. http://www.ajmadison.com/cgi-bin/ajmadison/CAE2743BQ.html

Source: AJMadison 2015[393]

Figure 10-25: 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. Front-loaders 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 users 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.

[393] AJ Madison 2015. AJ Madison website. Maytag MHN30PDCWW pictured. Accessed Dec 3, 2015. http://www.ajmadison.com/cgi-bin/ajmadison/MHN30PDCWW.html

10.7.2 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 washer extractors are shown in Figure 10-26, which is a product line illustrating the range of product capacities.

Source: Continental 2015[394]

Figure 10-26: Washer Extractor product line with 20 – 255 lb capacity

Commercial Clothes Dryers

Commercial clothes dryers are segmented into single-load dryers for coin-operated and multi-housing laundries and larger-capacity, multi-load dryers for coin-ops and OPLs. Even larger, industrial-sized dryers for off-premise industrial laundries are not considered in detail for this report. 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, OPLs, and off-premise laundries.

10.7.3 Single-Load Commercial Dryers

Single-load commercial 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

[394] Continental 2015. Continental website. E-series product line pictured. Accessed Dec 3, 2015. http://www.continentalgirbau.com/opl/commercial-washers-eseries.html

- 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 10-27 shows an example of single-load commercial dryer configurations.

Sources: Maytag 2015[395]

Figure 10-27: Single-load commercial dryer configurations

10.7.4 Multi-load Commercial Dryers

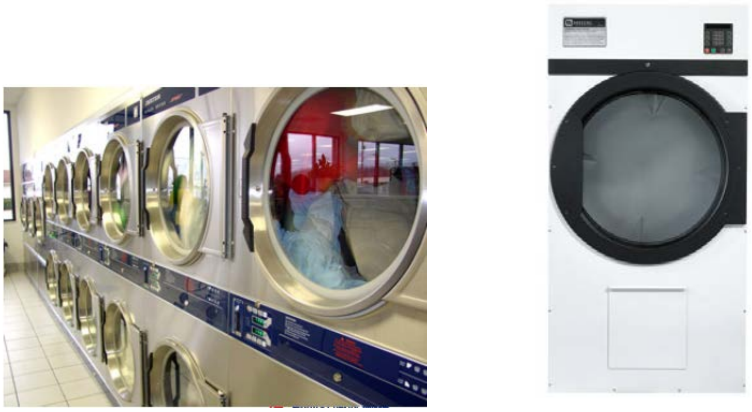
Larger-capacity, multi-load "tumblers" are used in coin-operated laundries, on-premise and off-premise laundry facilities. Their larger capacities are ideal for use with moderately-sized multi-load washers. There is no clear distinction between multi-load dryers and single-load dryers aside from increased capacity, measured by weight of laundry per load, which range from 30 to 170 pounds. Smaller sized multi-load dryers might be used in laundromats while larger multi-load dryers would be used for OPL applications with higher laundry volumes. Common features may include the following:

- Reverse tumbling to help prevent "balling" or "roping" of clothes
- Automatic dry control
- Heavy duty materials and construction

[395] Maytag. 2015. Maytag Commercial Laundry website. MDG17CSAWW (left) and MLE24PNAGW (right) pictured. Accessed Dec 3, 2015. http://www.maytagcommerciallaundry.com/

- Self-cleaning lint screens
- Self-diagnostic microcontrollers.

Figure 10-28 shows examples of large-capacity multi-load "tumbler" dryers.



Sources: Left: SDGE 2008[396] ; Right: Maytag 2015[397]

Figure 10-28: Examples of multi-load dryers

10.7.5 Dry-Cleaning Equipment

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 135 pounds of garments. Figure 10-29 shows traditional PCE dry-cleaning machines.

---

[396] SDGE. 2008. "SDG&E/SoCalGas Appliance Efficiency Efforts." Appliance Efficiency Standards Workshop. California Energy Commission. Presentation. January 2008.
[397] Maytag. 2015. Maytag Commercial Laundry website. MDG50PNHWW model pictured. Accessed Dec 3, 2015. http://www.maytagcommerciallaundry.com/

Source: Left: Parrisianne 2009[398] ; Right: Archiexpo 2015[399]

Figure 10-29: Traditional PCE dry-cleaning machines

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.

During the 1980s, the EPA and state environmental agencies began regulating PCE as a contaminant – in 1993, EPA implemented regulations for dry-cleaning PCE. 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, though often at the expense of energy efficiency. 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.

[398] Parrisianne. 2009. Parrisianne Dry Cleaning Solutions website. Accessed 07 Sept. 2009. http://www.parrisianne.com/.
[399] Archiexpo. 2015. Archiexpo website. Union L-P 800 model pictured. Accessed Dec 3, 2015. http://www.archiexpo.com/prod/union/product-10638-63275.html

Alternatives to PCE include hydrocarbon dry-cleaning, liquid carbon-dioxide technologies, silicon-based compounds, and wet cleaning methods similar to front-loading washers. These technologies are discussed in Section 8.6.3.

10.8 Miscellaneous End-Use Equipment

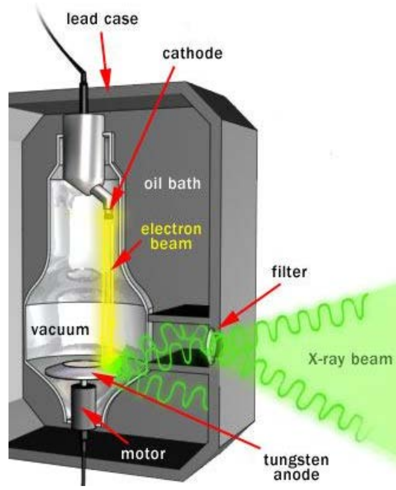
10.8.1 Medical Imaging Equipment

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).

10.8.1.1 X-Ray Machines

Doctors and radiologists use stationary diagnostic X-Ray machines in medical facilities. 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.

Figure 10-30 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. 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.



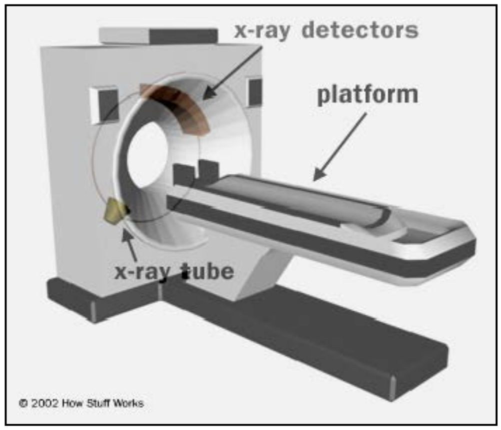
Source: HSW, 2015[400]

Figure 10-30: Major components of an X-Ray machine

10.8.1.2 Computed Tomography Scan Machines

Computed axial tomography (CT) scans, also referred to as 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 10-31 shows the cross-section of a CT scan machine and some of its common components.

[400] HowStuffWorks. "Elevators, Escalators, and Medical Equipment." Accessed December 2015 http://www.howstuffworks.com.

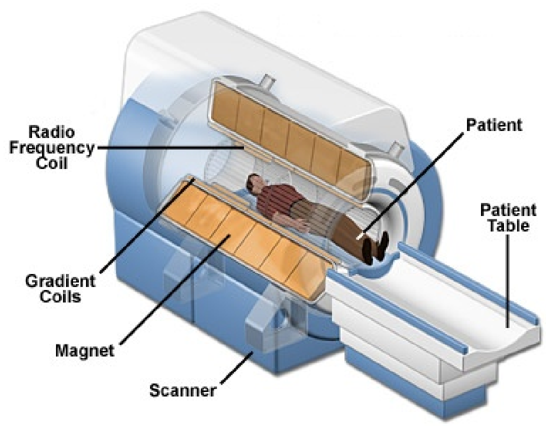


Source: HSW, 2015[401]

Figure 10-31: Major components of a CT scan machine

10.8.1.3 Magnetic Resonance Imaging

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. Figure 10-32 shows the cross-section of a CT scan machine and some of its common components.



Source: HSW, 2015[402]

Figure 10-32: Major components of a MRI machine

10.8.2 Elevators and Escalators

This section describes the general characteristics of the vertical-lift technologies researched in this study including elevators and escalators.

10.8.2.1 Elevators

The 2 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. Almost all

---

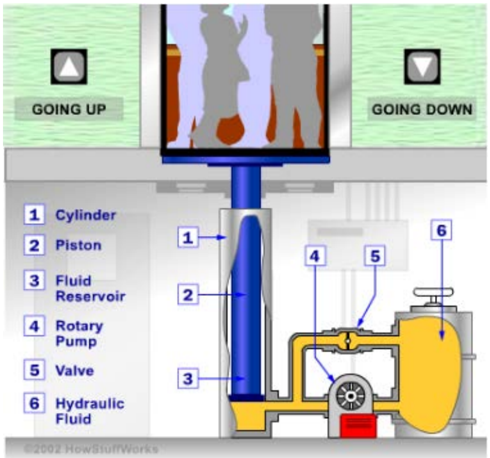
[401] Ibid.

[402] Ibid

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.

10.8.2.2 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 10-33 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, estimated to be 200 Watts per elevator cab, but are excluded from this analysis.



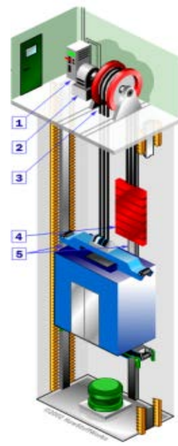
Source: HSW, 2015[403]

Figure 10-33: Hydraulic elevator schematic

10.8.2.3 Traction Elevators

Traction or roped elevators (see Figure 10-34) 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. 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.

[403] Ibid

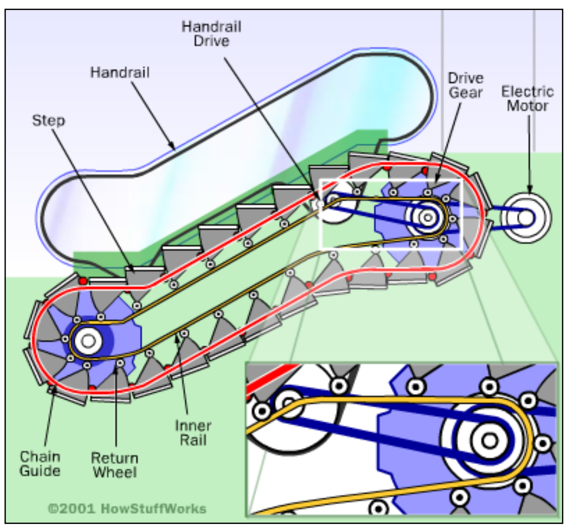


Source: HSW, 2015[404]
Note: 1) Control System; 2) Electric Motor; 3) Sheave Or Pulley; 4) Counterweight; 5) Guide Rails.

Figure 10-34: Traction or rope elevator schematic

10.8.2.4 Escalators

An escalator is a moving staircase conveyor machine used to transport people between floors of a building. Figure 10-35 identifies the major components of an escalator. This analysis does not include moving walkways.



Source: HSW, 2015[405]

Figure 10-35: Escalator cross-section and major components

10.8.3 Coffee Makers

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

[404] Ibid.
[405] Ibid

warming plate to keep the coffee pot warm. There are 3 major types of commercial-style coffee brewers listed in Table 10-9.

Table 10-9: Commercial-Style Coffee Maker Market Share by Type

Coffee Maker Type	Market Share
Decanter	45%
Thermal	30%
Satellite	25%
Source: ADL, 2002[406]	

10.8.4 Non-Refrigerated Vending Machines

The European Vending Association 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.
- **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.

10.8.5 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 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. **Error! Reference source not found.**
- **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.

[406] Roth et al. 2002. “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.

10.8.6 Point-of-Service Terminals

POS terminals are either traditional or non-traditional:

- **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 10-36). POS technologies and capabilities have developed with the advancement of computer technology.

Source: Sharp, 2015[407] Source: HP, 2015[408]

Figure 10-36: Traditional POS terminals

- **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.

[407] Sharp USA. http://www.sharpusa.com/. Accessed December 2015.
[408] HP http://www.hp.com/. Accessed December 2015.

U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy

For more information, visit: eere.energy.gov/buildings

DOE/EE-1393 • June 2016