Independent Statistics & Analysis
U.S. Energy Information Administration

Updated Buildings Sector Appliance and Equipment Costs and Efficiencies

April 2015

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Updated Buildings Sector Appliance and Equipment Costs and Efficiency

Energy used in the residential and commercial sectors provides a wide range of services: heating, cooling, lighting, refrigeration, cooking, and numerous other end uses.

The U.S. Energy Information Administration (EIA) conducts multiple building-sector surveys, the Residential Energy Consumption Survey (RECS) and Commercial Buildings Energy Consumption Survey (CBECS), that provide information on the equipment stock and energy consumption within existing buildings. However, these surveys do not directly gather other information that is important to forecasting future energy consumption, such as equipment cost information or nameplate efficiency ratings.

The Residential Demand Module (RDM) and Commercial Demand Module (CDM) of the National Energy Modeling System (NEMS) contain equipment cost and performance technology "menus" that represent competing options for most of the major end uses. Multiple equipment classes and types are represented in these menus so that the projected equipment stock can change over time in response to fuel prices and other factors that affect equipment choice, such as appliance standards. The equipment menus interact with other NEMS parameters to determine market shares, equipment efficiency levels, cost estimates, and equipment interactions,[1] and are used to translate service demand into energy demand.

The contract reports in Appendices A-D provide the information basis upon which these menus can be built with a consistent perspective on cost and efficiency characterizations across equipment and fuel types. Previous editions of the Annual Energy Outlook (AEO) used similar contract reports.

Appendices A and B constitute one set of reports that characterizes most major residential equipment and commercial heating, cooling, and water heating equipment. Appendix A is used in developing Reference case projections, while Appendix B is used in developing advanced technology cases.[2] These assumptions were developed and implemented during the AEO2015 cycle.

Appendices C and D constitute another set of reports that characterizes residential and commercial lighting, as well as commercial ventilation and refrigeration equipment. Appendix C is used in developing the Reference case, while Appendix D is used in developing advanced technology cases. These assumptions were developed and implemented during the AEO2013 cycle.

When referencing the contract reports in Appendices A-D, they should be cited as reports by Navigant Consulting, Inc. and Leidos (formerly SAIC) prepared for the U.S. Energy Information Administration.

[1] Examples of equipment interactions are solar water heaters that supplement traditional water heaters, clothes washers that reduce the need for clothes drying, or water heaters that provide dishwashers and clothes washers with heated water.

[2] In addition to the Reference case, the demand sectors also project scenarios to explore different assumptions for the cost and performance of future technologies. For the more optimistic cases, some equipment achieves lower life-cycle costs through improved efficiency or lower upfront costs, or both. The contracted reports provide a base case and an advanced case for modeling the AEO Reference case along with the more optimistic cases. Advanced case assumptions are used to develop side cases for full AEO report years that include such analyses.

APPENDIX A

FINAL
EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case

Presented to:

U.S. Energy Information Administration

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Objective

The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

- 2003 and 2012 baselines (or 2009 for residential products), as well as today's (2013)
  - Review of literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
- Forecast of technology improvements that are projected to be available through 2040
  - Review of trends in standards, product enhancements, and Research and Development (R&D).
  - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- All cost forecasts are shown in 2013 dollars.

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Definitions

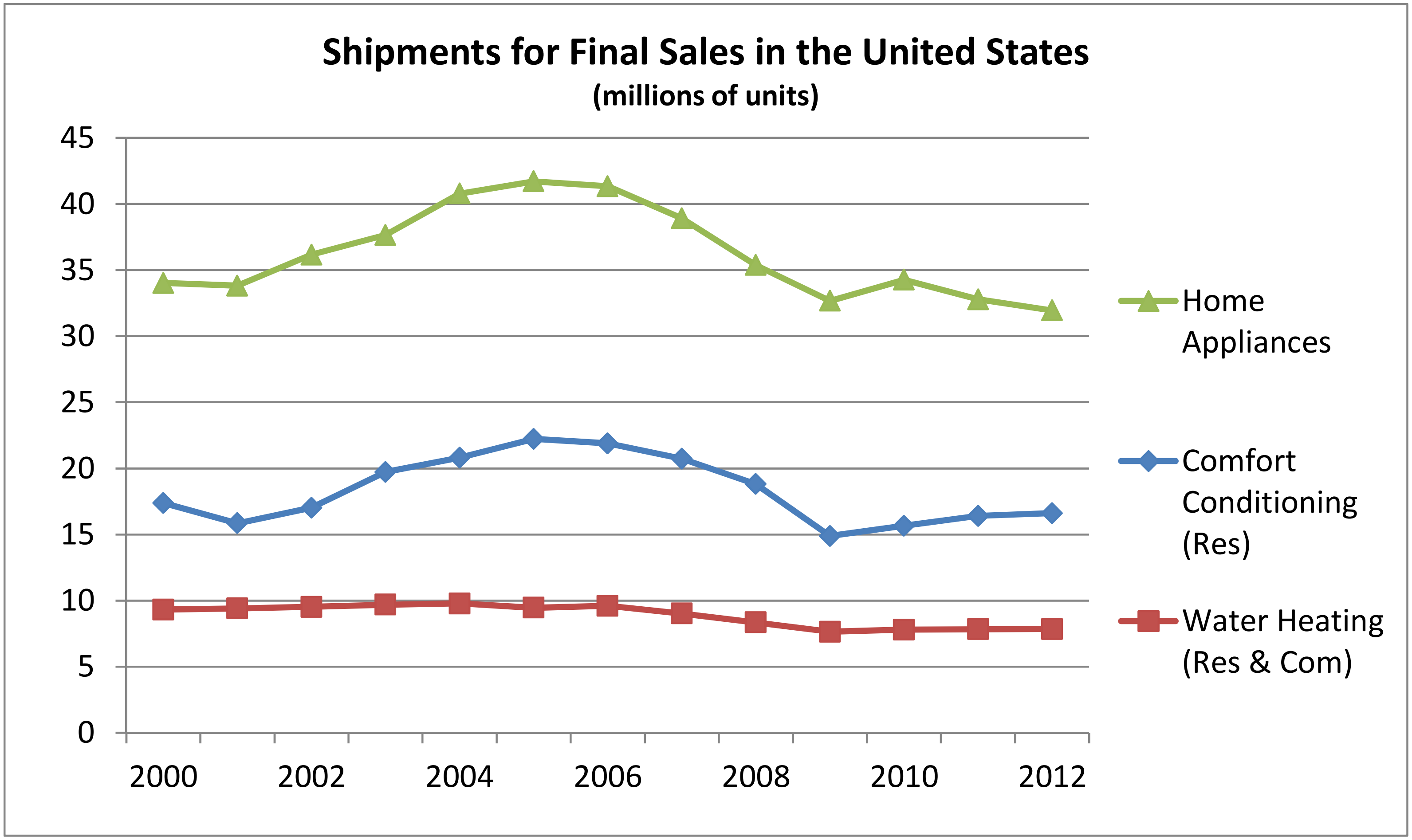
The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (or 2009 for residential products) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- 2003/2009/2012 Installed Base: Efficiency values are for those units installed and "in use" in that year. Cost values are for the typical new unit sold in that year.
- 2013 Current Standard: the minimum efficiency required by current standards.
- Typical: the average, or "typical" product being sold in the particular timeframe.
- ENERGY STAR: the minimum efficiency required to meet the ENERGY STAR criteria, where applicable.
- Mid-Level: middle tier high-efficiency product available in the particular timeframe.
- High: the product with the highest efficiency available in the particular timeframe.

The market for the reviewed products has changed since the analysis performed in 2011 and is reflected in the efficiency and cost characteristics.

- In some categories the typical new product purchased today is significantly more efficient than the average product in the installed base in 2003 (comm.) or 2009 (res.):
  - Residential sector: room and central air conditioners, heat pumps, refrigerators, freezers, clothes washers
  - Commercial sector: rooftop air conditioners and hot food holding cabinets
- More stringent Federal standards are taking effect for the following products:
  - residential and commercial boilers in 2012
  - residential furnaces and dishwashers in 2013
  - room air conditioners, refrigerators, and freezers in 2014
  - residential central air conditioners, air-source heat pumps, water heaters, clothes washers, and clothes dryers in 2015
- ENERGY STAR continues to raise the bar with revised criteria for residential furnaces and new criteria for commercial water heaters, both effective in early 2013.

Shipments of home appliances and comfort conditioning (heating and cooling) equipment peaked during the housing boom in 2005 then declined. Shipment volumes bottomed out in 2009 and have changed little since.



Source: Analysis by Navigant Consulting of data from *Appliance Magazine*.

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Residential Gas-Fired Water Heaters

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	40	40	40	40	50	40	50	40	50	40	50
Energy Factor	0.6	0.59	0.62	0.67	0.80	0.62	0.85	0.62	0.85	0.62	0.85
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	500	500	510	830	1,500	510	1,470	510	1,330	510	1,280
	540	540	540	860	3,000	540	3,100	540	2,930	540	2,870
Total Installed Cost ($)	980	980	990	1,310	1,980	990	1,950	990	1,810	990	1,760
	1,020	1,020	1,020	1,340	3,480	1,020	3,580	1,020	3,410	1,020	3,350
Annual Maintenance Cost ($)	-	-	14	18	18	14	18	14	18	14	18

Residential Gas-Fired Water Heaters

- The current Federal standard, which came into effect in January 2004 mandates an EF of 0.59 for a 40-gallon water heater. The equation for the Federal standard is:

  EF=0.67-(0.0019*Gal), which is used to expand the analysis to a greater range of storage capacities.

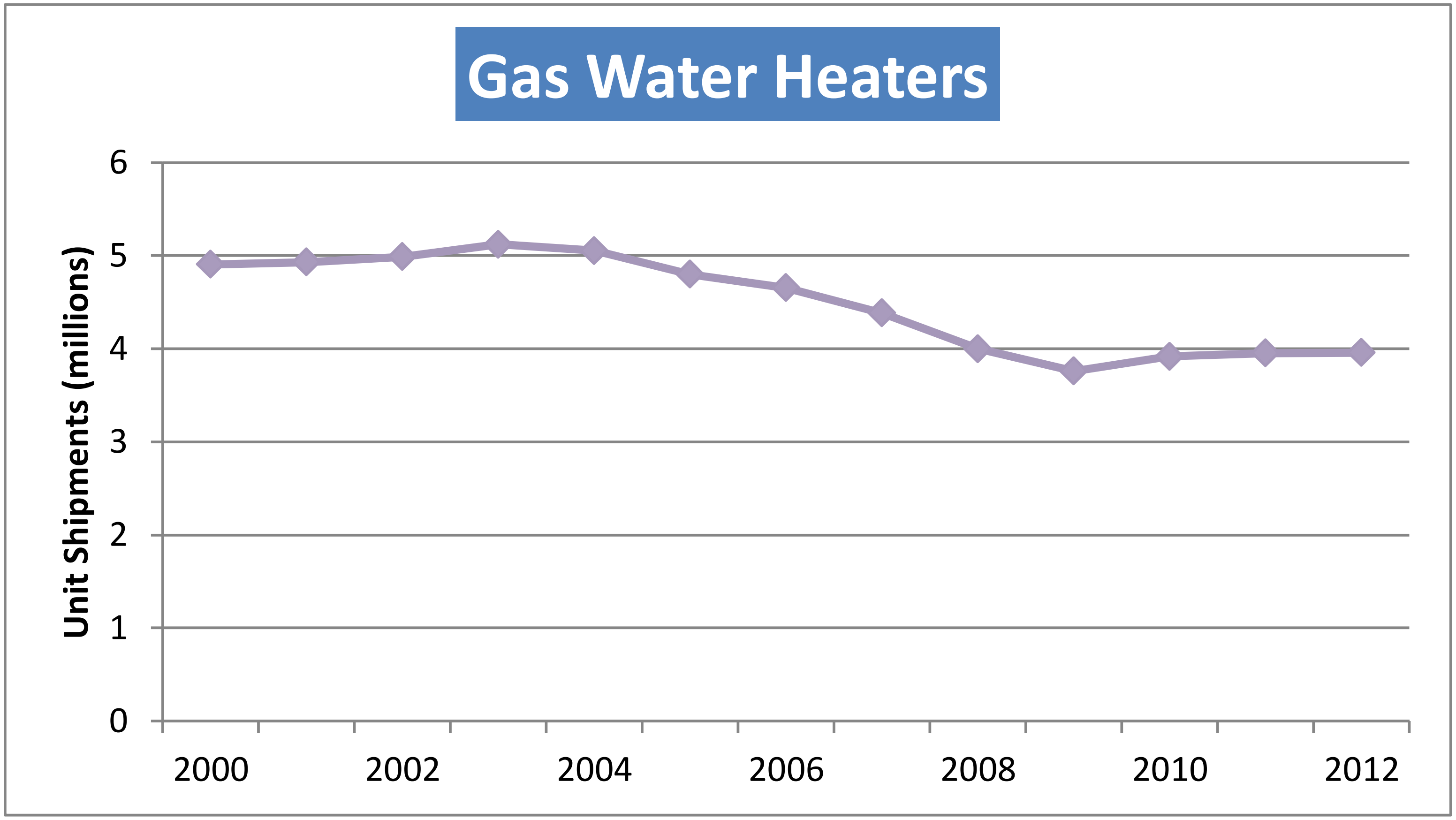
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  EF=0.675-(0.0015*Gal) for a volume ≤ 55 gallons and

  EF=0.8012-(0.00078*Gal) for a volume > 55 gallons

- The current minimum EF for ENERGY STAR qualification is 0.67.
- Per discussions with National Labs, there is a potential trend towards a capacity of 50 gallons as efficiency increases.
- Gas-fired water heater capacities typically fall between 30 and 75 gallons.
- As part of the heating products Federal standards rulemaking, a high efficiency model was examined, EF=0.77 at 40 gallons, which represents a condensing unit with two inches of insulation and a power vent.
- The cost of installation is approximately $450, which is higher than electric water heaters for a number of reasons, which includes an extra 1.5 hours of labor for 2 plumbers that is required for gas units.

Shipments were flat at 5 million units per year through 2004, then declined gradually over 4 years to a new plateau at 4 million units.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

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Residential Oil–Fired Water Heaters

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	30	30	30	30	32	30	30	30	30	30	30
Energy Factor	0.50	0.53	0.54	0.62	0.68	0.62	0.68	0.62	0.68	0.62	0.68
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	1,280	1,380	1,440	1,540	1,700	1,530	1,700	1,510	1,700	1,510	1,700
	1,380	1,490	1,540	1,650	1,810	1,640	1,810	1,640	1,810	1,640	1,810
Total Installed Cost ($)	1,920	2,020	2,080	2,180	2,340	2,170	2,340	2,150	2,340	2,150	2,340
	2,020	2,130	2,180	2,290	2,450	2,280	2,450	2,280	2,450	2,280	2,450
Annual Maintenance Cost ($)	-	-	167	167	167	167	167	167	167	167	167

Residential Oil-Fired Water Heaters

- The current Federal standard, which came into effect in January 2004 mandates an EF of 0.53 for a 30-gallon water heater. The equation for the Federal standard is:

  EF=0.59-(0.0019*Gal), which is used to expand the analysis to a greater range of storage capacities.

- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  EF=0.68-(0.0019*Gal)

- Oil-fired water heaters often have small tanks with larger input ratings, relative to natural gas and electric residential water heaters.
- No condensing oil-fired, storage residential water heaters currently exist on the U.S. market. The range of efficiencies currently reach their peak at near-condensing efficiency levels.
- The max-tech model on the market is achieved using a proprietary "turbo flue" design.

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Residential Electric Resistance Water Heaters

DATA	2009	2013		2020		2030		2040	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	40	50	40	50	40
Energy Factor	0.9	0.904	0.92	0.95	0.95	0.96	0.95	0.96	0.95	0.96
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	270	270	290	350	290	350	290	350	290	350
	320	320	350	470	350	470	350	470	350	470
Total Installed Cost ($)	590	590	610	670	610	670	610	670	610	670
	640	640	670	790	670	790	670	790	670	790
Annual Maintenance Cost ($)	-	-	6	6	6	6	6	6	6	6

Residential Electric Resistance Water Heaters

- The current Federal minimum efficiency standard, which went into effect in January 2004, requires an EF of 0.90 for a 50-gallon electric resistance water heater. The equation for the Federal standard is:

  EF=0.97-(0.00132*volume), which is used to expand the analysis to a greater range of storage capacities.

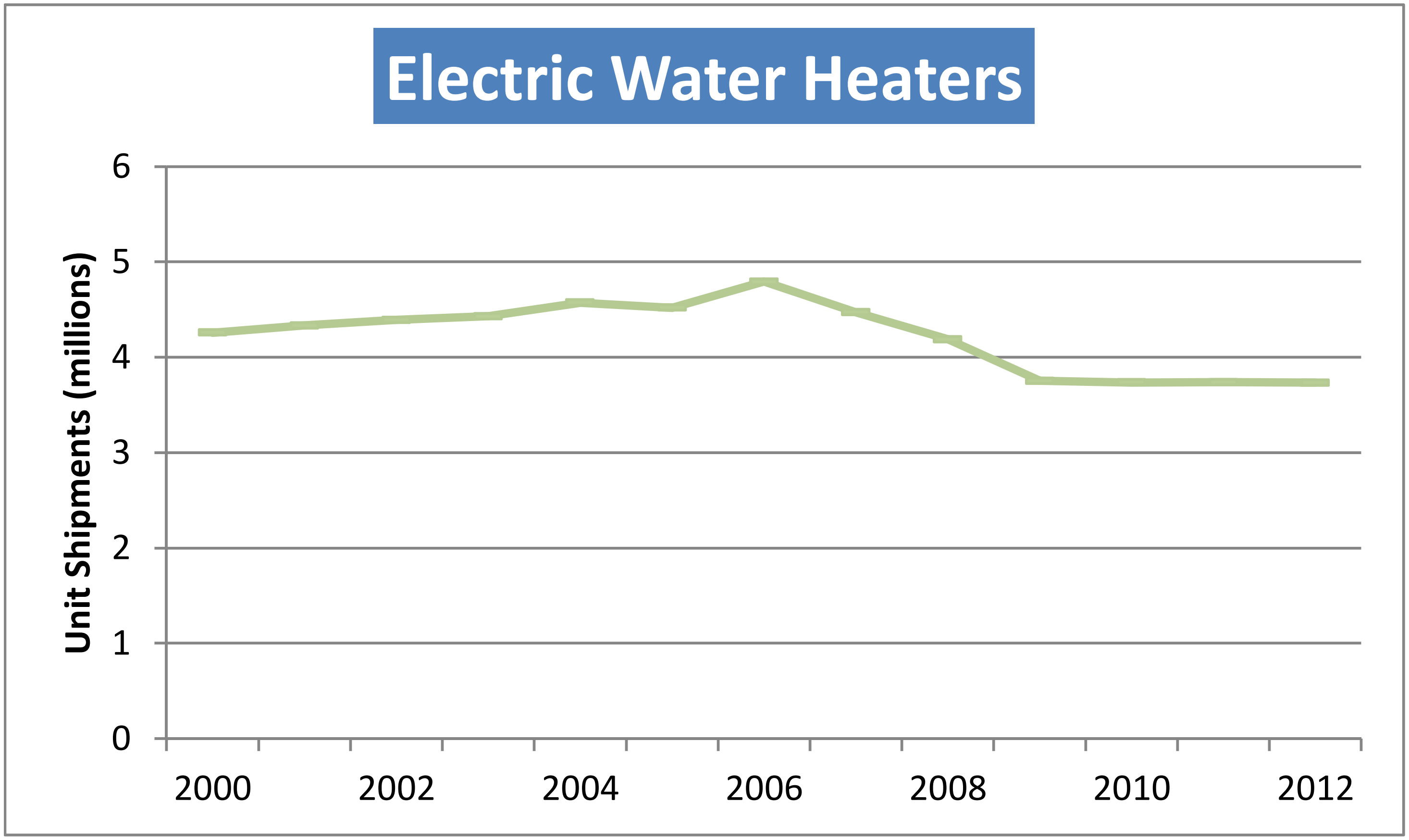
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  EF=0.96-(0.0003*Gal) for a volume $\leq$ 55 gallons, and

  EF=2.057-(0.00113*Gal) for a volume > 55 gallons.

- Residential electric resistance water heater capacities usually range between 30 and 119 gallons.

Shipments peaked in 2006 then dropped a total of 22 percent over three years and leveled off at 3.7 million units per year.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

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Residential Heat Pump Water Heaters

DATA	2009	2013		2020		2030		2040	
	Installed Base	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50
Energy Factor	2	2	2.45	2.3	2.75	2.45	3.6	2.5	3.6
Average Life (yrs)	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	1,500	1,500	1,600	1,400	1,600	1,400	5,950	1,400	5,250
	1,800	1,800	2,100	1,700	2,100	1,700	6,800	1,700	6,000
Total Installed Cost ($)	1,610	1,610	1,710	1,510	1,710	1,510	1,710	1,510	1,710
	2,330	2,330	2,630	2,230	2,630	2,230	2,630	2,230	2,630
Annual Maintenance Cost ($)	16	16	16	16	16	16	16	16	16

Residential Heat Pump Water Heaters

- The minimum EF for ENERGY STAR qualification is 2.0 for heat pump water heaters (HPWH). All HPWH products on the market meet ENERGY STAR minimums and no HPWH products are being offered below the ENERGY STAR efficiency level.
- There is no unique Federal standard HPWH, but integrated HPWHs are in the same product class as electric resistance water heaters, so the Federal electric resistance water heaters standard also applies to HPWH.
- Technology improvements have advanced efficiency and reliability, but the high first-cost still precludes high-volume market penetration. Although there is an installed base listed for 2009, the market penetration of HPWHs was quite low at that time.
- Several major water heater manufacturers have an integrated HPWH model on the market, and other competitors offer integrated or retrofit units (for existing electric or indirect storage water heaters).
- Stiebel Eltron has an 80 gallon, 2.51 EF HPWH. This unit was not included in this analysis because it has a significantly larger capacity than the units included on the previous slide.
- Sales are estimated to be driven partly by rebates and tax credits at the utility, local, state, and Federal level.
- Resistive heating elements are virtually 100% efficient, but there is a jump in efficiency when heat pump technology is adopted because heat pumps' COP are usually between 2 and 3.
- Heat pumps raise the water temperature at a slow rate, so it is usual for these systems to use resistive heat for some of the water heating process. All HPWH systems examined by DOE allow the consumer to adjust the HPWH behavior.
- First-hour ratings range from 57 to 68 gallons.

Residential Instantaneous Water Heaters

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	185	117	178	178	150	178	150	185	185	185	150
Energy Factor	0.82	0.62	0.82	0.82	0.98	0.82	0.98	0.82	0.98	0.82	0.98
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8
	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	1,120	900	900	900	2,300	900	2,300	900	2,300	900	2,300
	1,220	1,400	1,400	1,400	2,400	1,400	2,400	1,400	2,400	1,400	2,400
Total Installed Cost ($)	1,650	1,430	1,430	1,430	2,830	1,430	2,830	1,430	2,830	1,430	2,830
	1,750	1,930	1,930	1,930	2,930	1,930	2,930	1,930	2,930	1,930	2,930
Annual Maintenance Cost ($)	85	85	85	85	85	85	85	85	85	85	85

- The current minimum EF for ENERGY STAR qualification is 0.80 EF or higher. Most instantaneous water heaters sold in 2013 are gas-fired and qualify for ENERGY STAR. In July 2013, the criteria will increase to 0.82 EF, which many existing models qualify for.
- Navien manufactures the highest efficiency gas-fired models currently available on the market, which have an EF of 0.98. This is achieved through the use of electronic ignition, powered direct venting, and through condensing the flue gases.
- All of the major water heater manufacturers now offer an instantaneous model.
- The maintenance cost includes cleaning the water inlet filter and the heat exchanger of mineral deposits and replacing the water valve approximately once every five years for all energy efficiency levels of instantaneous water heaters.
- When replacing a storage water heater with an instantaneous water heater, there are significant additional costs to upsize the gas supply line to ¾ inch from the typical ½ inch and change the venting.

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Residential Solar Water Heaters

DATA	2009	2013		2020	2030	2040
	Installed Base	Current Standard	Typical / ENERGY STAR	Typical	Typical	Typical
Typical Capacity (sq. ft.)	42	NA	42	42	42	42
	63	NA	63	63	63	63
Overall Efficiency (Solar Fraction)	0.5	NA	0.5	0.5	0.5	0.5
Solar Energy Factor	2.5	NA	2.5	3	3.5	3.5
Average Life (yrs)	20	NA	20	20	20	20
Retail Equipment Cost ($)	3,300	NA	3,300	3,000	2,600	2,600
	5,200	NA	5,200	4,700	4,100	4,100
Total Installed Cost ($)	7,600	NA	7,600	7,300	6,900	6,900
	10,000	NA	10,000	9,500	8,900	8,900
Annual Maintenance Cost ($)	25	NA	25	25	25	25

[1] Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.
[2] ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

Residential Solar Water Heaters

- ENERGY STAR requires an OG-300 rating from the Solar Rating and Certification Corporation (SRCC). Most installations use SRCC rated collectors, so there is no high efficiency category.
- Solar water heaters (SWHs) can be either active or passive. An active system uses an electric pump to circulate the heat transfer fluid; a passive system has no pump. Most solar water heaters in the United States are the active type.
- Solar water heaters are also characterized as open loop (also called "direct") or closed loop (also called "indirect"). An open-loop system circulates household (potable) water through the collector. A closed-loop system uses a heat transfer fluid (water or diluted antifreeze, for example) to collect heat and a heat exchanger to transfer the heat to household water.
- Solar fraction represents the fraction of total annual water heating energy met by the solar water heater. A backup water heating system is required with SWHs, and it is typically most economical to size the system to provide about 50% of water heating energy (solar fraction = 0.5).
- Solar Energy Factor (SEF) is defined by the SRCC as the useful energy delivered by the system divided by the total electrical and/or fossil fuel required for backup heating, pumping, and controls (the free solar energy input is neglected).
- Over 2/3 of the current SWH market is in the southern or western US (including Hawaii). The collector area of 42 ft^2 would be typical for these areas. Colder areas of the US would require a larger collector (63 ft^2).
- Installed costs are higher for colder areas where larger collectors are required. Costs also vary widely depending on collector quality, type of system, and site-specific characteristics.

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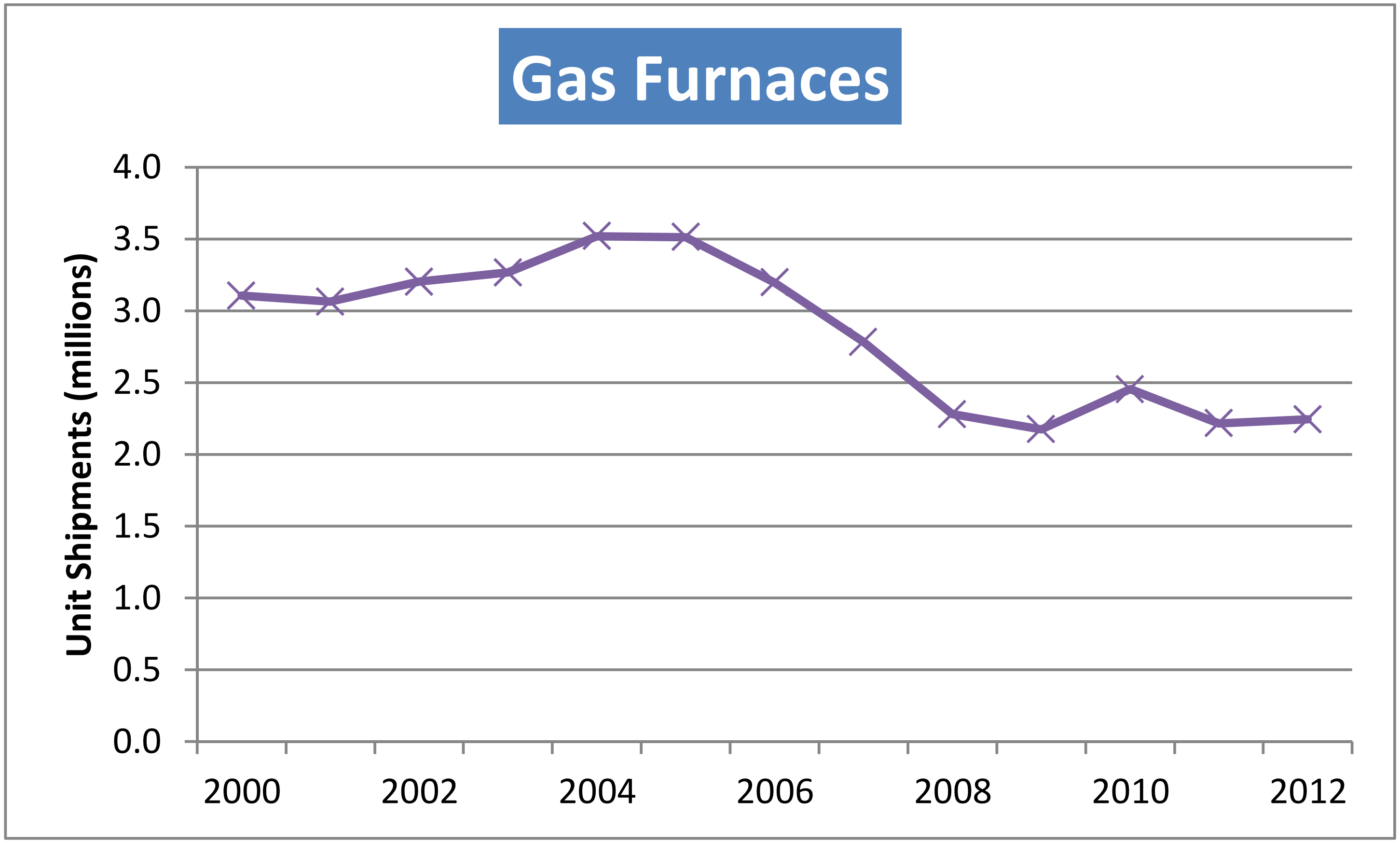
Residential Gas-Fired Furnaces

DATA	2009	2013					2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR (South)	ENERGY STAR (North)	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	75	75	75	75	75	75	75	75	75	75	75	75
AFUE (%)	80	80	80	90	95	98	90	98	92	98	92	98
Electric Consumption (kWh/yr)	312	312	312	289	275	363	289	363	283	363	283	363
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
	17	17	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost ($)	750	750	750	1,000	1,200	1,500	1,000	1,500	1,100	1,500	1,100	1,500
	1,100	1,100	1,100	1,300	1,500	1,700	1,300	1,700	1,300	1,700	1,300	1,700
Total Installed Cost ($)	1,500	1,500	1,500	2,200	2,400	2,700	2,200	2,700	2,300	2,700	2,300	2,700
	2,300	2,300	2,300	2,800	3,000	3,200	2,800	3,200	2,800	3,200	2,800	3,200
Annual Maintenance Cost ($)	45	45	45	45	45	45	45	45	45	45	45	45

Residential Gas-Fired Furnaces

- Current Federal standards for non-weatherized units:
  - South: AFUE ≥ 80%
  - North: AFUE ≥ 90%
  - ≤ 10 watts of electrical power when in standby and off modes
  - Contested in court and not being enforced by DOE
- ENERGY STAR criteria:
  - South: AFUE ≥ 90%
  - North: AFUE ≥ 95%
- Most efficient available: 98% AFUE. The market is nearly evenly split between non-condensing units (AFUE≤85) and condensing units (AFUE≥90).
- Condensing furnaces use an additional heat exchanger to extract additional energy from the flue gases; some models also have variable speed blowers, which decrease electrical energy consumption, and inducer fan systems, which usually have modulating gas valves to allow the furnace to modulate in very small increments, providing an AFUE boost of a few percentage points.
- Non-condensing AFUE levels for natural gas top out at around 81%; above this level, the potential for exhaust gas condensation increases. This condensate is corrosive and requires cost restrictive corrosion resistant venting.
- High-efficiency condensing furnaces typically have aluminized steel heat exchangers and low NO_x emissions, flexible installation, direct vent, and sealed combustion systems. Direct vent furnaces do not use room air for combustion, but instead draws combustion air directly from outdoors.
- Depending on the location of the home, piping materials in use, and other considerations, condensing furnaces may need an acid neutralizer and/or lift pump for the condensate.
- Furnaces may contain permanent split capacitor (PSC) or electronically commutated motor (ECM) fan motors, though the type of motor has no impact on the AFUE measurement. It only impacts SEER/EER of the associated air conditioner.

Annual shipments peaked at 3.5 million units in 2005 then declined each year until 2009 and leveled off at about 2.25 million units.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

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Residential Oil-Fired Furnaces

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	83	83	85	97	83	97	84	97	84	97
Electric Consumption (kWh/yr)	490	477	477	460	410	477	410	472	410	472	410
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15
	19	19	19	19	19	19	19	19	19	19	19
Retail Equipment Cost ($)	2,050	2,300	2,300	2,300	2,700	2,300	2,700	2,300	2,700	2,300	2,700
	2,250	2,400	2,400	2,400	2,900	2,400	2,900	2,400	2,900	2,400	2,900
Total Installed Cost ($)	2,600	3,050	3,050	3,150	4,550	3,050	4,550	3,050	4,550	3,050	4,550
	3,250	3,550	3,550	4,650	5,200	3,550	5,200	4,350	5,200	4,350	5,200
Annual Maintenance Cost ($)	65	65	65	65	65	65	65	65	65	65	65

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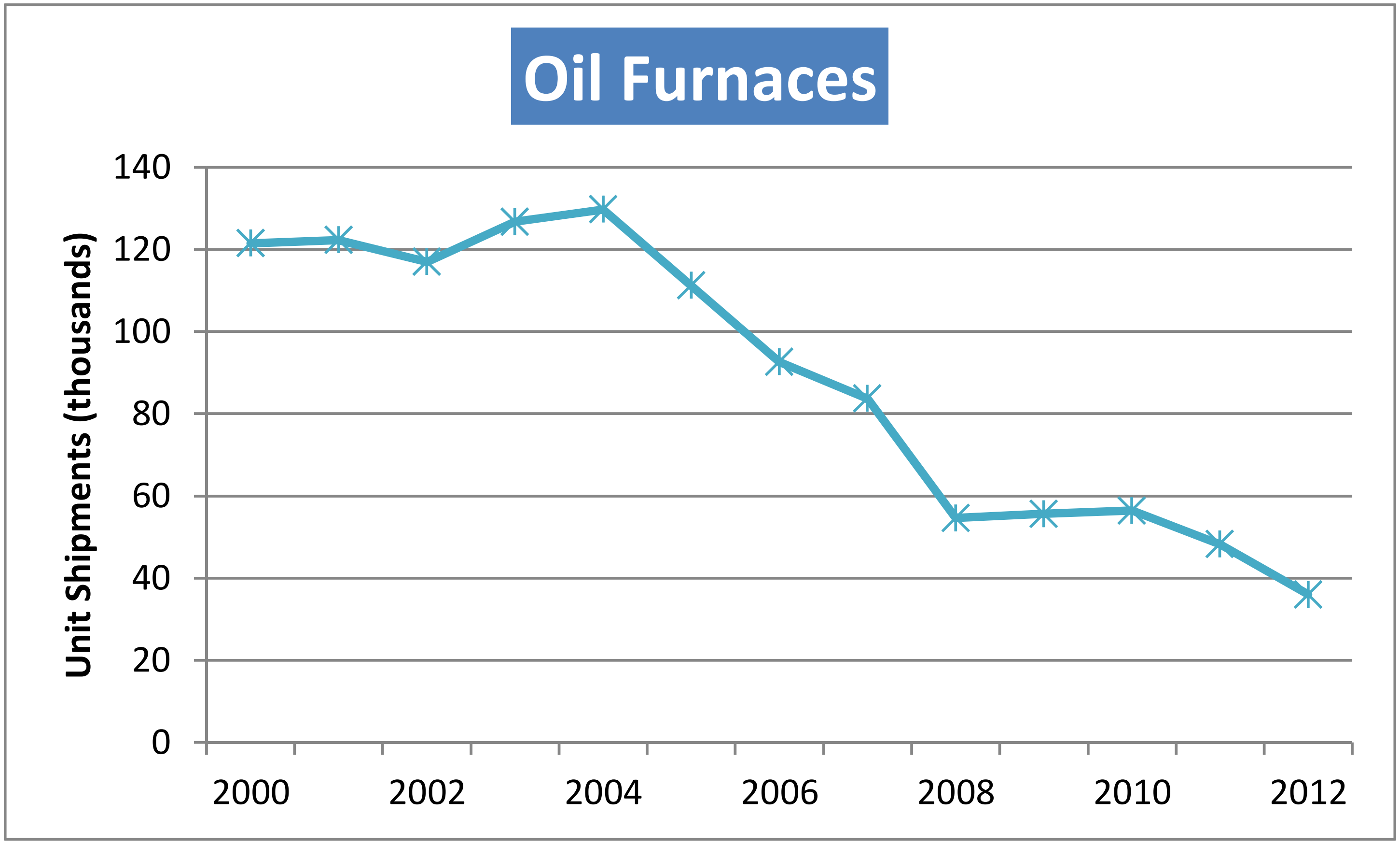
Residential Oil-Fired Furnaces

- Current Federal standards:
  - AFUE ≥ 83%
  - ≤ 11 watts of electrical power when in standby and off modes (non-weatherized models only)
- ENERGY STAR criteria: AFUE ≥ 85%
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Most efficient available: 96% AFUE – condensing units with tiny market share (<1%), due to market acceptance issues.
- Condensate from condensing oil furnaces is typically even more corrosive than that of gas-fired systems due to the higher sulfur content in fuel oil. Hence, condensing oil furnaces also likely require the use of an acid neutralizer.
- Oil-fired furnaces, like gas-fired furnaces, achieve condensing conditions through the use of a secondary heat exchanger. Typically, these heat exchangers use a high-grade stainless steel (Al29-4C) as the primary heat exchange surface.
- Sooting is an issue for all oil-fired appliances, but secondary heat exchangers, with their narrow passages, are even more prone to be plugged by soot. Because of this, oil furnaces require frequent cleaning and maintenance.

Annual shipments declined rapidly after 2004, likely due at least in part to an increase in fuel oil prices, which more than tripled from 2002 to 2008.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

Final

Residential Gas-Fired Boilers

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	82	82	85	96	90	96	90	96	90	96
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17
	24	24	24	24	24	24	24	24	24	24	24
Retail Equipment Cost ($)	1,950	2,100	2,100	2,300	3,450	3,000	3,450	3,000	3,450	3,000	3,450
	2,550	2,900	2,900	3,100	4,500	3,800	4,500	3,800	4,500	3,800	4,500
Total Installed Cost ($)	3,900	4,050	4,050	4,700	6,350	5,900	6,350	5,900	6,350	5,900	6,350
	4,500	4,850	4,850	5,500	7,600	6,900	7,600	6,900	7,600	6,900	7,600
Annual Maintenance Cost ($)	50	50	50	50	50	50	50	50	50	50	50

Residential Gas-Fired Boilers

- Federal standard for hot-water gas-fired boilers (more common than steam):
  - AFUE ≥ 82%
  - Design requirements that took effect on September 1, 2012 prohibit a constant burning pilot and require an automatic means for adjusting water temperature
- ENERGY STAR criteria: AFUE ≥ 85%
- Most efficient available: 96% AFUE
- Have lost market share to furnaces and heat pumps over the past 30 years
- The bulk of U.S. boiler sales are non-condensing boilers, which are primarily manufactured in North America. These are typically high-mass systems whose heat exchangers are made of cast iron.
- Due to incentives and market pressure, the U.S. boiler industry has been shifting towards also providing condensing boilers. Most of these boilers are private-labeled products sourced from Europe, where the hydronic market is much bigger and condensing appliances are much more common and/or required by law.
- Typically, condensing boilers are low-mass in construction with modulating burners, variable-speed inducer fan systems, sealed powered direct-vent combustion, multiple sensor technologies, and electronic ignition and control.
- Most value-added components for condensing boilers are sourced abroad, even when the condensing boiler is assembled in North America (i.e. heat exchanger, gas valve, burner, blower systems, sensors, and/or controls).

Final

Residential Oil-Fired Boilers

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	140	140	140	140	140	140	140	140	140	140	140
AFUE (%)	80	84	84	85	91	84	91	84	91	84	91
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	2,300	2,300	2,300	2,300	3,300	2,300	3,300	2,300	3,300	2,300	3,300
	2,900	2,900	2,900	3,350	4,150	2,900	4,150	2,900	4,150	2,900	4,150
Total Installed Cost ($	4,150	4,150	4,150	4,700	6,200	4,150	6,200	4,150	6,200	4,150	6,200
	4,750	4,750	4,750	5,900	7,250	4,750	7,250	4,750	7,250	4,750	7,250
Annual Maintenance Cost ($)	135	135	135	135	135	135	135	135	135	135	135

Final

Residential Oil-Fired Boilers

- Federal standard for hot-water oil-fired boilers (more common than steam):
  - AFUE ≥ 84%
  - Design requirements that took effect on September 1, 2012 require an automatic means for adjusting water temperature
- ENERGY STAR criteria: AFUE ≥ 85%
- Most efficient available: 91% AFUE
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Oil boilers have heat exchangers comprised of cast iron or steel.

Final

Residential Room Air Conditioners

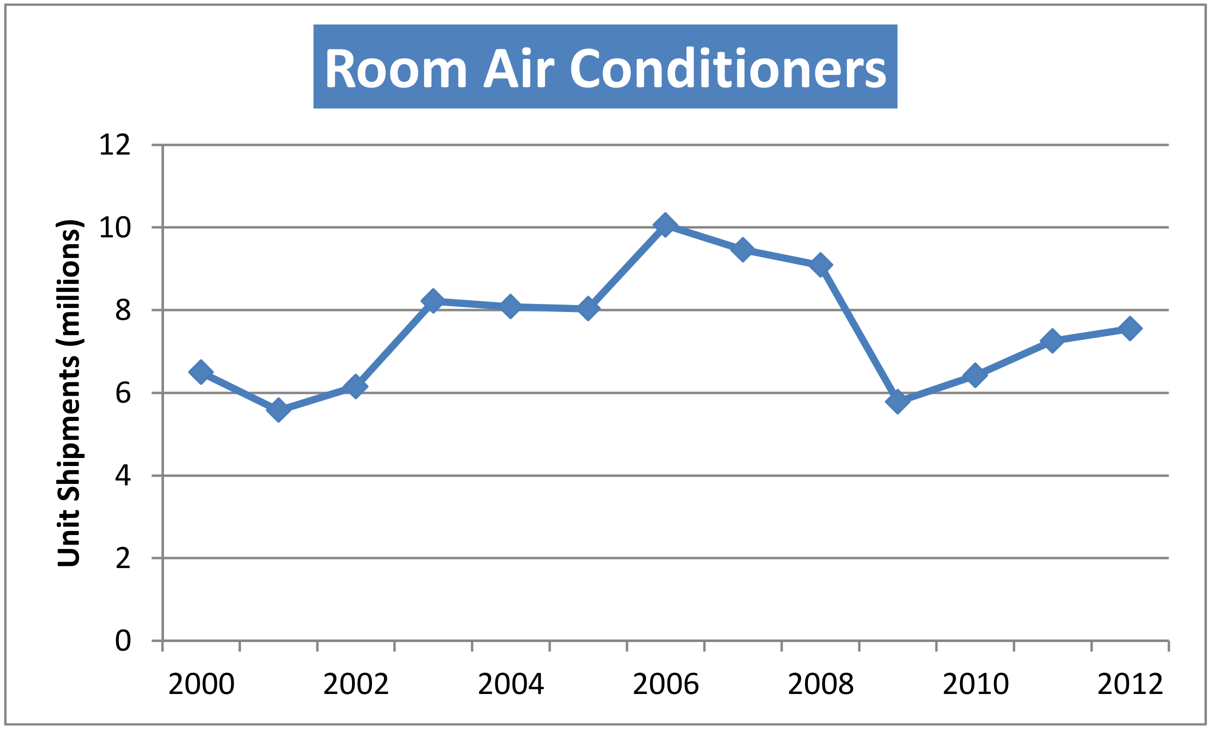
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)*	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
EER**	9.2	9.8	10.8	10.8	11.5	*10.9*	*11.9*	*10.9*	*12.9*	*11.1*	*12.9*
CEER**	*9.3*	*9.9*	*10.9*	*10.9*	*11.6*	11	12	11	13	11.2	13
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6
	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost ($)	220	250	270	270	430	270	480	270	510	270	510
	300	320	340	340	500	340	550	340	590	340	590
Total Installed Cost ($)	320	350	370	370	530	370	580	370	610	370	610
	400	420	440	440	600	440	650	440	690	440	690
Annual Maintenance Cost ($)***	-	-	-	-	-	-	-	-	-	-	-

* All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).
** Italicized values are estimated. The federal standard is expressed in EER, but will be expressed in CEER beginning in 2014. The two metrics are not strictly comparable, but both values are shown here to facilitate longitudinal analyses.
*** Maintenance costs are negligible.

Residential Room Air Conditioners

- Focus on most common type: louvered sides (window air conditioners) without reverse cycle and having cooling capacity of 8,000–13,999 Btu/h (DOE Product Class 3).
- Federal standards for Product Class 3:
  - EER ≥ 9.8 (until May 31, 2014)
  - CEER ≥ 10.9 (beginning June 1, 2014)
- Combined Energy Efficiency Ratio (CEER) is a new metric that incorporates energy use in all operating modes, including standby and off modes.
- Of the 538 models in Product Class 3 listed in DOE's CCMS database:
  - 1/3 are at the standard level (9.8 EER)
  - 2/3 are at the ENERGY STAR level (10.8 EER)
  - Most efficient model is at 11.8 EER
- New ENERGY STAR criteria take effect on 10/1/2013: EER ≥ 11.3.
- Most efficient product in 2030: 13.0 EER, based on Building Technologies Program R&D.
- Efficiency improvements are attained by:
  - Higher efficiency compressor and fan motors, and
  - An increased heat transfer area in the evaporator and condenser through the use of larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.

Sales were down in 2009, likely due to the recession and an unusually cool summer in the Northeast. Sales have increased each year since.



Source: *Appliance Magazine.*

South (Hot-Dry and Hot-Humid)

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	13.0	13.5	14.5	24.0	14.5	24.0	14.5	24.0	14.5	24.0
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	1,700	1,700	1,750	1,900	4,550	1,900	4,550	1,900	4,550	1,900	4,550
Total Installed Cost ($)*	2,100	2,100	2,150	2,300	5,100	2,300	5,100	2,300	5,100	2,300	5,100
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22
	130	130	130	130	130	130	130	130	130	130	130

* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs are for "coil-only" systems, meaning they do not include a blower.

North (Rest of Country)

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	13.0	13.0	14.5	24.0	14.0	24.0	14.5	24.0	14.5	24.0
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)*	1,700	1,700	1,700	1,900	4,500	1,800	4,500	1,900	4,500	1,900	4,500
Total Installed Cost ($)*	2,300	2,300	2,300	2,500	5,300	2,400	5,300	2,500	5,300	2,500	5,300
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22
	130	130	130	130	130	130	130	130	130	130	130

* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs are for "coil-only" systems, meaning they do not include a blower.

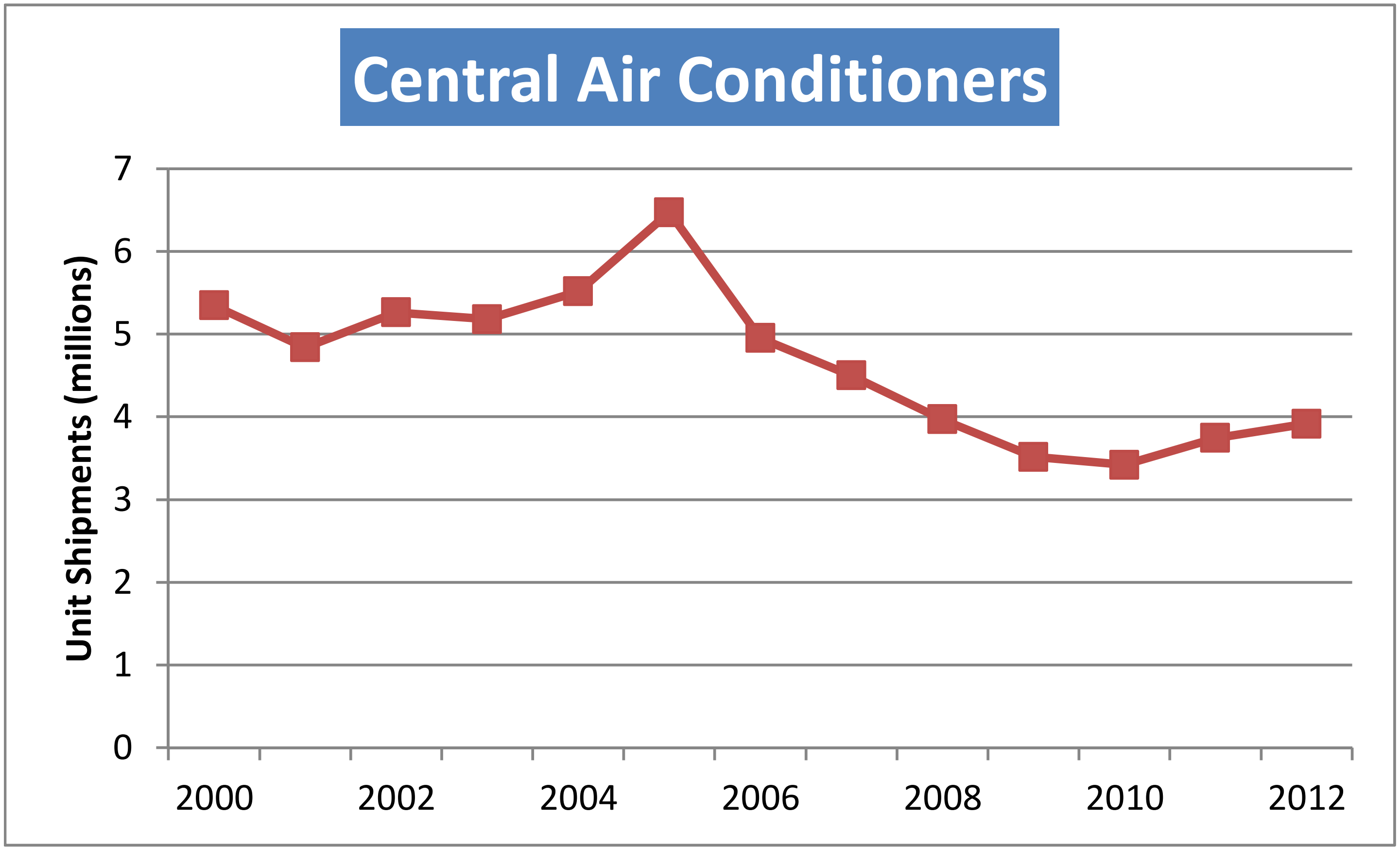
Final

Residential Central Air Conditioners

Residential Central Air Conditioner Product Class	Current Standard	Current ENERGY STAR Criteria		Future Standards (Jan. 1, 2015)		
	Min. SEER	Min. SEER	Min. EER	Min. SEER in North	Min. SEER in South	Max. Off Mode Power (W)
Split-System AC	13	14.5	12	13	14	30
Single-Package AC	13	14	11	14	14	30
Small-Duct, High-Velocity	13	–	–	13	13	30
Space-Constrained	12	–	–	12	12	30

- Current standards, which took effect in 2006, represent a significant improvement in efficiency from 10 SEER for split systems and 9.7 SEER for single-package units.
- Typical new units today are at the standard level of 13 SEER (for most product classes).
- Effective Jan. 1, 2015, the standard for split systems will increase to 14 SEER in the South and the standard for single-package units will increase to 14 SEER nationwide.
- Beginning in 2015, central AC units installed in the Southwest (CA, AZ, NM, and NV) will also have to meet a new energy efficiency ratio (EER) standard that varies by cooling capacity.

Annual shipments spiked at 6.5 million units in 2005 at the peak of the housing boom and just before more stringent Federal standards took effect in 2006.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

Residential Air Source Heat Pumps

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
SEER (Cooling)*	12.0	13.0	14.0	14.5	22.0	14.5	23.0	15.5	24.0	16.0	25.0
HSPF (Heating)*	7	7.7	8.3	8.2	9	8.4	10.8	8.6	10.9	8.7	11
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)*	2,700	2,700	2,850	2,900	4,000	2,900	4,150	3,150	4,250	3,250	4,400
Total Installed Cost ($)*	3,150	3,150	3,300	3,400	4,500	3,400	4,600	3,650	4,750	3,750	4,900
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22
	130	130	130	130	130	130	130	130	130	130	130

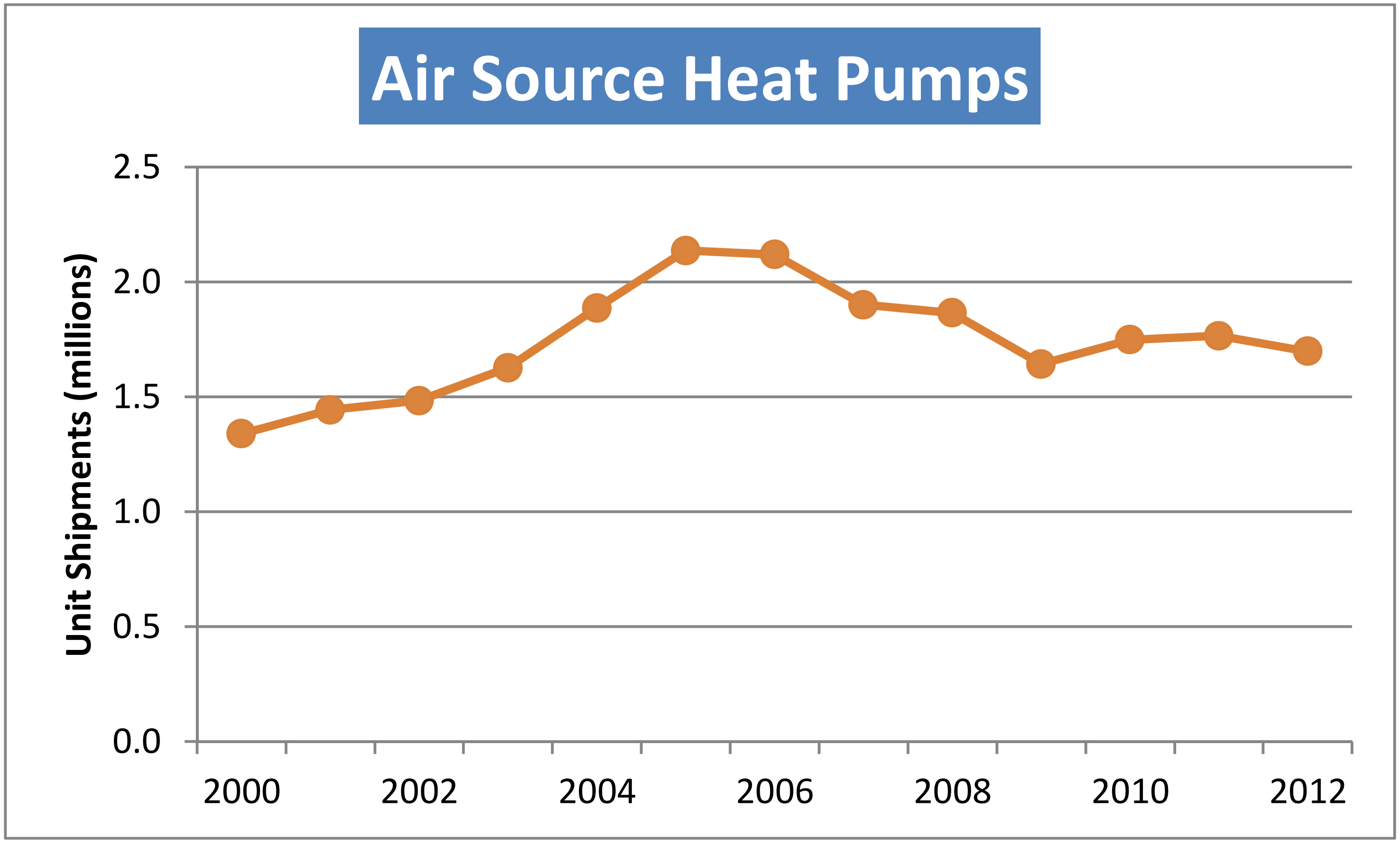
* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. "High" units were selected for maximum cooling, not heating, efficiency.

Residential Air Source Heat Pumps

Residential Heat Pump Product Class	Current Standard		Current ENERGY STAR Criteria			Future Standards (Jan. 1, 2015)		
	Min. SEER	Min. HSPF	Min. SEER	Min. EER	Min. HSPF	Min. SEER	Min. HSPF	Max. Off Mode Power
Split-System	13	7.7	14.5	12	8.2	14	8.2	33 W
Single-Package	13	7.7	14	11	8.0	14	8	33 W
Small-Duct, High-Velocity	13	7.7	–	–	–	13	7.7	30 W
Space-Constrained	12	7.4	–	–	–	12	7.4	33 W

- High efficiency cooling does not necessarily correlate with high efficiency heating. The range of SEER–HSPF combinations is very broad.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, electric resistance heat is used to supplement.
- When the heat pump's heating capacity exceeds the heating load, the heat pump starts and stops more frequently, causing wear and tear on the components and an overall loss of efficiency. Multi-stage and/or variable-speed compressors can help, as does sophisticated refrigerant management.

From 2000 to 2005 annual shipments increased nearly 60% to 2.1 million units, then dropped and leveled off around 1.7 million units.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

- Principal energy efficiency drivers for central air conditioners and heat pumps :
  - Heat exchanger (surface area, number of tube rows)
  - Compressor (type and single-stage vs. two-stage vs. variable-speed operation)
  - Fan motor choices (PSC vs. ECM fan motors on inside and outside)
  - Control choices (i.e., piston, thermal, and electronic expansion valves)
- Typical high-efficiency unit (≥16 SEER) has very large heat exchanger, ECM evaporator fan motor, and two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, making possible high-SEER condensing units with smaller enclosures.
- Efficiency levels >21 SEER made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and electronic expansion valves.

Residential Ground Source Heat Pumps

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
COP (Heating)	3	3.1	3.2	3.6	4.5	3.6	4.9	3.8	5.2	4	5.4
EER (Cooling)	12.3	13.4	14.2	17.1	28	17.1	36	21	42	24	46
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	5,000	3,000	3,000	5,000	7,000	5,000	7,000	5,000	7,000	5,000	7,000
	7,000	5,000	5,000	7,000	9,000	7,000	9,000	7,000	9,000	7,000	9,000
Total Installed Cost ($)	15,000	10,000	10,000	15,000	20,000	15,000	20,000	15,000	20,000	15,000	20,000
	20,000	15,000	15,000	20,000	27,000	20,000	27,000	20,000	27,000	20,000	27,000
Annual Maintenance Cost ($)	75	75	75	75	75	75	75	75	75	75	75

- There are currently over 20 ground source heat pump manufacturers/OEMs in the US.
- Heating COP does not correlate with cooling EER (coefficient of determination, $R^2 = 0.59$ for ENERGY STAR certified products). The highest efficiency GSHP is the 7 Series by WaterFurnace International, Inc. (41 EER & 5.3 COP). Note that these are equipment-level thermal ratings tested according to standardized lab conditions and do not necessarily represent system-level or "real-world" performance.
- The ENERGY STAR® criteria for water-to-air ground source heat pumps are:

Type	Tier 1 (12/1/2009)		Tier 2 (1/1/2011)		Tier 3 (1/1/2012)	
	Heating COP	Cooling EER	Heating COP	Cooling EER	Heating COP	Cooling EER
Closed Loop	3.3	14.1	3.5	16.1	3.6	17.1
Open Loop	3.6	16.2	3.8	18.2	4.1	21.1
Direct Expansion	3.5	15	3.6	16	3.6	16

- The most common ground source heat pump is a closed-loop system in which water or an anti-freeze solution is circulated through plastic pipes buried underground. Open loop systems that employ ground water or surface water (e.g., open well, pond, lake) are used in some parts of the country, but water supply and water quality issues impose limitations on such applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger represents a majority of the installation cost. Installed costs for these systems vary widely.
- Variable speed electronically commutated motors (ECMs) improve performance on high end models.

Residential Gas Heat Pumps

DATA	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	60	60	60	60	60
Heating (COP)	1.3	1.3	1.3	1.3	1.3
Cooling (COP)	0.6	0.6	0.7	0.7	0.7
Annual Electric Use (kWh/yr)	2,000	1,500	1,500	1,500	1,500
Average Life (yrs)	15	15	15	15	15
Retail Equipment Cost ($)	10,500	10,500	10,500	10,500	10,500
	11,700	11,700	11,700	11,700	11,700
Total Installed Cost ($)	12,000	12,000	12,000	12,000	12,000
	14,200	14,200	14,200	14,200	14,200
Annual Maintenance Cost ($)	160	160	160	160	160

NAECA does not cover residential gas heat pumps, but the CEC Title 24, Part 6 Section 112 does indicate minimum cooling efficiency for gas heat pumps.

Residential Gas Heat Pumps

- Residential Gas Heat Pumps are not currently covered by NAECA. CEC Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for gas heat pumps.
- Gas heat pumps are much more popular in Europe and Asia. Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market in the U.S.
- Currently, Robur is the predominant manufacturer of residential-sized gas heat pumps with sales to the US. Robur units are 5-ton cooling capacity, a size typically associated with larger homes. Since only one product is available, no mid-level or high efficiency categories are included.
- The data represents air-source absorption heat pumps. Gas engine-driven vapor compression heat pumps are available in other parts of the world; York formerly offered the Triathlon gas engine-driven heat pump in the US. It is possible to couple either technology to the ground (ground source) rather than the atmosphere (air source).
- The absorption heat pump is a gas-fired, ammonia-water absorption cycle, combined with a high-efficiency low-pressure boiler integrated into one outdoor unit.
- The cooling efficiency of a gas-fired air source absorption heat pump is considerably lower than for an electric air source heat pump. Heating efficiency of an air source heat pump (electric or gas-fired absorption) decreases as outdoor temperature decreases; however the gas-fired absorption heat pump recovers waste heat from the combustion process to improve heating efficiency.

Final

Residential Electric Resistance Furnaces

DATA	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	68	68	68	68	68
AFUE (%)	99	99	99	99	99
Average Life (yrs)	20	20	20	20	20
	30	30	30	30	30
Retail Equipment Cost ($)	600	600	600	600	600
	700	700	700	700	700
Total Installed Cost ($)	1,000	1,000	1,000	1,000	1,000
	1,200	1,200	1,200	1,200	1,200
Annual Maintenance Cost ($)	40	40	40	40	40

Residential Electric Resistance Furnaces

- This analysis examined non-weatherized (installed indoors) electric resistance central warm-air furnaces.
- There are currently no federal requirements on electric resistance furnaces. ASHRAE 90.1-2010 unit heater requirements only capture gas and oil-fired units.
- According to RECS 2009 data, electric central warm-air furnaces are the main source of space heating in approximately 19.1 million US homes or about 17%.
- Electric furnaces range in capacity from 10 to 25 kW (34 to 85 kBtu/hr), with 20 kW (68 kBtu/hr) being the typical for units on the market.
- Electric resistance furnaces are considered near 100% efficient because there is no flue heat loss and any jacket losses are contained within the home. For this analysis, the efficiency is 99% to account for IR losses. Furnace fans or blowers have no impact on AFUE measurements.

Final

Residential Electric Resistance Unit Heaters

DATA	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBTU/h)	3.5	3.5	3.5	3.5	3.5
Efficiency (%)	0.98	0.98	0.98	0.98	0.98
Average Life (yrs)	18	18	18	18	18
Retail Equipment Cost ($)	75	75	75	75	75
	200	200	200	200	200
Total Installed Cost ($)	125	125	125	125	125
	275	275	275	275	275
Annual Maintenance Cost ($)*	-	-	-	-	-

* Annual Maintenance Cost is negligible

Residential Electric Resistance Unit Heaters

- This analysis examined electric wall and baseboard heaters. Plug-in space heaters are considered plug loads and, therefore, not included.
- There are currently no federal requirements on electric resistance unit heaters. ASHRAE 90.1-2010 unit heater requirements only capture gas and oil-fired units.
- According to RECS 2009 data, electric resistance unit heaters are the main source of space heating in approximately 5.7 million US homes or about 5%.
- Electric heaters range in capacity from 500 to 2,500 watts (1.7 to 8.5 kBtu/hr), with 1,000 watts (3.5 kBtu/hr) being the most typical for units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion. For this analysis, the efficiency is 98% to account for IR losses and fan inefficiency.

Residential Cordwood Stoves

DATA	2009	2013			2020		2030		2040	
	Installed Base	EPA Certified (Default)	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (Non-Catalytic) (HHV)	58	63	63	74	70	77	73	78	74	79
Efficiency (Catalytic) (HHV)	68	72	72	81	78	84	81	85	82	86
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($) (Non-Catalytic)	2,400	2,400	2,400	3,200	2,600	3,400	2,800	3,600	3,000	3,800
Retail Equipment Cost ($) (Catalytic)	3,300	3,300	3,300	4,100	3,500	4,300	3,700	4,500	3,700	4,700
Total Installed Cost ($) (Non-Catalytic)	7,000	7,000	7,000	7,800	7,200	8,000	7,400	8,200	7,400	8,400
Total Installed Cost ($) (Catalytic)	7,900	7,900	7,500	8,700	8,100	8,900	8,300	9,100	8,500	9,300
Annual Maintenance Cost ($) (Non Catalytic)	150	150	150	150	150	150	150	150	150	150
Annual Maintenance Cost ($) (Catalytic)	225	225	225	225	225	225	225	225	225	225

*Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
**Installed cost includes cost of hearth and stainless steel chimney liner - materials and labor.
***Annual maintenance cost of catalytic stove includes periodic cost of replacing the catalytic combustor.

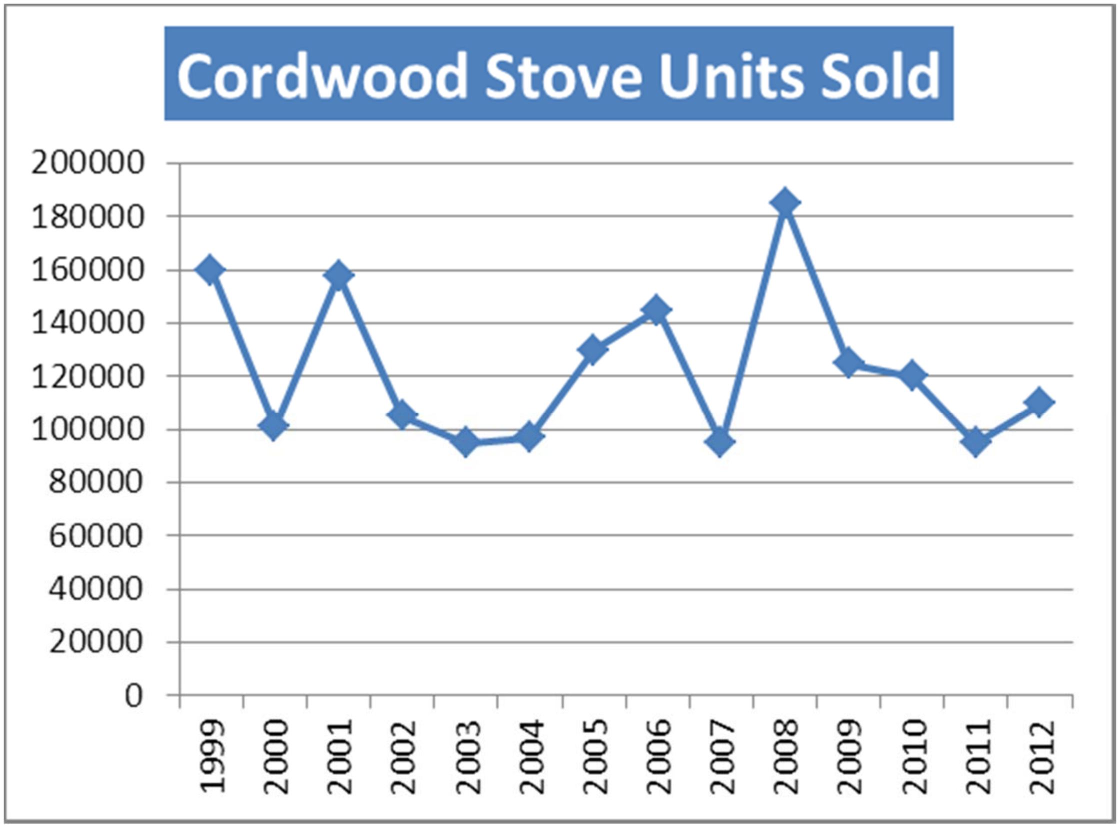
Residential Cordwood Stoves

- Residential cordwood stoves that must meet EPA particulate limits fall into two broad classes based on whether or not they use a catalyst for air treatment. Catalytic wood stoves use a catalytic combustor to reduce emissions from the combustion air. Non-catalytic wood stoves use baffles and introduce secondary air above the flames for more complete combustion to help reduce emissions.
- There are no efficiency standards for wood stoves. EPA publishes a list of stoves that have met emission limits for particulates and includes default efficiencies by type (non-catalytic and catalytic wood stoves). The emission limits are 7.5 grams/hr. for EPA certified non-catalytic wood stoves and 4.1 grams/hr. for catalytic wood stoves.
- The EPA default efficiencies are 63% for certified non-catalytic wood stoves and 72% for catalytic wood stoves. Manufacturers may submit efficiency data from laboratory testing to EPA, to include with the default values, but very few have done so.
- Data from product literature does not generally identify the efficiency test method. It's not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies.

Residential Cordwood Stoves

- Some states have instituted tighter emission standards along with minimum efficiency requirements (e.g., Oregon).
- EPA is considering updates to its New Source Performance Standards (NSPS) which would tighten the emissions limits and may include minimum efficiency requirements. However, the timing remains uncertain.
- Cordwood stoves require chimneys for venting combustion gases. Whether conventional masonry chimneys are used or metal chimney liners, these add considerable cost to the overall system. Installed costs can be double that of the wood stove itself.

Cordwood stove shipments have averaged 123,000 per year since 1999, and have rebounded somewhat since 2011.



Source: HPBA

Final

Residential Wood Pellet Stoves

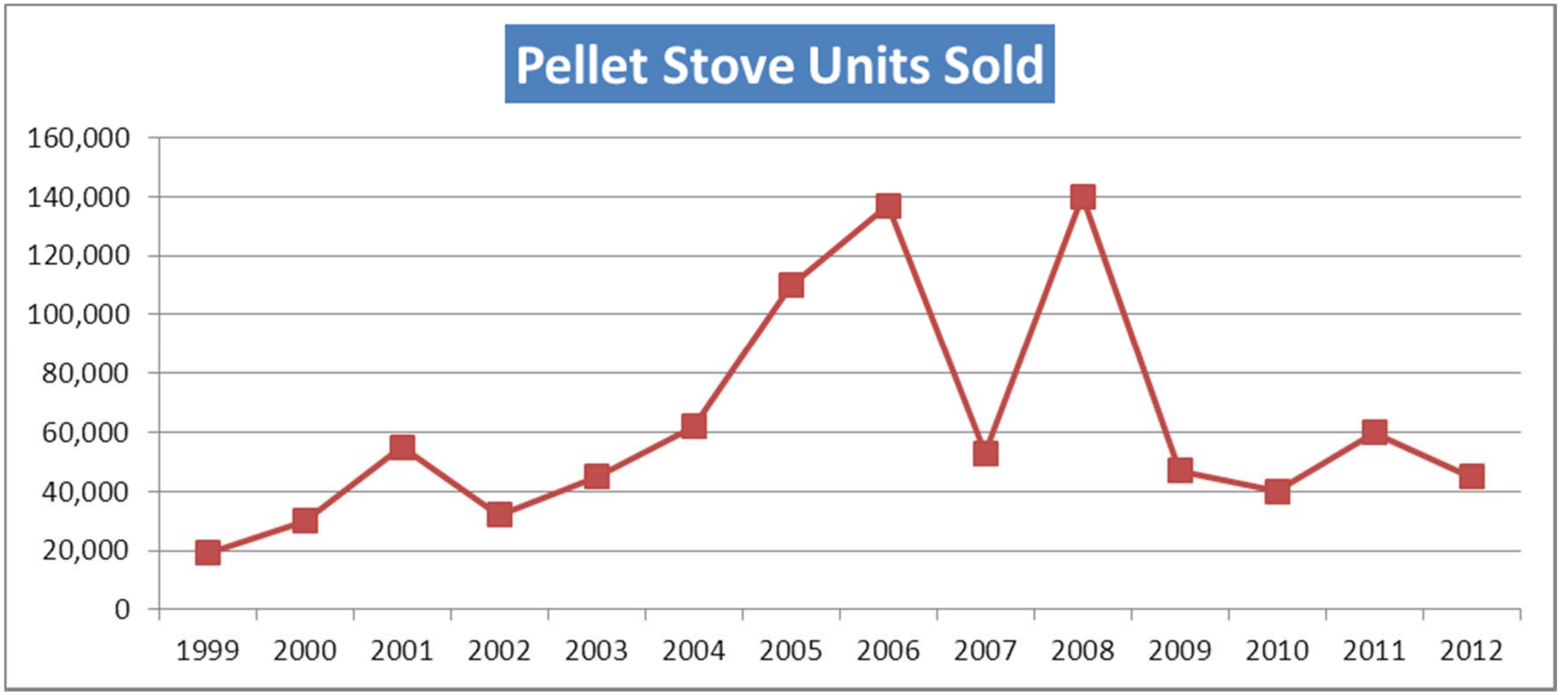
DATA	2009	2013			2020		2030		2040	
	Installed Base	EPA Certified (Default)	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)	65	78	78	81	81	84	83	86	84	87
Annual Electricity Consumption (kWh)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	3,300	3,300	3,300	4,200	3,500	4,400	3,700	4,600	3,900	4,800
Total Installed Cost ($)	4,700	4,700	4,700	5,600	4,900	5,800	5,100	6,000	5,300	6,200
Annual Maintenance Cost ($)	250	250	250	250	250	250	250	250	250	250

*Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
**Electricity consumption is for combustion air fan, distribution blower, and pellet feeder.
***Installed cost includes cost of hearth and vent pipe - materials and labor.

Residential Wood Pellet Stoves

- There are no efficiency standards for wood pellet stoves and they are not required to be certified by EPA. However, manufacturers that wish to be certified must meet an emission limit of 2.5 grams/hr.
- The EPA default efficiency for wood pellet stoves is 72%. Manufacturers may submit efficiency data from laboratory testing to EPA, to include with the default values, but very few have done so.
- Data from product literature does not generally identify the efficiency test method
- Some states have instituted tighter emission standards along with minimum efficiency requirements (e.g., Oregon).
- EPA is considering updates to its New Source Performance Standards (NSPS) which would tighten the emissions limits and may include minimum efficiency requirements. However, the timing remains uncertain.
- Wood pellet stoves may be able to be direct vented to the outdoors, eliminating the need for a chimney. This reduces the overall system cost as compared to a cord wood stove. However, they do use electricity to power the pellet feeder, the combustion air fan, and the blower. In the event of a power outage, a pellet stove can not operate without some back-up source of electricity (e.g., battery) .

Wood pellet stove shipments grew substantially in the 2005 – 2008 time period, but have averaged only 40,000 – 60,000 units since that time.



Source: HPBA

Top-Mount (Product Class 3)

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/yr)**	586	482	407	385	311	403	311	385	311	385	311
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	550	530	570	620	880	570	880	620	880	620	880
Total Installed Cost ($)	550	530	570	620	880	570	880	620	880	620	880
Annual Maintenance Cost ($)	9	9	9	9	9	9	9	9	9	9	9

* The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 21 ft^3.

Bottom-Mount (Product Class 5)

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	21	21	21	21	21	21	21	21	21	21	21
Energy Consumption (kWh/yr)**	574	574	540	459	457	538	457	459	457	459	457
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	935	930	940	980	980	940	980	980	980	980	980
Total Installed Cost ($)	935	930	940	980	980	940	980	980	980	980	980
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22

* The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 25 ft3.

Side-Mount (Product Class 7)

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	26	26	26	26	26	26	26	26	26	26	26
Energy Consumption (kWh/yr)**	889	729	596	583	509	596	509	583	509	583	509
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	1,150	1,130	1,170	1,180	1,380	1,170	1,380	1,180	1,380	1,180	1,380
Total Installed Cost ($)	1,150	1,130	1,170	1,180	1,380	1,170	1,380	1,180	1,380	1,180	1,380
Annual Maintenance Cost ($)	24	24	24	24	24	24	24	24	24	24	24

* The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 32 ft3.

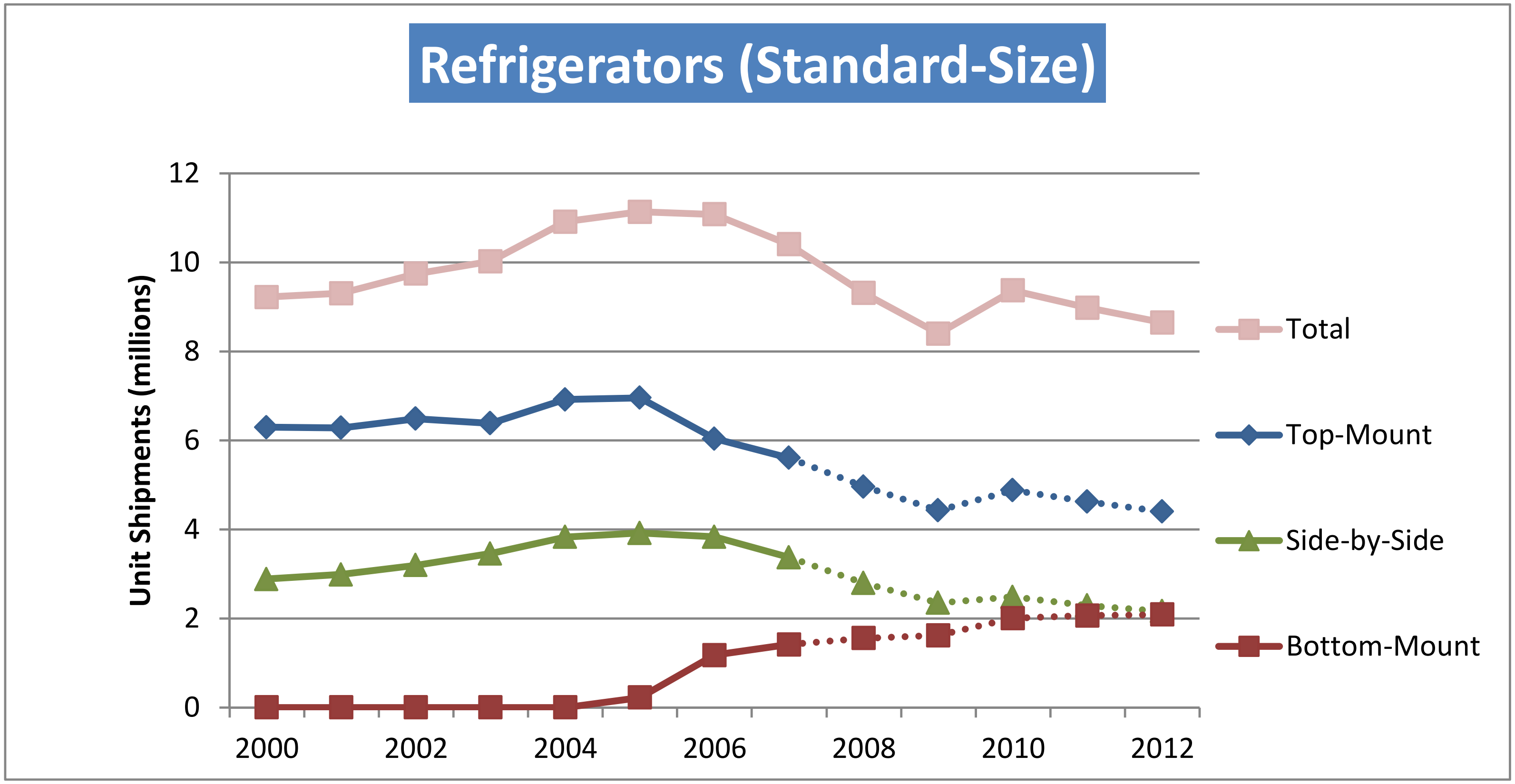
Final

Residential Refrigerator-Freezers

- Current Federal standards:
  - Compliance required beginning July 1, 2001
  - Models divided into 12 product classes based on size (standard or compact), location of freezer (top, bottom, or side), type of defrost (automatic or manual), and presence of through-the-door ice
  - Limits on annual electricity consumption expressed as functions of adjusted volume[1]
- ENERGY STAR criteria limit annual electricity consumption to 20% less than the Federal standard.
- More stringent Federal standards:
  - Compliance required beginning September 15, 2014
  - New product classes for built-in units
  - Amount by which standards are tightened varies by product class
- Current analysis focuses on the three representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Better gasketing
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating

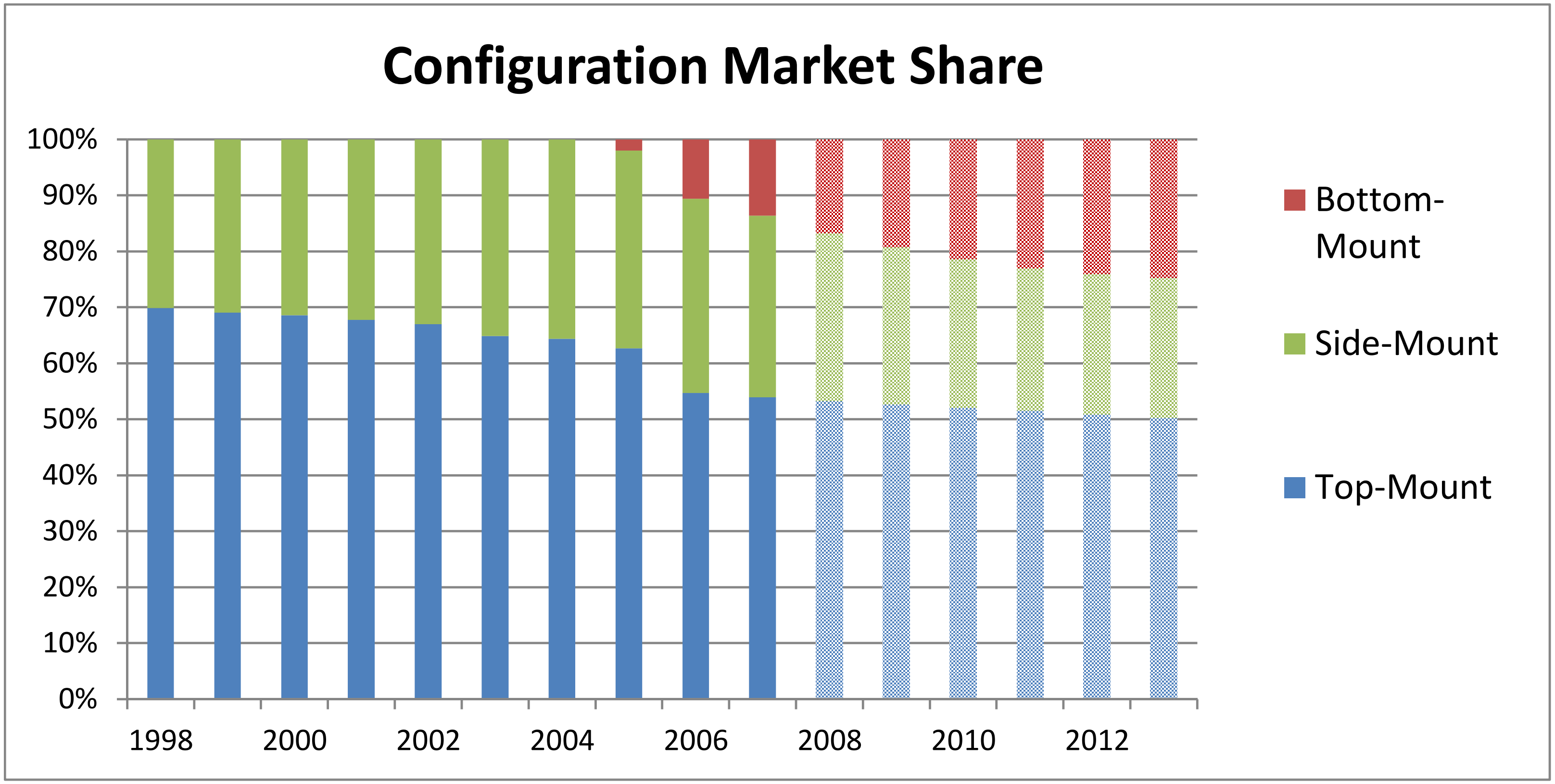
[1]Adjusted Volume (AV) = (Fresh Volume) + 1.63 × (Freezer Volume). Beginning in 2004, the 1.63 coefficient will change to 1.76.

Annual shipment volumes declined 25% from 2006 to 2009, rebounded slightly in 2010, then declined again to 8.6 million units in 2012.



Source: *Appliance Magazine*; data provided by AHAM and Navigant analysis for configuration shares.

Bottom-mount units likely have captured somewhere between 15 and 35 percent of the market, based on shipment-weighted data through 2007, DOE analysis, and counts of currently available models.



Sources: AHAM data; August 2011 Refrigerator Final Rule TSD; Navigant analysis.

Upright Freezers (Product Class 9)

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	17	17	17	17	17	17	17	17	17	17	17
Energy Consumption (kWh/yr)**	775	687	642	618	615	487	487	487	487	487	487
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost ($)	550	550	555	560	560	660	660	660	660	660	660
Total Installed Cost ($)	550	550	555	560	560	660	660	660	660	660	660
Annual Maintenance Cost ($)	5	5	5	5	5	5	5	5	5	5	5

* The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 29 ft^3 (30 ft^3 beginning in 2014).

Chest Freezers (Product Class 10)

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	17	17	17	17	17	17	17	17	17	17	17
Energy Consumption (kWh/yr)**	430	401	370	361	354	327	327	327	327	327	327
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost ($)	400	400	405	410	410	425	425	425	425	425	425
Total Installed Cost ($)	400	400	405	410	410	425	425	425	425	425	425
Annual Maintenance Cost ($)	3	3	3	3	3	3	3	3	3	3	3

* The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 26 ft^3 (30 ft^3 beginning in 2014).

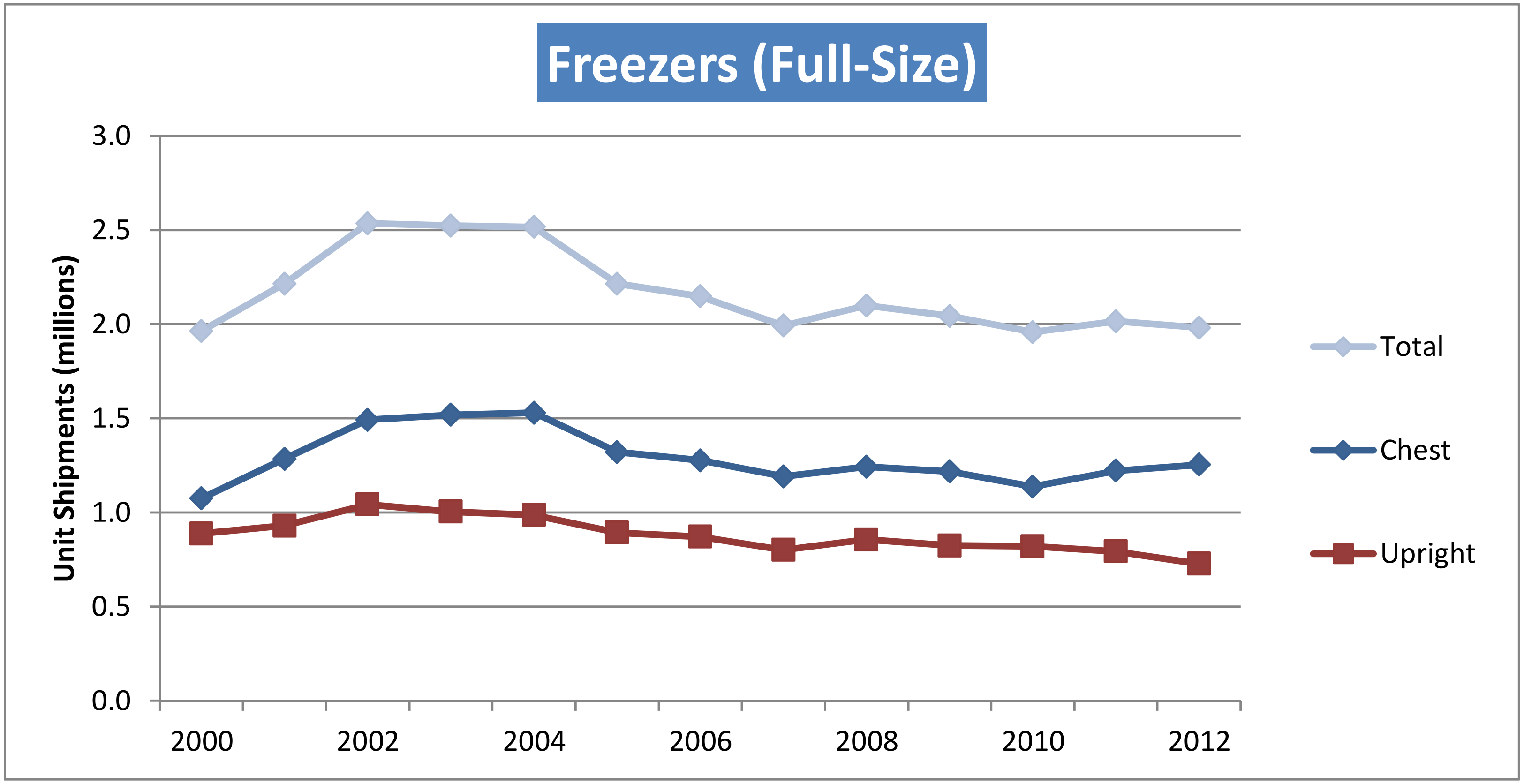
Final

Residential Freezers

- Current Federal standards:
  - Compliance required beginning July 1, 2001
  - Models divided into 6 product classes based on size (standard or compact), orientation (chest or upright), and type of defrost (automatic or manual).
  - Limits on annual electricity consumption expressed as functions of adjusted volume[1]
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard.
- More stringent Federal standards:
  - Compliance required beginning September 15, 2014
  - New product classes for built-in freezers and freezers with an automatic icemaker
  - Amount by which standards are tightened varies by product class
- Current analysis focuses on the two representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Better gasketing
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating
  - Use of forced convection condenser (for upright freezers)

[1]Adjusted Volume (AV) = (Fresh Volume) + 1.63 × (Freezer Volume). Beginning in 2004, the 1.63 coefficient will change to 1.76.

Shipment volumes have held steady since 2007 at about 2 million units per year. Chest freezers represent about 60% of the market .



Source: *Appliance Magazine.*

Final

Residential Natural Gas Cooktops and Stoves

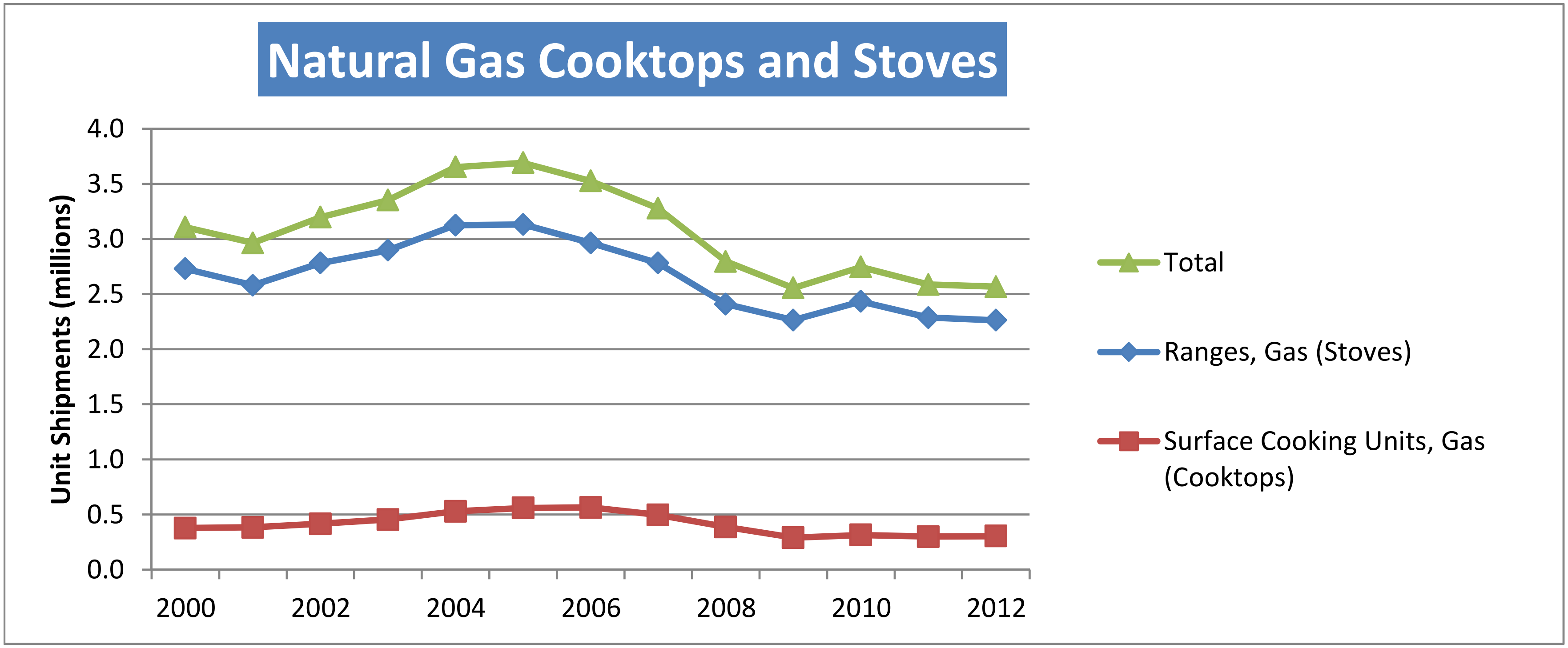
DATA	2009	2013		2020		2030		2040	
	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9
	12	12	12	12	12	12	12	12	12
Cooking Efficiency (%)	38.5	39.9	42	39.9	42	39.9	42	39.9	42
Average Life (yrs)	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)*	225	250	300	250	300	250	300	250	300
	300	350	400	350	400	350	400	350	400
Total Installed Cost ($)*	275	300	350	300	350	300	350	300	350
	350	400	450	400	450	400	450	400	450
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-

* Equipment and installed costs are for stand-alone cooktops only (not stoves).
** Maintenance costs are negligible.

Residential Natural Gas Cooktops and Stoves

- Since January 1, 1990, gas cooking products *with* an electrical supply cord have been required to not be equipped with a constant burning pilot light. This requirement extended to gas cooking products *without* an electrical supply cord, as of April 9, 2012.
- Little variation in cooking efficiency among gas cooktops and stoves (or "ranges").
- DOE final rule published in 2009: no standard for cooking efficiency is cost-justified.

Shipments are down from their peak in 2005 and appear to have leveled off in the past five years.



Note: Excludes separate ovens, which were categorized as "built-in" units prior to 2007.
Source: *Appliance Magazine.*

Residential Clothes Washers – Front-Loading

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.09	3.00	3.90	3.00	5.20	3.90	5.20	3.90	5.20	3.90	5.20
Modified Energy Factor (ft3/kWh/cycle)	2.07	1.26	3.09	2.00	3.45	3.09	3.45	3.09	3.45	3.09	3.45
Water Factor (gal/cycle/ft^3)	6.2	9.5	3.1	6.0	3.0	3.1	3.0	3.1	3.0	3.1	3.0
Average Life (yrs)	7	7	7	7	7	7	7	7	7	7	7
	14	14	14	14	14	14	14	14	14	14	14
Water Consumption (gal/cycle)	19	29	12	18	15	12	15	12	15	12	15
Hot Water Energy (kWh/cycle)	0.32	0.82	0.16	0.29	0.27	0.16	0.27	0.16	0.27	0.16	0.27
Machine Energy (kWh/cycle)	0.15	0.2	0.12	0.15	0.11	0.12	0.11	0.12	0.11	0.12	0.11
Dryer Energy (kWh/cycle)	1.02	1.37	0.99	1.03	1.13	0.99	1.13	0.99	1.13	0.99	1.13
Retail Equipment Cost ($)	550	550	900	800	1,200	900	1,200	900	1,200	900	1,200
	700	700	1,000	900	1,500	1,000	1,500	1,000	1,500	1,000	1,500
Total Installed Cost ($)	650	650	1,000	900	1,300	1,000	1,300	1,000	1,300	1,000	1,300
	800	800	1,100	1,000	1,600	1,100	1,600	1,100	1,600	1,100	1,600
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Maintenance costs are negligible.

Final

Residential Clothes Washers – Top-Loading

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.0	3.2	3.5	3.6	4.8	3.6	4.8	3.6	4.8	3.6	4.8
Modified Energy Factor (ft3/kWh/cycle)	1.20	1.26	1.40	2.00	2.87	2.00	2.87	2.00	2.87	2.00	2.87
Water Factor (gal/cycle/ft^3)	12.0	9.5	8.5	6.0	3.65	6.0	3.65	6.0	3.65	6.0	3.65
Average Life (yrs)	7	7	7	7	7	7	7	7	7	7	7
	14	14	14	14	14	14	14	14	14	14	14
Water Consumption (gal/cycle)	36	30	30	22	18	22	18	22	18	22	18
Hot Water Energy (kWh/cycle)	0.91	0.87	0.64	0.51	0.39	0.51	0.39	0.51	0.39	0.51	0.39
Machine Energy (kWh/cycle)	0.28	0.28	0.28	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Dryer Energy (kWh/cycle)	1.31	1.39	1.58	1.21	1.20	1.21	1.20	1.21	1.20	1.21	1.20
Retail Equipment Cost ($)	550	350	450	550	850	550	850	550	850	550	850
	700	450	550	650	950	650	950	650	950	650	950
Total Installed Cost ($)	650	450	550	650	950	650	950	650	950	650	950
	800	550	650	750	1,050	750	1,050	750	1,050	750	1,050
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Maintenance costs are negligible.

Final

Residential Clothes Washers

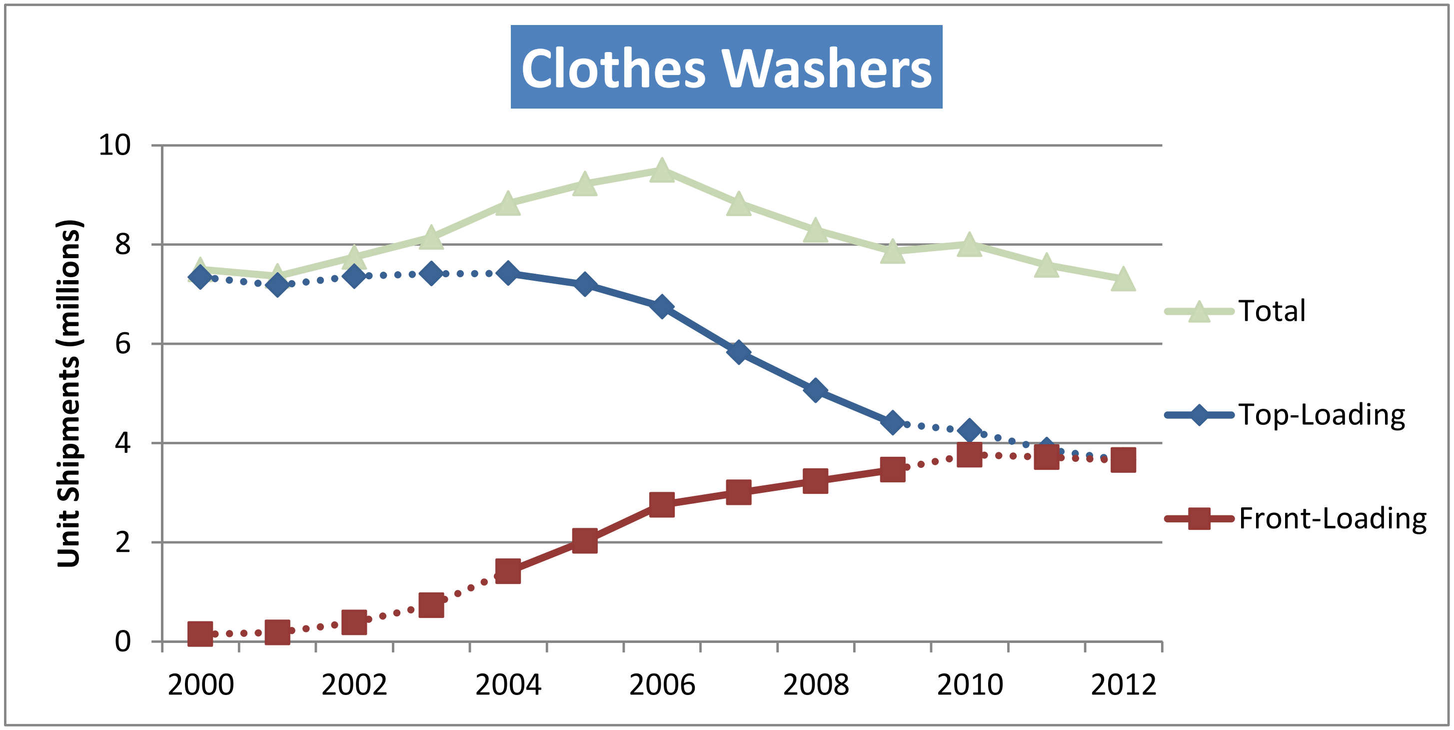
- Present analysis treats front- and top-loading models separately. Past analyses did not consider the two types separately.
- Federal standards for standard-capacity clothes washers (≥ 1.6 cubic feet):

	Modified Energy Factor		Water Factor	
	Top-Loading	Front-Loading	Top-Loading	Front-Loading
Current DOE Standard	≥ 1.26 (effective 1/1/2007)		≤ 9.5 (effective 1/1/2011)	
Current ENERGY STAR	≥ 2.00		≤ 6.0	
	Integrated Modified Energy Factor[1]		**Integrated Water Factor[2]**	
March 7, 2015	≥ 1.29	≥ 1.84	≤ 8.4	≤ 4.7
January 1, 2018	≥ 1.57	≥ 1.84 (no change)	≤ 6.5	≤ 4.7 (no change)

1. IMEF differs from MEF as follows: (a) includes standby power energy; (b) smaller capacity measurement for top-loaders; (c) higher drying energy estimate; and (d) additional wash cycles required for testing.
2. IWF differs from WF as follows: WF incorporates water usage from cold water cycles only while IWF incorporates water usage from all wash temperatures.

- Most front-loading models on the market today surpass the ENERGY STAR levels by a comfortable margin; typical new front-loading unit has MEF = 3.09 and WF = 3.1
- Energy efficiency improvement opportunities include:
  - Higher efficiency motors and higher spin speeds
  - Better load sensing for adaptive water fill control
  - Reduced water temperature and quantity, while providing equivalent cleaning and rinsing performance

Shipment volumes have returned to pre-housing boom levels. Front-loaders' market share grew from 5% to about 50% in 10 years.



Source: *Appliance Magazine* and Residential Clothes Washer Direct Final Rule TSD, EERE, April 2012.

Electric

DATA	2009	2013			2020		2030		2040	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7
EF (lb/kWh)*	3.01	3.01	3.10	3.16	*3.10*	*4.51*	*3.16*	*4.51*	*3.16*	*4.51*
CEF (lb/kWh)*	*3.55*	*3.55*	*3.73*	*3.81*	3.73	5.42	3.81	5.42	3.81	5.42
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8
	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	400	400	450	500	450	650	500	650	500	650
	500	500	550	600	550	750	600	750	600	750
Total Installed Cost ($)	510	510	560	610	560	780	610	780	610	780
	610	610	660	710	660	880	710	880	710	880
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-

not strictly comparable, but both values are shown here to facilitate longitudinal analyses.

** Maintenance costs are negligible.

Natural Gas

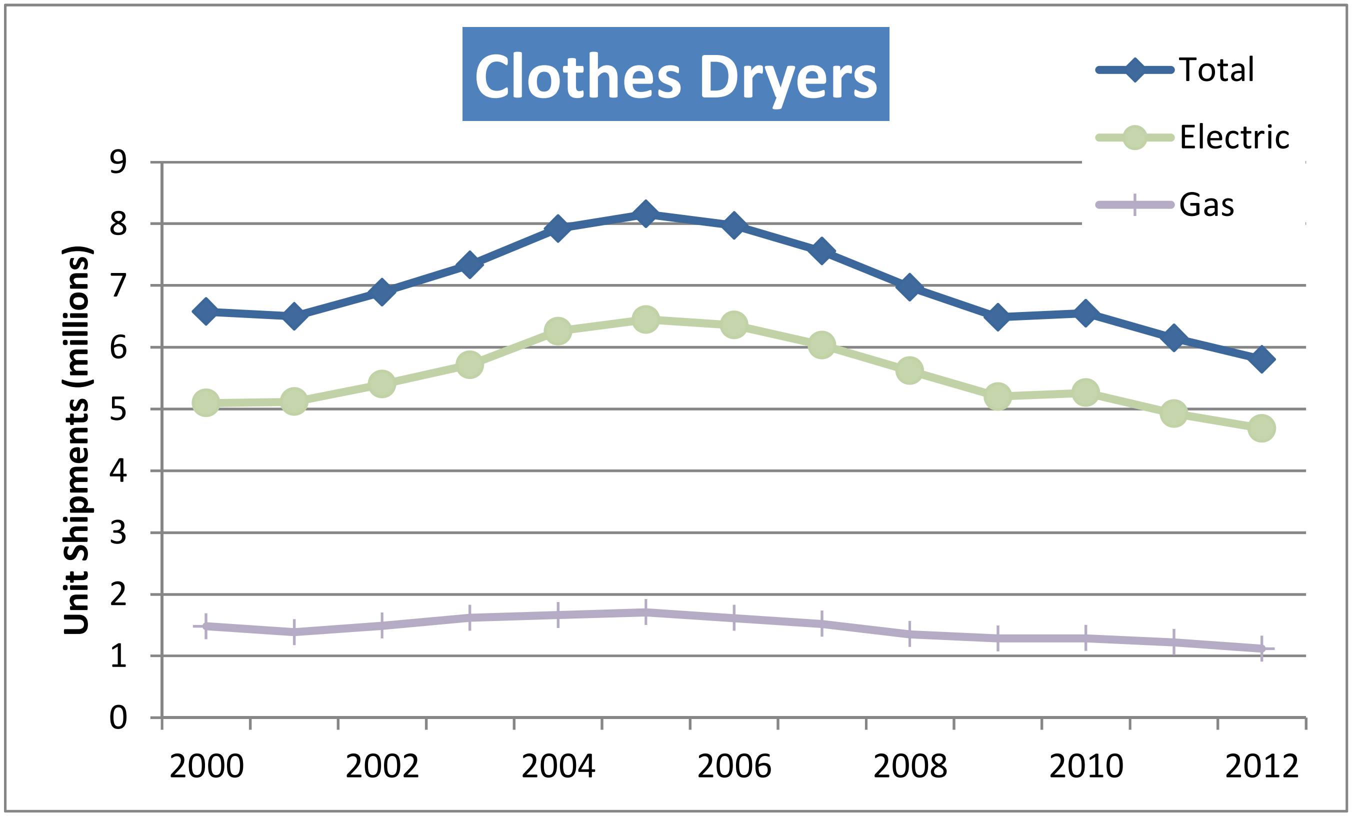
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7
EF (lb/kWh)*	2.67	2.67	2.75	2.85	3.02	*2.81*	*3.02*	*2.81*	*3.02*	*2.81*	*3.02*
CEF (lb/kWh)*	*3.14*	*3.14*	*3.24*	*3.35*	*3.61*	3.30	3.61	3.30	3.61	3.30	3.61
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8
	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	450	400	425	450	550	400	550	400	550	400	550
	550	450	475	550	650	500	650	500	650	500	650
Total Installed Cost ($)	610	560	585	610	710	560	710	560	710	560	710
	710	610	635	710	810	660	810	660	810	660	810
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-

* Italicized values are estimated. The federal standard is expressed in EF, but will be expressed in CEF beginning in 2015. The two metrics are not strictly comparable, but both values are shown here to facilitate longitudinal analyses.
** Maintenance costs are negligible.

Residential Clothes Dryers

- Current standards in effect since 1994:
  - For standard-size electric units : EF ≥ 3.01 lb/kWh
  - For gas units: EF ≥ 2.67 lb/kWh
- New standards announced in April 2011 with compliance date of Jan. 1, 2015. Efficiency metric will change from energy factor (EF) to combined energy factor (CEF), which incorporates standby mode power consumption:
  - For standard-size vented electric units : CEF ≥ 3.73 lb/kWh (≅3.17 EF)
  - For vented gas units: CEF ≥ 3.30 lb/kWh (≅2.81 EF)
- Remaining efficiency improvement opportunities include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Better control systems for cycle termination (not reflected per the current test procedure, however)
  - Heat pump (for electric clothes dryers)
- Heat pump clothes dryers with EF around 4.5 currently available in Europe. High initial cost and potential reliability issues have kept them out of the U.S. market, but anticipated to arrive by 2020.
- In 2012, EPA announced the Emerging Technology Award for Clothes Dryers, which would be awarded to a manufacturer that introduces a high-efficiency clothes dryer to the U.S. market.

Shipment volumes are now slightly below pre-housing boom levels. Gas dryers continue to account for about one-fifth of the market.



Source: *Appliance Magazine.*

Final

Residential Dishwashers

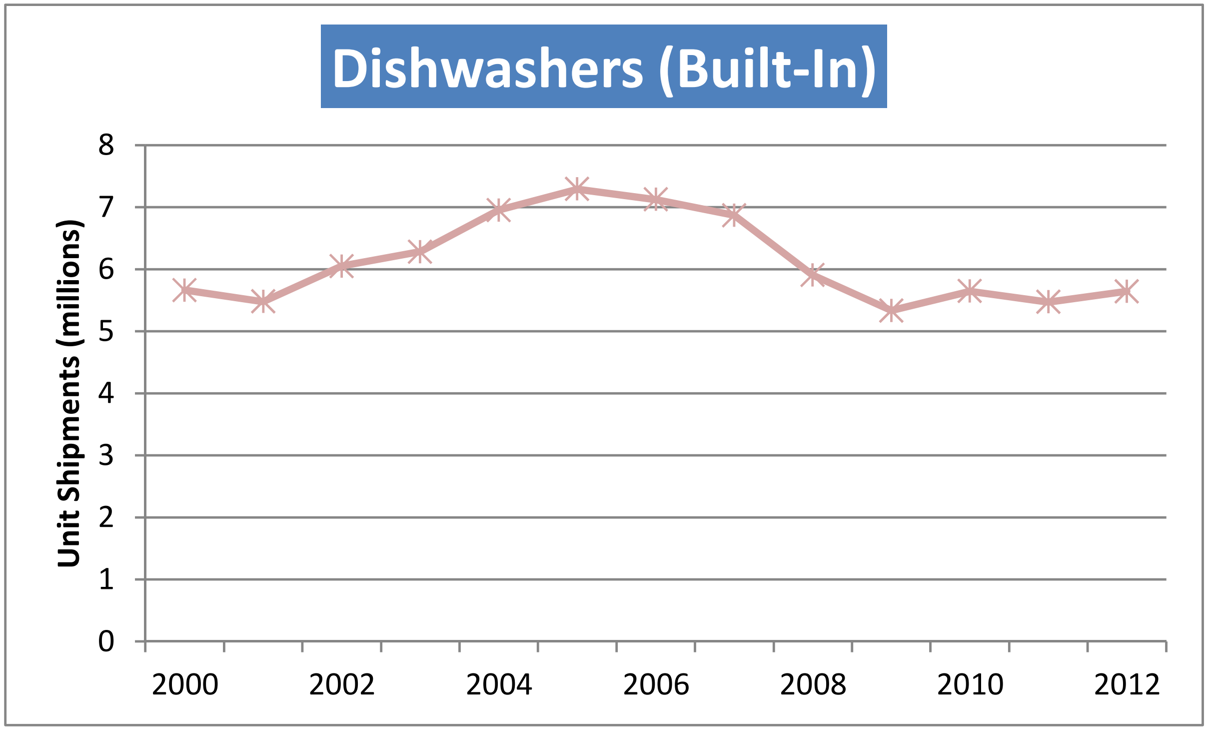
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/yr)	312	307	295	295	180	295	180	295	180	295	180
Water Consumption (gal/cycle)	4.50	5.00	4.25	4.25	2.22	4.25	2.22	4.25	2.22	4.25	2.22
Water Heating Energy Use (kWh/yr)*	163	181	153	153	80	153	80	153	80	153	80
Average Life (yrs)	14	14	14	14	14	14	14	14	14	14	14
	24	24	24	24	24	24	24	24	24	24	24
Retail Equipment Cost ($)	390	395	450	450	470	450	470	450	470	450	470
Total Installed Cost ($)	710	715	770	770	790	770	790	770	790	770	790
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-

* Refers to that portion of "Typical Annual Energy Use" that is the energy used to heat water in a separate water heater before it enters the dishwasher. The energy used to heat water inside the dishwasher cannot be disaggregated from the total.
** Maintenance costs are negligible.

Residential Dishwashers

- Performance criteria for standard-capacity dishwashers (assumes 215 cycles/year):
  - Federal Standards:
    - Jan. 1, 2010: ≤ **355** kWh/yr, ≤ **6.5** gal/cycle (EISA 2007)
    - May 30, 2013: ≤ **307** kWh/yr, ≤ **5.0** gal/cycle (DOE Direct Final Rule, published May 2012)
  - ENERGY STAR Criteria:
    - Aug. 11, 2009 : ≤ **324** kWh/yr, ≤ **5.8** gal/cycle (version 4.0, announced Nov. 2008)
    - Jan. 20, 2012: ≤ **295** kWh/yr, ≤ **4.25** gal/cycle (version 5.0, announced April 2011)
- ENERGY STAR has maintained a very high market share for several years, so sales-weighted-average efficiency has tracked ENERGY STAR levels.
- Test procedures:
  - Accounts for motor, dryer, booster heater (if present), and hot water from separate water heater
  - Amended test procedure, enters into force May 30, 2013, includes standby and off-mode energy
  - Cleaning performance test method expected to be part of future ENERGY STAR requirements
- Efficiency improvement opportunities include:
  - Better soil sensing in the water, the filter, and the controls to make use of that
  - Water distribution (small pipes, fine filter, small sump, alternating water use)
  - Inline water heater (to minimize sump volume)
  - High-efficiency, variable-speed pump motor
  - Vent assembly to help drying of dishes

Shipments peaked in 2005 during the housing boom then declined and appear to have leveled off at between 5 and 6 million units per year.



Source: *Appliance Magazine*

Commercial Gas-Fired Furnaces

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400	400	400	400	400
Thermal Efficiency (%)*	76	80	80	80	90	80	90	80	90	80	90
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	1,920	2,370	2,910	2,910	3,590	2,910	3,590	2,910	3,590	2,910	3,590
	2,130	2,580	3,120	3,120	3,900	3,120	3,900	3,120	3,900	3,120	3,900
Total Installed Cost ($)	2,300	2,750	3,290	3,290	3,970	3,290	3,970	3,290	3,970	3,290	3,970
	2,510	2,960	3,500	3,500	4,280	3,500	4,280	3,500	4,280	3,500	4,280
Annual Maintenance Cost ($)	320	320	320	320	930	320	930	320	930	320	930

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Commercial Gas-Fired Furnaces

- Current Federal standard requires minimum 80% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- The Federal standard applies to all units manufactured on or after January 1, 1994 with maximum rated heat input ≥ 225,000 Btu per hour.
- Commercial furnace efficiency ranges are as wide as those for residential, and the technology options are similar (though usually scaled up).
- Besides scale, commercial units can differ in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies) and they may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Final

Commercial Oil-Fired Furnaces

DATA	2003	2012	2013		2020	2030	2040
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400
Thermal Efficiency (%)*	81	81	81	82	82	82	82
Average Life (yrs)	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3,200	3,400	4,000	4,000	4,000	4,000	4,000
	3,800	3,900	4,200	4,200	4,200	4,200	4,200
Total Installed Cost ($)	3,800	3,800	4,380	4,380	4,380	4,380	4,380
	4,400	4,400	4,580	4,580	4,580	4,580	4,580
Annual Maintenance ($)	320	320	320	320	320	320	320

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Commercial Oil-Fired Furnaces

- Current Federal standard requires minimum 81% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
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- Commercial furnace efficiency ranges are as wide as those for residential, and the technology options are similar (though usually scaled up).
- Besides scale, commercial units can differ in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies) and they may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Commercial Electric Boilers

DATA	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (kW)*	165	165	165	165	165	165
Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($)	$6,400	$7,000	$7,000	$7,000	$7,000	$7,000
	$7,500	$7,800	$7,800	$7,800	$7,800	$7,800
Total Installed Cost ($)	$8,000	$10,500	$10,500	$10,500	$10,500	$10,500
	$9,600	$11,800	$11,800	$11,800	$11,800	$11,800
Annual Maintenance Cost ($)	110	110	110	110	110	110
	160	160	160	160	160	160

* Capacity is *output*

Commercial Electric Boilers

- There are currently no federal standards associated with electric boilers.
- The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/hr.
- Service life is determined mainly by water quality. Water conditioning (e.g., filters, softeners, de-alkizers, chemical feeders) may be necessary for a given application.
- Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.
- Minor end-use inefficiencies for electric boilers result from heat loss through the boiler (jacket losses).

Final

Commercial Gas-Fired Boilers

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard*	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)**	76	77	80	80	85	98	82	98	83	98	83	98
Average Life (yrs)	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)***	10,650	11,350	13,050	13,050	15,900	18,150	14,200	18,150	14,750	18,150	14,750	18,150
	12,750	13,400	15,100	15,100	18,000	20,200	16,250	20,200	16,800	20,200	16,800	20,200
Total Installed Cost ($)	17,850	18,550	20,250	20,250	23,100	25,350	21,400	25,350	21,950	25,350	21,950	25,350
	19,950	20,600	22,300	22,300	25,200	27,400	23,450	27,400	24,000	27,400	24,000	27,400
Annual Maintenance Cost ($)	480	480	480	480	480	480	480	480	480	480	480	480

* The standard level shown here is for small hot water boilers, the most common type of boiler.
** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.
*** Installed Base costs have been adjusted to reflect the cost of two 427 kBtu/h boilers rather than one, as was reported in prior editions.

Commercial Gas-Fired Boilers

- Commercial packaged gas-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
  - Draft type (natural draft or not)
- Most common type is small hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Federal standards require thermal efficiency ≥ 77%, 79%, or 80%, depending on type.
- Exception is large hot water boilers, which must have *combustion* efficiency ≥ 82%.
- Similar technologies to the those used in the residential market can be leveraged in the commercial arena. The higher efficiency units typically include electronic ignition, power burners, and improved heat exchangers. They may even condense and/or pre-heat incoming air.

Commercial Oil-Fired Boilers

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard*	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Thermal Efficiency (%)**	79	81	82	83	98	83	98	84	98	84	98
Average Life (yrs)	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	11,700	12,400	13,400	14,400	24,700	14,400	24,700	15,500	24,700	15,500	24,700
	12,800	14,400	15,400	16,500	26,800	16,500	26,800	17,500	26,800	17,500	26,800
Total Installed Cost ($)	15,800	16,500	17,500	18,500	30,900	18,500	30,900	19,600	30,900	19,600	30,900
	16,900	18,500	19,500	20,600	33,000	20,600	33,000	21,600	33,000	21,600	33,000
Annual Maintenance Cost ($)	115	115	115	115	115	115	115	115	115	115	115
	165	165	165	165	165	165	165	165	165	165	165

* The standard level shown here is for small hot water boilers, the most common type of boiler.
** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.

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Commercial Oil-Fired Boilers

- Commercial packaged oil-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
- Most common type is small hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Federal standards require thermal efficiency ≥ 81% for steam boilers and ≥ 82% for hot water boilers.
- Exception is large hot water boilers, which must have *combustion* efficiency ≥ 84%.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.

Final

Commercial Gas-Fired Chillers[1]

DATA	2003		2012		2013		2020		2030		2040	
	Installed Base				Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven
	Absorption	Engine-Driven	Absorption	Engine-Driven								
Typical Capacity (tons)*	150	150	150	150	150	150	150	150	150	150	150	150
	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400
COP	1.0	1.5	1.1	1.7	1.1	1.7	1.2	1.8	1.3	1.8	1.4	1.8
Average Life (yrs)	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost ($/ton)	650	750	700	700	700	700	700	700	700	700	700	700
	800	850	850	800	850	800	850	800	850	800	850	800
Total Installed Cost ($/ton)	800	900	800	800	800	800	800	800	800	800	800	800
	950	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000
Annual Maintenance Cost ($/ton)	16	37	16	31	16	31	16	31	16	31	16	31
	32	48	32	47	32	47	32	47	32	47	32	47

* Capacity is *output*

[1] This analysis assumes a water-cooled chiller; both gas-fired chiller types (absorption and engine-driven) are shown.

Commercial Gas-Fired Chillers

- Gas-fired chillers are available as either air-cooled (~25-50 tons) or water-cooled (150+ tons). This analysis includes only water-cooled chillers. Two direct-fired gas chiller technologies are in the market; absorption and engine-driven.
- Direct gas firing provides high enough temperatures to operate double effect absorption chillers, which operate at a 50-60% higher COP than single effect absorption chillers. Triple effect absorption chillers are expected to boost cooling COP 30-50% beyond double effect chillers. Prototype direct-fired triple effect absorption chillers have been tested by York and Trane, but are not commercially available. Due to the prohibitively high cost of advanced high heat/corrosion-resistant materials required for triple effect absorption chillers, it is expected that this technology will not likely have a commercial market impact in the near-term. Some absorption chillers can be operated in reverse to provide heating; these are referred to as chiller/heaters.
- Gas-fired engine-driven chillers pair conventional vapor compression technologies (typically screw or centrifugal compressors) with natural gas powered reciprocating engines. Gas-fired engine-driven chillers exhibit higher peak cooling COP than absorbers, and engine modulation results in even better part load performance. Future efficiency improvements for engine-driven chillers are not anticipated. Engine driven chillers allow the opportunity to recover waste heat useful purposes.
- Sales dropped by nearly 75 percent in the US from 2006 to 2010. Most new gas-fired chillers sales in the US are for replacement, not for new installations. The increase in electric chiller efficiency has narrowed the operating cost differential with gas chillers. Gas chiller technologies remain popular and development will in other markets, such as Asia, which currently has 80 percent of the gas-fired chiller market.
- Gas-fired chiller installations hold value in niche applications such as where electric demand charges are high, electrical capacity is limited, alternative energy sources are available (such as digester or landfill gas) or where waste heat is available (such as from an industrial process or microturbine CHP system) that could be used with a hybrid direct/indirect-fired absorption chiller to offset the use of natural gas.

Final

Commercial Centrifugal Chillers

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	400	400	400	400	400	400	400	400	400	400	400
	600	600	600	600	600	600	600	600	600	600	600
Efficiency [full-load] (kW/ton)[1]	0.70	0.66	0.58	0.56	0.45	0.54	0.44	0.52	0.43	0.50	0.42
Efficiency [IPLV] (kW/ton)[1]	0.67	0.61	0.40	0.36	0.33	0.36	0.32	0.35	0.31	0.34	0.30
COP [full-load][1]	5.0	5.4	6.1	6.3	7.8	6.5	8.0	6.8	8.2	7.0	8.4
COP [IPLV] [1]	5.2	5.9	8.8	9.8	10.7	9.8	11.0	10.0	11.3	10.3	11.7
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($/ton)	250	250	250	300	400	300	400	300	400	300	400
	350	350	350	400	500	400	500	400	500	400	500
Total Installed Cost ($/ton)	300	300	300	350	450	350	450	350	450	350	450
	450	450	450	500	600	500	600	500	600	500	600
Annual Maintenance Cost ($/ton)	16	16	16	16	16	16	16	16	16	16	16
	32	32	32	32	32	32	32	32	32	32	32

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.
[2] 2013 typical efficiency based on ASHRAE 90.1-2010.
[3] 2013 mid efficiency based on FEMP recommendations.

Commercial Centrifugal Chillers

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- ASHRAE 90.1-2010 and Addendum M of 90.1-2007 became effective 1/1/10 and instituted the following Separate compliance paths for applications that spend a significant amount of time at full load versus part load (encourages the use of chillers with better IPLVs in part-load applications and full-load efficiencies in full-load applications; for either path, minimum requirements for both full load and IPLV must still be met). The Addendum also added a new size category for centrifugal chillers ≥600 tons, strengthened minimum efficiency requirements for centrifugal chillers <150 tons and ≥600 tons, and changed how efficiency is expressed, from coefficient of performance (COP) to kW/ton to reflect industry practice.
- The Federal Energy Management Program (FEMP) requires separate minimum efficiencies for full-load optimized and part-load optimized applications. For full-load optimized applications, a full-load efficiency less than 0.56 kW/ton and an IPLV efficiency less than 0.55 kW/ton. For full-load optimized applications, a full-load efficiency less than 0.60 kW/ton and an IPLV efficiency less than 0.36 kW/ton.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed drive (VSD) compressors
  - Dedicated heat recovery (heat pump chiller)
  - Magnetic bearing technology (oil-free operation)
  - Greater heat exchanger surface areas; enhanced tube configurations (counterflow)
  - Optimized fluid flow velocities
  - High efficiency electric motors
  - Improved turbomachinery design, resulting in higher compressor efficiency
  - Better piping and valving, including electronic expansion valves
  - Evaporative condenser for the heat rejection equipment
- Installed costs vary widely depending on equipment needed for installation (e .g. crane) and size of system. This is a mature market with centrifugal chillers representing 75% of commercial chiller sales larger than 200 tons.

Final

Commercial Reciprocating Chillers

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	100	100	100	100	100	100	100	100	100	100	100
	200	200	200	200	200	200	200	200	200	200	200
Efficiency [full-load] (kW/ton)[1]	1.26	1.26	1.25	1.15	1.00	1.15	1.00	1.15	1.00	1.15	1.00
Efficiency [IPLV] (kW/ton)[1]	1.15	1.13	0.96	0.80	0.79	0.80	0.79	0.80	0.79	0.80	0.79
COP [full-load][1]	2.80	2.80	2.81	3.06	3.52	3.06	3.52	3.06	3.52	3.06	3.52
COP [IPLV][1]	3.05	3.12	3.66	4.40	4.45	4.40	4.45	4.40	4.45	4.40	4.45
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	400	575	550	650	750	650	750	650	750	650	750
	500	675	650	750	850	750	850	750	850	750	850
Total Installed Cost ($/ton)	475	650	675	775	875	775	875	775	875	775	875
	600	775	825	925	1025	925	1025	925	1025	925	1025
Annual Maintenance Cost ($/ton)	27	27	27	27	27	27	27	27	27	27	27
	43	43	43	43	43	43	43	43	43	43	43

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.
[2] 2013 typical efficiency based on ASHRAE 90.1-2010.
[3] 2013 mid efficiency based on FEMP recommendations.

Commercial Reciprocating Chillers

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- Reciprocating chillers are most cost effective for small loads. Reciprocating chiller market share continues to be supplanted by screw and scroll chillers. Large manufacturers no longer manufacture reciprocating chillers since most packaged reciprocating chillers under 80 tons utilize R-22 which is being phased out under the Montreal Protocol.
- Reciprocating chillers can be used in either air-cooled or water cooled applications. Reciprocating chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use (as required for compliance with ASHRAE 90.1-2010).
- ASHRAE 90.1-2010 instituted separate minimum efficiency requirements for air-cooled chillers more and less than 150 tons and both sets of requirements are more stringent than 90.1-2007. The 90.1-2007 minimum efficiency requirements were the same as 90.1-2004.
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (updated December 2012) include a full-load efficiency of 1.15 or less kW/ton for base-loaded chillers or an IPLV efficiency of 0.78 kW/ton and 0.80 kW/ton for chillers with seasonally variable loads that are less than 150 tons and more than 150 tons, respectively.
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Commercial Screw Chillers

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	100	100	100	100	100	100	100	100	100	100	100	100
	300	300	300	300	300	300	300	300	300	300	300	300
Efficiency [full-load] (kW/ton)	1.26	1.26	1.25	1.24	1.13	1.02	1.13	0.99	1.10	0.96	1.08	0.94
Efficiency [IPLV] (kW/ton)	1.15	1.13	0.94	0.94	0.77	0.61	0.77	0.58	0.72	0.56	0.70	0.55
COP [full-load]	2.80	2.80	2.81	2.84	3.10	3.46	3.10	3.55	3.20	3.66	3.26	3.74
COP [IPLV]	3.05	3.12	3.74	3.74	4.58	5.80	4.58	6.06	4.88	6.28	5.02	6.39
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	300	500	500	500	600	700	600	700	600	700	600	700
	400	600	600	600	700	800	700	800	700	800	700	800
Total Installed Cost ($/ton)	375	625	625	625	725	825	725	825	725	825	725	825
	500	800	800	800	900	1000	900	1000	900	1000	900	1000
Annual Maintenance Cost ($/ton)	11	11	11	11	11	11	11	11	11	11	11	11
	53	53	53	53	53	53	53	53	53	53	53	53

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.
[2] 2013 typical, mid, and high efficiency levels determined base on the range of products currently available on the market.

Commercial Screw Chillers

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- Screw chillers are available from ~50-1100 tons but are most cost effective for small (<300 tons) loads. Screw chillers dominate the current market for small to mid-size chillers.
- Screw chillers can be used in either air-cooled or water cooled applications. Screw chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use (as required for compliance with ASHRAE 90.1-2010).
- ASHRAE 90.1-2010 instituted separate minimum efficiency requirements for air-cooled chillers more and less than 150 tons and both sets of requirements are more stringent than 90.1-2007. The 90.1-2007 requirements were the same as 90.1-2004.
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (updated December 2012) include a full-load efficiency of 1.15 or less kW/ton for base-loaded chillers or an IPLV efficiency of 0.78 kW/ton and 0.80 kW/ton for chillers with seasonally variable loads that are less than 150 tons and more than 150 tons, respectively.
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Economizers
  - Improved heat-exchangers

Final

Commercial Scroll Chillers

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical[2]	Mid[2]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	20	20	20	20	20	20	20	20	20	20	20	20
	140	140	140	140	140	140	140	140	140	140	140	140
Efficiency [full-load] (kW/ton)[1]	1.26	1.23	1.25	1.17	1.14	1.11	1.14	1.09	1.11	1.07	1.09	1.06
Efficiency [IPLV] (kW/ton)[1]	1.15	0.99	0.94	0.77	0.75	0.72	0.75	0.71	0.73	0.69	0.71	0.68
COP [full-load][1]	2.80	2.88	2.81	3.02	3.08	3.17	3.08	3.23	3.17	3.29	3.23	3.32
COP [IPLV] [1]	3.05	3.67	3.74	4.54	4.67	4.86	4.67	4.99	4.82	5.10	4.95	5.17
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	320	450	450	450	550	650	550	650	550	650	550	650
	420	550	550	550	650	800	650	800	650	800	650	800
Total Installed Cost ($/ton)	420	700	700	700	800	900	800	900	800	900	800	900
	530	800	800	800	900	1050	900	1050	900	1050	900	1050
Annual Maintenance Cost ($/ton)	37	37	37	37	37	37	37	37	37	37	37	37
	53	53	53	53	53	53	53	53	53	53	53	53

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.

[2] 2013 typical, mid, and high efficiency levels determined base on the range of products currently available on the market.

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- Scroll chillers can be used in either air-cooled or water cooled applications. Scroll chillers shown in the data are air-cooled, which is most common. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use (as required for compliance with ASHRAE 90.1-2010).
- ASHRAE 90.1-2010 instituted separate minimum efficiency requirements for air-cooled chillers more and less than 150 tons and both sets of requirements are more stringent than 90.1-2007. The 90.1-2007 requirements were the same as 90.1-2004.
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (updated December 2012) include a full-load efficiency of 1.15 or less kW/ton for base-loaded chillers or an IPLV efficiency of 0.78 kW/ton and 0.80 kW/ton for chillers with seasonally variable loads that are less than 150 tons and more than 150 tons, respectively.
- The highest efficiency scroll chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Commercial Rooftop Air Conditioners

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Output Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	9.2	10.6	11.2	11.2	11.7	13.9	11.5	13.9	11.5	13.9	11.5	13.9
Part Load Efficiecny (IEER)	-	12.4	-	12.4	11.8	20.8	12.7	20.8	12.7	20.8	12.7	20.8
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3,500	5,850	5,850	5,850	6,450	21,500	6,250	21,500	6,250	21,500	6,250	21,500
	4,800	6,900	6,900	6,900	7,500	22,500	7,300	22,500	7,300	22,500	7,300	22,500
Total Installed Cost ($)	5,300	8,000	8,000	8,000	8,600	23,500	8,400	23,500	8,400	23,500	8,400	23,500
	6,600	9,050	9,050	9,050	9,650	25,500	9,450	25,500	9,450	25,500	9,450	25,500
Annual Maintenance Cost ($)	160	160	160	160	160	160	160	160	160	160	160	160
	320	320	320	320	320	320	320	320	320	320	320	320

* Values shown are for air-cooled units with either electric resistance heating or no heating within the same enclosure.

Air-Cooled Commercial Packaged Air Conditioners

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010 Min. EER	ENERGY STAR version 2.2 Effective 1/1/2011	
			Min. EER	Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	11.2	11.7	11.8
	Any other type	11.0	11.5	11.6
Large (≥ 135 and < 240)	Electric resistance or none	11.0	11.7	11.8
	Any other type	10.8	11.5	11.6

- This analysis focused on small air-cooled commercial packaged air conditioners (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial air conditioners.
- The high efficiency unit includes a variable capacity digital scroll compressor, which saves energy during off-design hours—approximately 17% annual energy savings over a typical unit.

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners

DATA	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	25	18	11	11	11	11
Heating COP	NA	1.4	1.4	1.4	1.4	1.4
Cooling COP	0.7	0.9	1.1	1.1	1.1	1.1
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($/ton)	800	2,700	2,700	2,700	2,700	2,700
	900	3,300	3,300	3,300	3,300	3,300
Total Installed Cost ($/ton)	1,300	3,100	3,100	3,100	3,100	3,100
	1,400	4,100	4,100	4,100	4,100	4,100
Annual Maintenance Cost ($)	59	59	59	59	59	59

* Capacity is *output*

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners/Heat Pumps

- The only gas-fired engine-driven rooftop unit currently available in the US market is by NextAire (an Aisin Seiki product line). It is an 11 ton packaged heat pump with dual scroll compressors, variable refrigerant flow, and a variable speed supply fan. Engine coolant heat recovery improves the heating mode COP. This heat pump was introduced in 2010.
- There are currently no Federal requirements on gas-fired engine-driven rooftop air conditioners or heat pumps.
- Annual sales of the engine-driven rooftop heat pump are estimated at less than 5,000 units per year.

Final

Commercial Rooftop Heat Pumps

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	ENERGY STAR**	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	9.3	10.2	11.0	11.0	11.3	12.0	11.0	12.0	11.0	12.0	11.0	12.0
Part Load Efficiecny (IEER)	-	12.0	-	12.0	11.4	20.2	12.0	20.2	12.0	20.2	12.0	20.2
COP (Heating)	3.1	3.25	3.3	3.3	3.35	3.4	3.3	3.4	3.3	3.4	3.3	3.4
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3,700	5,300	5,300	5,300	5,500	5,850	5,300	5,850	5,300	5,850	5,300	5,850
	4,800	6,400	6,400	6,400	6,600	6,900	6,400	6,900	6,400	6,900	6,400	6,900
Total Installed Cost ($)	5,300	6,900	6,900	6,900	7,100	8,400	6,900	8,400	6,900	8,400	6,900	8,400
	6,900	7,750	7,750	7,750	7,950	10,100	7,750	10,100	7,750	10,100	7,750	10,100
Annual Maintenance Cost ($)	105	105	105	105	105	105	105	105	105	105	105	105
	160	160	160	160	160	160	160	160	160	160	160	160

** ENERGY STAR qualified products must also have IEER of 11.4 or greater.

Air-Cooled Commercial Packaged Heat Pumps

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010		ENERGY STAR version 2.2 Effective 1/1/2011		
		Min. EER	Min. COP at 47°F	Min. EER	Min. IEER	Min. COP at 47°F
Small (≥ 65 and < 135)	Electric resistance or none	11.0	3.3	11.3	11.4	3.35
	Any other type	10.8	3.3	–	–	–
Large (≥ 135 and < 240)	Electric resistance or none	10.6	3.2	10.9	11.0	3.25
	Any other type	10.4	3.2	–	–	–

- This analysis focused on small air-cooled commercial packaged heat pumps (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial heat pumps.

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Commercial Ground Source Heat Pumps

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	48	48	48	48	48	48	48	48	48	48	48	48
COP (Heating)	3.4	3.5	3.1	3.6	3.7	4	3.8	4.2	4	4.4	4.2	4.5
EER (Cooling)	13.8	14	13.4	17.1	17.6	20.6	18	22	20	24	22	26
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	6,000	6,000	6,000	6,500	7,000	8,500	6,500	8,500	6,500	8,500	6,500	8,500
	11,000	11,000	7,000	7,500	8,500	11,000	7,500	11,000	7,500	11,000	7,500	11,000
Total Installed Cost ($)	16,000	16,000	16,000	16,500	17,000	18,500	16,500	18,500	16,500	18,500	16,500	18,500
	36,400	36,400	32,400	32,900	33,900	36,400	32,900	36,400	32,900	36,400	32,900	36,400
Annual Maintenance Cost ($)	150	150	150	150	150	150	150	150	150	150	150	150

Commercial Ground Source Heat Pumps

- The most common commercial ground source heat pump systems are closed-loop in which water or anti-freeze solution is circulated through plastic pipes buried underground. Commercial water-to-air heat pumps (WAHPs) range in size from 1 ton or less to over 500 tons depending on whether a distributed or centralized architecture is used. Distributed systems are more prevalent.
- Most geothermal WAHPs are rated for capacity and efficiency based on the ISO 13256-1 standard. Heating and cooling efficiency measurements under this standard include input energy for fans and pumps on a proportional basis that only includes that power required to transport air and liquid through the heat pump. The reason for this method is to simplify comparisons between heat pumps and to allow equipment to be optimized for real world conditions without suffering rating penalties. Real world energy use will exceed ratings predictions as a result of higher fluid static pressure requirements.
- ISO 13256-1 cooling rating conditions call for 77F entering water temperature and 80.6F entering air temperature. More typical peak design criteria would be 80-90F entering water temperature and 75F entering air temperature. As a result, ISO 13256-1 rated cooling efficiency would be higher than typical design peak operation.
- Some WAHPs include efficiency data for a part load operating condition as allowed by ISO 13256-1 for multiple stage or variable speed compressors. No seasonal energy efficiency metric (analogous to SEER or IEER) currently applies to WAHPs. The annual performance of a geothermal WAHP system can vary more widely than for other system types due to the large influence of ground loop design and characteristics.
- The ENERGY STAR® criteria for ground source heat pumps apply only to residential applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger and distribution pumping systems represent a majority of the installation cost.
- Low end WAHPs utilize single stage compressors. Higher efficiency units incorporate multiple stage or variable speed compressor controls to improve efficiency as well as humidity and temperature control. Variable speed electronically commutated (EC) fan motors also improve overall energy efficiency.

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Commercial Electric Resistance Heaters

DATA	2003		2012		2013		2020		2030		2040	
	Installed Base				Small	Large	Small	Large	Small	Large	Small	Large
	Small	Large	Small	Large								
Typical Capacity (kBtu/h)*	17	170	17	170	17	170	17	170	17	170	17	170
Efficiency (%)	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Average Life (yrs)	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost ($)	500	3,400	500	3,400	500	3,500	500	3,500	500	3,500	500	3,500
	700	3,800	700	3,800	700	3,900	700	3,900	700	3,900	700	3,900
Total Installed Cost ($)	600	3,500	600	3,500	650	4,000	650	4,000	650	4,000	650	4,000
	800	3,900	800	3,900	850	4,500	850	4,500	850	4,500	850	4,500
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-	-

* Capacity is *output*
** Annual Maintenance Cost is negligible

Commercial Electric Resistance Heaters

- This analysis examined electric unit heaters.
- Electric unit heaters range in capacity from 2 to 100 kW (7 to 340 kBtu/hr), with 5 to 50 kW (17 to 170 kBtu/hr) being the most typical units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion. For this analysis, the efficiency is 98% to account for IR losses and fan inefficiency.
- Installation time and costs are estimated to be minimal.

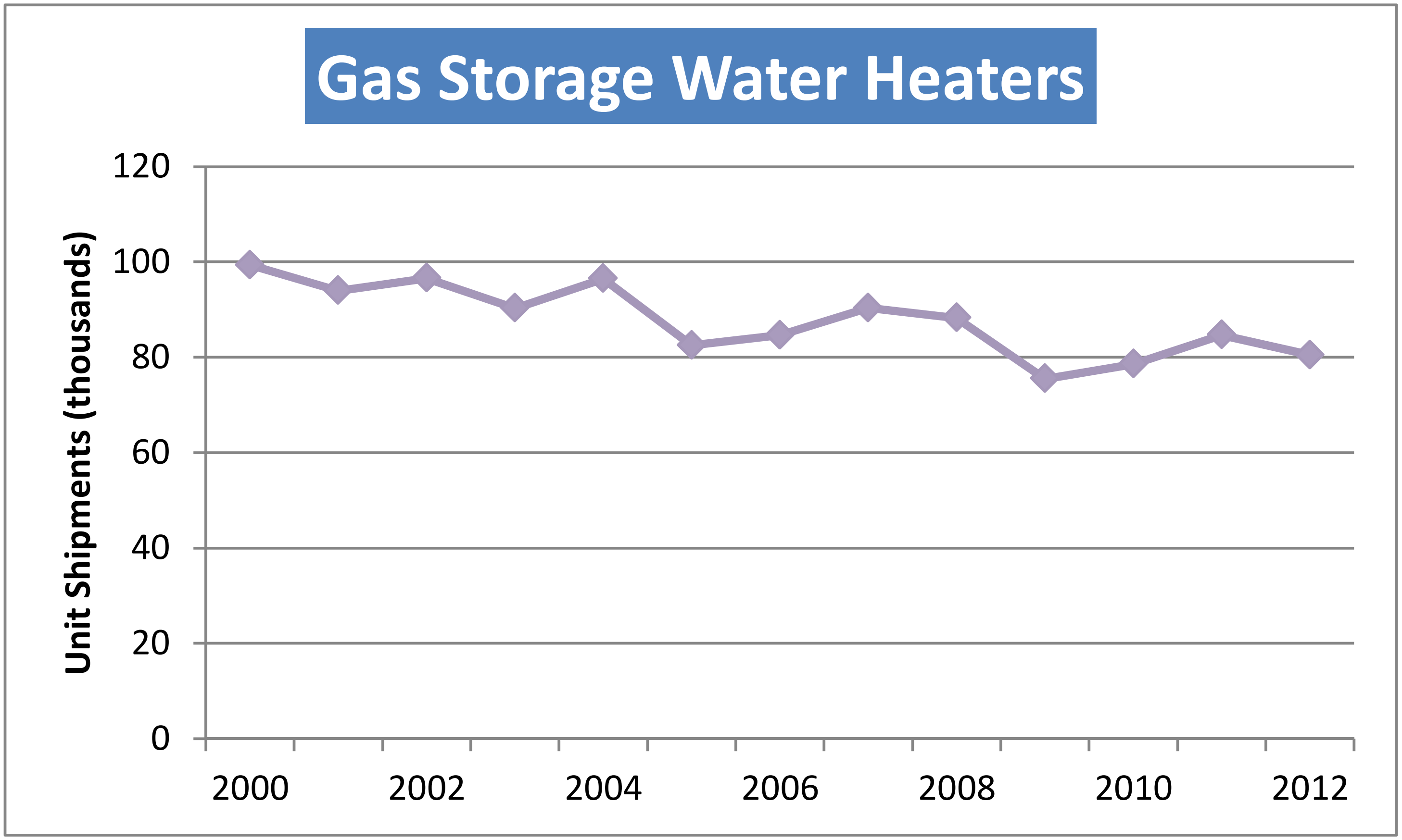
Commercial Gas Storage Water Heaters

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	100	100	100	100	100	100	100	100	100	100	100
Typical Input Capacity (kBtu/h)	200	200	200	200	200	200	200	200	200	200	200
Thermal Efficiency (%)	77	79	80	80	99	80	99	80	99	80	99
Average Life (yrs)	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost ($)	3000	3200	3700	3700	5300	3700	5300	3700	5300	3700	5300
	4500	4800	6100	6100	6900	6100	6900	6100	6900	6100	6900
Total Installed Cost ($)	3530	3730	4230	4230	5830	4230	5830	4230	5830	4230	5830
	5030	5330	6630	6630	7430	6630	7430	6630	7430	6630	7430
Annual Maintenance Cost ($)	110	110	110	110	110	110	110	110	110	110	110
	210	210	210	210	210	210	210	210	210	210	210

Commercial Gas Storage Water Heaters

- Input capacity ≥ 75,000 Btu/h
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss: Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss: 0.84 × [(Input Rate/800) + 110 × (Rated Volume)$^{1/2}$]
- Baseline units are constructed similarly to residential units, though typically with greater storage and/or input capacities.
- High-efficiency integrated units feature condensing heat exchangers, consisting of either stainless or enameled tubing and an inducer fan system or power burner. Other designs incorporate an external heating module with a storage tank assembly. Either design approach can yield a condensing appliance.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $100–$200 per year for one or two cleanings performed by a plumber.

Annual shipments dropped almost 20 percent over 12 years from 99 thousand units in 2000 to 80 thousand units in 2012.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

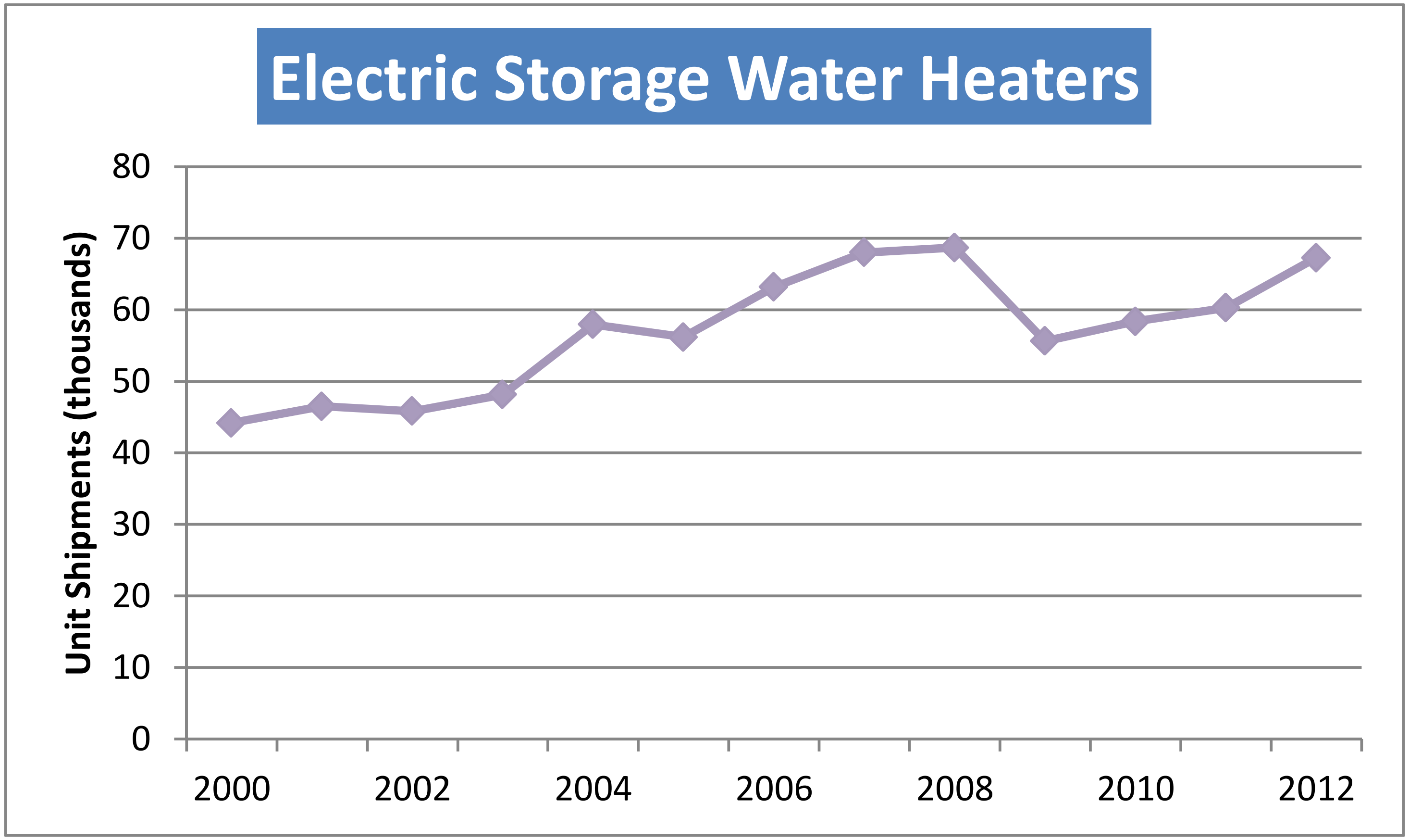
Commercial Electric Resistance Water Heaters

DATA	2003	2012	2013		2020	2030	2040
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	120	120	120	120	120	120	120
Typical Input Capacity (kW)	45	45	54	54	54	54	54
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (yrs)	13	13	13	13	13	13	13
Retail Equipment Cost ($)	3600	3600	3600	3600	3600	3600	3600
	5600	5600	5600	5600	5600	5600	5600
Total Installed Cost ($)	4240	4240	4240	4240	4240	4240	4240
	6340	6340	6340	6340	6340	6340	6340
Annual Maintenance Cost ($)	110	110	110	110	110	110	110
	210	210	210	210	210	210	210

Commercial Electric Resistance Water Heaters

- Federal standard:
  - Maximum standby loss: 0.30 + 27/Measured Storage Volume
  - Minimum thermal efficiency: no standard, but all units ≥ 98% anyway
- Storage capacity: typically 50 to 120 gallons, though larger units exist for specialized applications
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $100–$200 per year for one or two cleanings performed by a plumber.

Annual shipments increased more than 50 percent over 12 years from 44 thousand units in 2000 to 67 thousand units in 2012.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

Commercial Oil-Fired Water Heaters

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	70	70	70	70	70	70	70	70	70	70	70
Typical Input Capacity (kBtu/h)	300	300	140	140	140	140	140	140	140	140	140
Thermal Efficiency (%)	78	79	78	80	85	80	85	80	85	80	85
Average Life (yrs)	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost ($)	4360	4420	4360	6500	8500	6500	8500	6500	8500	6500	8500
Total Installed Cost ($)	4890	4950	4890	7030	9030	7030	9030	7030	9030	7030	9030
Annual Maintenance Cost ($)	110	110	110	110	110	110	110	110	110	110	110
	210	210	210	210	210	210	210	210	210	210	210

Commercial Oil-Fired Water Heaters

- Input capacity ≥ 105,000 Btu/h
- Federal standard:
  - Minimum thermal efficiency: 78%
  - Maximum standby loss: Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- Condensing units do not exist, thus the highest attainable thermal efficiency is ≅ 86%.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of \$100–\$200 per year for one or two cleanings performed by a plumber.

Commercial Gas-Fired Instantaneous Water Heaters

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	180	180	180	180	180	180	180	180	180	180	180
	230	230	250	250	250	250	250	250	250	250	250
Thermal Efficiency (%)	76	78	80	89	97	89	97	89	97	89	97
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	530	640	850	1300	1500	1300	1500	1300	1500	1300	1500
	800	900	1050	1650	1850	1650	1850	1650	1850	1650	1850
Total Installed Cost ($)	680	790	1000	1550	1750	1550	1750	1550	1750	1550	1750
	950	1050	1200	2200	2400	2200	2400	2200	2400	2200	2400
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

Commercial Gas-Fired Instantaneous Water Heaters

- Input capacity ≥ 200,000 Btu/h
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss: Input Rate/800 + 110 x (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss: 0.84 x [(Input Rate/800) + 110 x (Rated Volume)$^{1/2}$]
- Use similar technologies for improving energy efficiency as residential systems; however, unlike condensing residential systems, condensing commercial systems typically do not use multiple heat exchangers.
- Depending on the manufacturer, input ratings for condensing systems usually top out at 800,000 Btu/h, requiring the use of multiple units for staging purposes; however, there are reliability, comfort, and efficiency benefits to staging multiple units.
- When replacing a storage water heater with an instantaneous water heater, there may be significant additional costs to upsize the gas supply line and change the venting.

Final

Commercial Electric Booster Water Heaters

DATA	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (gal)	6	6	6	6	6	6
	16	16	16	16	16	16
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	3	3	3	3	3	3
	10	10	10	10	10	10
Retail Equipment Cost ($)	1300	1250	1250	1250	1250	1250
	1600	2700	2700	2700	2700	2700
Total Installed Cost ($)	1500	1450	1450	1450	1450	1450
	1800	2900	2900	2900	2900	2900
Annual Maintenance Cost ($)*	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

Final

Commercial Gas Booster Water Heaters

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	6	3	3	3	3	3	3	3	3	3	3
	10	5	5	5	5	5	5	5	5	5	5
Thermal Efficiency (%)	79	80	80	80	91	82	93	85	95	85	95
Average Life (yrs)	3	3	3	3	3	3	3	3	3	3	3
	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost ($)	5,300	4,500	4,500	4,500	8,000	4,500	8,000	4,500	8,000	4,500	8,000
	6,400	6,500	6,500	6,500	10,000	6,500	10,000	6,500	10,000	6,500	10,000
Total Installed Cost ($)	5,600	4,800	4,800	4,800	8,300	4,800	8,300	4,800	8,300	4,800	8,300
	6,700	6,800	6,800	6,800	10,300	6,800	10,300	6,800	10,300	6,800	10,300
Annual Maintenance Cost ($)	160	160	160	160	160	160	160	160	160	160	160

Commercial Booster Water Heaters

- Booster water heaters are installed, often at the point of use, in series with the main service water heating system to boost service water temperatures. The main service water heating system may provide 110-140°F water, and the booster water heater may increase that temperature to 180-195°F. Typical commercial applications for booster water heaters include commercial dishwashers, laundromats, hospitals, and car washes.
- There is currently no energy efficiency standard for electric booster water heaters. Gas booster water heater minimum efficiency is dictated by ASHRAE Standard 90.1-2010 under the "gas instantaneous water heaters" category.
- Booster water heaters typically have short lifetimes because of high usage and extreme temperatures.
- Typical sales are small due to the limited number of applications.

Commercial Gas Griddles

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Cooking Surface (ft^2)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Cooking Energy Efficiency (%)	30	30	30	38	52	30	52	30	52	30	52
Normalized Idle Energy Rate (Btu/h/ft^2)	3,000	3,000	3,000	2,650	1,180	3,000	1,180	3,000	1,180	3,000	1,180
Average Life (yrs)	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	5,000	5,000	5,000	5,360	6,160	5,000	6,160	5,000	6,160	5,000	6,160
Total Installed Cost ($)	5,150	5,150	5,150	5,510	6,310	5,150	6,310	5,150	6,310	5,150	6,310
Annual Maintenance Cost ($)*	–	–	–	–	–	–	–	–	–	–	–

* Maintenance costs are negligible.

Commercial Electric Griddles

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Cooking Surface (ft^2)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Cooking Energy Efficiency (%)	65	65	65	70	82	65	82	65	82	65	82
Normalized Idle Energy Rate (W/ft^2)	440	440	440	320	210	440	210	440	210	440	210
Average Life (yrs)	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	7,800	7,800	7,800	7,800	9,000	7,800	9,000	7,800	9,000	7,800	9,000
Total Installed Cost ($)	7,950	7,950	7,950	7,950	9,150	7,950	9,150	7,950	9,150	7,950	9,150
Annual Maintenance Cost ($)*	–	–	–	–	–	–	–	–	–	–	–

Commercial Gas and Electric Griddles

- Used throughout the hospitality industry to crisp, brown, sear, warm, and toast foods.
- Transfers heat to food by direct contact with a hot plate, usually made of polished steel.
- Energy performance metrics are "Cooking Efficiency" (%) and "Normalized Idle Energy Consumption Rate" (Watts/ft^2), measured using ASTM F1275-03 and ASTM F1605-01.
- No Federal standards, but ENERGY STAR criteria version 1.1 took effect May 8, 2009 and became more stringent on January 1, 2011 for electric griddles.

ENERGY STAR Requirements	Gas	Electric
Cooking Energy Efficiency	≥ 38%	≥ 70%
Normalized Idle Energy Rate	≤ 2,650 Btu/h per ft^2	≤ 320 Watts per ft^2

- Price premiums for ENERGY STAR qualified products: estimated at $0 for electric and $360 for gas models.
- Incentives ranging from $25 to $600 per unit available from more than 30 utilities in 19 states.
- Energy savings achieved by using highly conductive or reflective plate materials, improved thermostatic controls, sub-griddle insulation (electric only), and through the strategic placement of thermocouples to better regulate temperature.

Final

Commercial Hot Food Holding Cabinets

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		State Standards	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4
Maximum Idle Energy Rate (W)	1,400	900	856	856	297	154	856	154	856	154	856	154
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost ($)	2,400	2,400	2,400	2,400	2,400	2,800	2,400	2,800	2,400	2,800	2,400	2,800
Total Installed Cost ($)	2,400	2,400	2,400	2,400	2,400	2,800	2,400	2,800	2,400	2,800	2,400	2,800
Annual Maintenance Cost ($)*	–	–	–	–	–	–	–	–	–	–	–	–

* Maintenance costs are negligible.

Commercial Hot Food Holding Cabinets

- Used in commercial kitchens to keep food warm until it is served.
- Many shapes and sizes, but interior volumes around 21.4 ft^3 typical in many settings.
- Annual unit energy consumption can range from < 1,000 to > 30,000 kWh/y, depending on size, efficiency, and usage.
- Energy performance metric is "Idle Energy Consumption Rate" in Watts, measured using ASTM Standard F2140-11.
- No Federal standards, but eight identical State standards, first took effect in California in 2006, now considered the typical or "baseline" product. ENERGY STAR version 2.0 took effect October 1, 2011.
- Maximum Idle Energy Consumption Rate for products $12 \leq V < 28$:
  - State standards: $\mathbf{\leq 40 \times \mathit{V}}$ (baseline)
  - ENERGY STAR: $\mathbf{\leq 2.0 \times \mathit{V} + 254}$ (about 65% below baseline)

  where V is interior volume in ft^3.
- Small, if any, price premium for ENERGY STAR qualified products, yet incentives ranging from $110 to $900 per unit are available from more than 25 utilities in 7 states.
- The most efficient products are about 80% below baseline.
- Energy savings achieved with insulation, automatic door closers, magnetic door gaskets, and Dutch doors (half-doors).

Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19 St. NW, Suite 700
Washington, D.C. 20036
(202) 973-2400

www.navigantconsulting.com

Data Sources » Residential Gas-Fired Water Heaters

SOURCES	2009	2013				2020	2030	2040
	Installed Base	**Current Standard**	**Typical**	**ENERGY STAR**	**High**	**Typical / High**		
Typical Capacity (gal)	AHRI / Distributors	EERE	AHRI	ENERGY STAR	AHRI	Navigant		
Energy Factor	AHRI	EERE	AHRI	ENERGY STAR	AHRI			
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Distributors	EERE			Distributors			
Total Installed Cost ($)	Distributors / RS Means 2010	EERE						
Annual Maintenance Cost ($)	EERE	EERE						

Data Sources » Residential Oil Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>Mid-Level</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td>EERE</td><td>AHRI</td><td>AHRI</td><td>AHRI</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Energy Factor</td><td>AHRI</td><td>EERE</td><td colspan="3">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors</td><td colspan="4">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors / RS Means 2007</td><td colspan="4">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE</td><td colspan="4">EERE</td></tr>
</table>

Data Sources » Residential Electric Resistance Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="3">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td>EERE</td><td>AHRI</td><td>AHRI</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Energy Factor</td><td>AHRI</td><td>EERE</td><td>AHRI</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors</td><td colspan="2">EERE</td><td>Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors / RS Means 2010</td><td colspan="3">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE</td><td colspan="3">EERE</td></tr>
</table>

Data Sources » Residential Heat Pump Water Heaters

SOURCES	2009	2013		2020	2030	2040
	Installed Base	ENERGY STAR	High	Typical / High		
Typical Capacity (gal)	AHRI	EERE	ENERGY STAR	Navigant		
Energy Factor	AHRI	ENERGY STAR				
Average Life (yrs)	EERE					
Retail Equipment Cost ($)	RS Means 2010 / ACEEE, 2007	Distributors				
Total Installed Cost ($)	RS Means 2010 / ACEEE, 2007	Distributors				
Annual Maintenance Cost ($)		EERE				

Data Sources » Residential Instantaneous Water Heaters

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/hr)	EERE	AHRI	ENERGY STAR / AHRI		ENERGY STAR	Navigant		
Energy Factor	Distributors	EERE	AHRI		ENERGY STAR			
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Distributors / RS Means 2010	Distributors						
Total Installed Cost ($)	DEER, 2008	Distributors						
Annual Maintenance Cost ($)	Navigant	EERE						

Data Sources » Residential Solar Water Heaters

SOURCES	2009	2013		2020	2030	2040
	Installed Base	Current Standard	Typical	Typical		
Typical Capacity (sq. ft.)	SRCC			SAIC		
Overall Efficiency (Solar Fraction)	0.3-0.5 (RETScreen); 0.58-0.83 (SRCC); 0.5-0.75 (EERE)					
Solar Energy Factor	ENERGY STAR range=0.53-47, median=2, average=2.83					
Average Life (yrs)	20 year system life (EERE); Collector warranties are 10 years (ENERGY STAR/SRCC)					
Retail Equipment Cost[1] ($)	RS Means					
Total Installed Cost[1] ($)	RS Means					

[1] Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.

[2] ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="5">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th colspan="2">ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>Navigant</td><td colspan="5">EERE</td><td colspan="3" rowspan="7">Navigant</td></tr>
<tr><td>AFUE (%)</td><td>Navigant</td><td>EERE</td><td>EERE</td><td>ENERGY STAR</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Electric Consumption (kWh/yr)</td><td>EERE</td><td colspan="5">EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">Appliance Magazine, 2012</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE</td><td colspan="5">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>EERE</td><td colspan="5">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE</td><td colspan="5">EERE</td></tr>
</table>

Final

Data Sources » Residential Oil-Fired Furnaces

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Input Capacity (kBtu/h)	Navigant	EERE				Navigant		
AFUE (%)	Navigant	EERE	EERE	ENERGY STAR	AHRI			
Electric Consumption (kWh)	EERE							
Average Life (yrs)	Appliance Magazine, 2012							
Retail Equipment Cost ($)	EERE							
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Gas-Fired Boilers

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Input Capacity (kBtu/h)	EERE 2007					Navigant		
AFUE (%)	EERE 2007 / Navigant	EERE 2007	EERE 2007 / Navigant	ENERGY STAR	AHRI			
Average Life (yrs)	Appliance Magazine, 2012							
Retail Equipment Cost ($)	EERE 2007							
Total Installed Cost ($)	EERE 2007							
Annual Maintenance Cost ($)	EERE 2007							

Data Sources » Residential Oil-Fired Boilers

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Input Capacity (kBtu/h)	EERE					Navigant		
AFUE (%)	EERE / Navigant	EERE	EERE / Navigant	ENERGY STAR	AHRI			
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	EERE							
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Room Air Conditioners

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/hr)</td><td>Distributors</td><td colspan="4">AHAM</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>EER and CEER</td><td>Navigant</td><td>EERE</td><td>CCMS</td><td>ENERGY STAR</td><td>CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2012</td><td colspan="4">Appliance Magazine, 2012</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors</td><td colspan="4">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors</td><td colspan="4">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>Navigant</td><td colspan="4">Navigant</td></tr>
</table>

South (Hot-Dry and Hot-Humid)

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	EERE					Navigant		
SEER	Navigant	eCFR	EERE	ENERGY STAR	AHRI			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE / Navigant				Navigant			
Total Installed Cost ($)	EERE / Navigant				Navigant			
Annual Maintenance Cost ($)	EERE							

North (Rest of Country)

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	EERE					Navigant		
SEER	Navigant	eCFR	EERE	ENERGY STAR	AHRI			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE				Navigant			
Total Installed Cost ($)	EERE				Navigant			
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Air Source Heat Pumps

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	EERE / AHRI					Navigant		
SEER (Cooling)	Navigant	eCFR	CCMS	ENERGY STAR	CCMS			
HSPF (Heating)	Navigant	eCFR	EERE	ENERGY STAR	CCMS			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE							
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Ground Source Heat Pumps

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI/SAIC					SAIC		
COP (Heating)	SAIC	ASHRAE 90.1-2010	SAIC	ENERGY STAR	ENERGY STAR Product Finder/ Product Literature			
EER (Cooling)	SAIC	ASHRAE 90.1-2010	SAIC	ENERGY STAR	ENERGY STAR Product Finder/ Product Literature			
Average Life (yrs)	System life 25 years, ground loop life 50 years (DOE)							
Retail Equipment Cost ($)	Distributors/IGSHPA/EERE/SAIC							
Total Installed Cost ($)	Distributors/IGSHPA/EERE/SAIC							
Annual Maintenance Cost ($)	SAIC							

Data Sources » Residential Gas Heat Pumps

SOURCES	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical		
Typical Capacity (kBTU/h)	Manufacturer		SAIC		
Heating (COP)	Product Literature				
Cooling (COP)	Product Literature				
Annual Electric Use (kWh/yr)	Product Literature/SAIC				
Average Life (yrs)	SAIC				
Retail Equipment Cost ($)	PERC/SAIC				
Total Installed Cost ($)	SAIC				
Annual Maintenance Cost ($)	SAIC				

Data Sources » Residential Electric Resistance Furnaces

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th>2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Typical</th><th colspan="3">Typical</th></tr>
<tr><td>Typical Capacity (kBTU/h)</td><td colspan="2">Distributor/SAIC</td><td colspan="3" rowspan="6">SAIC</td></tr>
<tr><td>Efficiency (%)</td><td colspan="2">DOE/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">Distributors</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">RS Means 2013/SAIC</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="2">RS Means 2013/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="2">SAIC</td></tr>
</table>

Data Sources » Residential Electric Resistance Heaters

SOURCES	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical		
Typical Capacity (kBTU/h)	Distributors/SAIC		SAIC		
Efficiency (%)	SAIC				
Average Life (yrs)	Technology Cost and Performance File for Commercial Model for AEO2010 (adapted for residential)				
Retail Equipment Cost ($)	Distributors/RS Means 2013/SAIC				
Total Installed Cost ($)	Distributors/RS Means 2013/SAIC				
Annual Maintenance Cost ($)	SAIC				

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="3">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>EPA Certified</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (kBTU/h)</td><td>Distributors / Product Literature</td><td>Distributors / Product Literature</td><td colspan="2">Distributors / Product Literature</td><td colspan="3" rowspan="7">SAIC</td></tr>
<tr><td>Efficiency (Non-Catalytic) (HHV)</td><td>SAIC/Lit.</td><td>EPA Default</td><td>EPA Default</td><td>Product Lit./SAIC</td></tr>
<tr><td>Thermal Efficiency (Catalytic) (HHV)</td><td>SAIC/Lit.</td><td>EPA Default</td><td>EPA Default</td><td>Product Lit./SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">SAIC</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Product Lit./Dealers</td><td colspan="3">Product Literature/Dealers</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Dealers</td><td colspan="3">Dealers/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>Dealers/SAIC</td><td colspan="3">Dealers/SAIC</td></tr>
</table>

Data Sources » Residential Wood Pellet Stoves

SOURCES	2009	2013			2020	2030	2040
	Installed Base	EPA Certified	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Distributors / Product Literature	Distributors / Product Literature	Distributors / Product Literature	Distributors / Product Literature	SAIC		
Efficiency (HHV)	SAIC/Lit.	EPA Default	EPA Default	Product Lit./ SAIC			
Average Life (yrs)	SAIC						
Retail Equipment Cost ($)	Product Lit./Dealers	Product Lit./Dealers					
Total Installed Cost ($)	Dealers	Dealers/SAIC					
Annual Maintenance Cost ($)	Dealers	Dealers/SAIC					

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td colspan="5">EERE / Navigant</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Energy Consumption (kWh/yr)</td><td colspan="5">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE / Navigant</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="5">EERE / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE / Navigant</td></tr>
</table>

Data Sources » Residential Natural Gas Cooktops

SOURCES	2009	2013		2020	2030	2040
	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Distributors / Product Literature	EERE		Navigant		
Cooking Efficiency (%)	Distributors / Product Literature	EERE				
Average Life (yrs)	Appliance Magazine, 2012					
Retail Equipment Cost ($)	EERE	EERE / Distributors				
Total Installed Cost ($)	EERE	EERE / Distributors				
Annual Maintenance Cost ($)	Navigant / EERE	Navigant / EERE				

Front-Loading

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (ft3)	Navigant	CCMS	Distributors	CCMS	CCMS	Navigant		
Modified Energy Factor (ft3/kWh/cycle)	Navigant	EERE	CCMS	ENERGY STAR	CCMS			
Water Factor (gal/cycle/ft^3)	Navigant	EERE	CCMS	ENERGY STAR	CCMS			
Average Life (yrs)	Appliance Magazine, 2012							
Water Consumption (gal/cycle)	[calculated]							
Hot Water Energy (kWh/cycle)	Navigant							
Machine Energy (kWh/cycle)	Navigant							
Dryer Energy (kWh/cycle)	Navigant							
Retail Equipment Cost ($)	EERE / Distributors							
Total Installed Cost ($)	RS Means 2010							
Annual Maintenance Cost ($)	Navigant							

Top-Loading

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (ft3)	Navigant	EERE			CCMS	Navigant		
Modified Energy Factor (ft3/kWh/cycle)	Navigant	EERE			CCMS			
Water Factor (gal/cycle/ft^3)	Navigant	EERE			CCMS			
Average Life (yrs)	Appliance Magazine, 2012							
Water Consumption (gal/cycle)	[calculated]							
Hot Water Energy (kWh/cycle)	Navigant							
Machine Energy (kWh/cycle)	Navigant							
Dryer Energy (kWh/cycle)	Navigant							
Retail Equipment Cost ($)	EERE / Distributors							
Total Installed Cost ($)	RS Means 2010							
Annual Maintenance Cost ($)	Navigant							

Data Sources » Residential Clothes Dryers

SOURCES	2009	2013			2020	2030	2040
	Installed Base	Current Standard	Typical	High	Typical / High		
Typical Capacity (ft3)	Navigant	CEC		CEC / Distributors	Navigant		
EF and CEF (lb/kWh)	Navigant	EERE / Navigant					
Average Life (yrs)	Appliance Magazine, 2012						
Retail Equipment Cost ($)	Navigant	EERE					
Total Installed Cost ($)	Navigant	EERE					
Annual Maintenance Cost ($)	EERE	EERE					

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Annual Energy Use (kWh/yr)	EERE	EERE	Distributors / CCMS / EPA	EPA	CCMS	Navigant		
Water Consumption (gal/cycle)	EERE	EERE	Distributors / CCMS / EPA	EPA	CCMS			
Water Heating Energy Use (kWh/yr)	EERE							
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE							
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	Navigant							

Final

Data Sources » Commercial Gas-Fired Furnaces

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Input Capacity (kBtu/h)	Arthur D. Little, 1997	AHRI	AHRI			Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004	AHRI	10 CFR 431.77	AHRI	Modine/ Reznor			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	RS Means 2010 / Navigant / Distributors	RS Means 2011	RS Means 2011					
Total Installed Cost ($)	RS Means 2011	RS Means 2011	RS Means 2011					
Annual Maintenance Cost $)	RS Means 2010/ Navigant / Distributors		Public Comments from Stakeholders					

Data Sources » Commercial Oil-Fired Furnaces

SOURCES	2003	2012	2013		2020	2030	2040
	Installed Base		Current Standard	Typical	Typical		
Typical Input Capacity (kBtu/h)	Navigant / Distributors / AHRI	AHRI			Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004	AHRI	10 CFR 431.77	AHRI			
Average Life (yrs)	EERE / Navigant						
Retail Equipment Cost ($)	RS Means 2010	Navigant	RS Means 2011				
Total Installed Cost ($)	RS Means 2010	Navigant	RS Means 2011				
Annual Maintenance Cost ($)	Navigant / Distributors						

Data Sources » Commercial Electric Boilers

SOURCES	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical		
Typical Capacity (kW)	BSRIA			SAIC		
Efficiency (%)	DOE/SAIC					
Average Life (yrs)	ASHRAE 2007 HVAC Applications					
Retail Equipment Cost ($)	RS Means 2010/SAIC	RS Means 2013/SAIC				
Total Installed Cost ($)	RS Means 2010/SAIC	RS Means 2013/SAIC				
Annual Maintenance Cost ($)	RS Means 2010/SAIC	RS Means 2013/SAIC				

Data Sources » Commercial Gas-Fired Boilers

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical / High		
Typical Input Capacity (kBtu/h)	Navigant						Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Navigant		EERE	Navigant					
Average Life (yrs)	EERE								
Retail Equipment Cost ($)	CEC / RS Means 2010	RS Means 2011	RS Means 2011						
Total Installed Cost ($)	CEC / RS Means 2010	RS Means 2011	RS Means 2011						
Annual Maintenance Cost ($)	Navigant								

Data Sources » Commercial Oil-Fired Boilers

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Input Capacity (kBtu/h)	Building Services Research and Information Association & Ducker Research Company, 1997, 1998	Navigant	Navigant			Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004		EERE	Navigant				
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Distributors / RS Means 2010 / Navigant	RS Means 2011 / Navigant	RS Means 2011 / Navigant					
Total Installed Cost ($)	RS Means 2011 / Navigant							
Annual Maintenance Cost ($)	Navigant		EERE					

Data Sources » Commercial Gas-Fired Chillers

<table>
<tr><th rowspan="3">SOURCES</th><th colspan="2">2003</th><th colspan="2">2012</th><th colspan="2">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="4">Installed Base</th><th rowspan="2">Absorption</th><th rowspan="2">Engine-Driven</th><th colspan="3" rowspan="2">Absorption / Engine-Driven</th></tr>
<tr><th>Absorption</th><th>Engine-Driven</th><th>Absorption</th><th>Engine-Driven</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">BSRIA/Distributors</td><td colspan="3" rowspan="7">SAIC</td></tr>
<tr><td>Efficiency (kW/ton)</td><td colspan="6">Product Literature/SAIC</td></tr>
<tr><td>COP</td><td colspan="6">Product Literature/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">2007 ASHRAE Applications Handbook/Distributors</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="6">Manufacturer/Distributors/RS Means 2013/GIT/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td><td colspan="6">Manufacturer/Distributors/RS Means 2013/GIT/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="6">Manufacturer/Distributors/RS Means 2013/GIT/SAIC</td></tr>
</table>

Data Sources » Commercial Centrifugal Chillers

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Typical	Mid	High	Typical / High		
Typical Capacity (tons)	US Census	IPCC/TEAP/CARB/SAIC				SAIC		
Efficiency (kW/ton)	DEER/FEMP/ Product Literature	ASHRAE 90.1-2010/FEMP/ eSource/Product Literature						
COP	DEER/FEMP/ Product Literature	ASHRAE 90.1-2010/FEMP/ eSource/Product Literature						
Average Life (yrs)	2007 ASHRAE Applications Handbook							
Retail Equipment Cost ($/ton)	RS Means/Distributors/SAIC							
Total Installed Cost ($/ton)	RS Means/Distributors/SAIC							
Annual Maintenance Cost ($/ton)	SAIC							

Data Sources » Commercial Reciprocating Chillers

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Typical	Mid	High	Typical / High		
Typical Capacity (tons)	BSRIA/DEER					SAIC		
Efficiency (kW/ton)	ASHRAE 90.1-2010/DEER/FEMP/Product Literature							
COP	ASHRAE 90.1-2010/DEER/FEMP/Product Literature							
Average Life (yrs)	Manufacturers							
Retail Equipment Cost ($/ton)	RS Means 2013/Distributors/SAIC							
Total Installed Cost ($/ton)	RS Means 2013/Distributors/SAIC							
Annual Maintenance Cost ($/ton)	SAIC							

Data Sources » Commercial Screw Chillers

<table>
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<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>Mid</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">SAIC</td><td colspan="3" rowspan="7">SAIC</td></tr>
<tr><td>Efficiency (kW/ton)</td><td>DEER/FEMP/ Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>COP</td><td>DEER/FEMP/ Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">Manufacturers</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="6">RS Means 2013/Distributors/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td><td colspan="6">RS Means 2013/Distributors/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="6">SAIC</td></tr>
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Data Sources » Commercial Scroll Chillers

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	Mid	High	Typical / High		
Typical Capacity (tons)	SAIC/Manufacturers						SAIC		
Efficiency [full-load/IPLV] (kW/ton)	Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC					
COP [full-load/IPLV]	Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC					
Average Life (yrs)	Manufacturers								
Retail Equipment Cost ($/ton)	Manufacturers/RS Means 2013/SAIC								
Total Installed Cost ($/ton)	Manufacturers/RS Means 2013/SAIC								
Annual Maintenance Cost ($/ton)	SAIC								

Data Sources » Commercial Rooftop Air Conditioners

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Output Capacity (kBtu/h)	AHRI / Navigant						Navigant		
Efficiency (EER)	ASHRAE Standard 90.1-2004	Distributors/ Navigant	EERE		ENERGY STAR	AHRI			
Average Life (yrs)	EERE								
Retail Equipment Cost $)	Navigant / LBNL, 2003	Distributors/ Navigant / DEER, 2008	EERE		Distributors				
Total Installed Cost ($)	Navigant / LBNL, 2003	Distributors/ Navigant / DEER, 2008	EERE		Distributors				
Annual Maintenance Cost ($)	EERE								

Data Sources » Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners/Heat Pumps

SOURCES	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical		
Typical Capacity (tons)	Manufacturer/Distributors/SAIC			SAIC		
Heating COP	NA	Product Literature				
Cooling COP	Product Literature/SAIC					
Average Life (yrs)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				
Retail Equipment Cost ($/ton)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				
Total Installed Cost ($/ton)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				
Annual Maintenance Cost ($)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				

Data Sources » Commercial Rooftop Heat Pumps

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="6">AHRI / Navigant</td><td colspan="3" rowspan="7">Navigant</td></tr>
<tr><td>Efficiency (EER)</td><td colspan="2">ASHRAE Standard 90.1-2004 / Navigant</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>COP (Heating)</td><td colspan="2">EERE / Navigant</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="6">Distributors / RS Means 2010 / DEER / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="6">Distributors / RS Means 2010 / DEER / Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">Distributors / RS Means 2010 / DEER / Navigant</td></tr>
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Data Sources » Commercial Ground Source Heat Pumps

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	Mid	High	Typical / High		
Typical Capacity (kBTU/h)	US DOE/EIA						SAIC		
COP (Heating)	SAIC		ASHRAE 90.1-2010	Product Literature	Product Literature	Product Literature			
EER (Cooling)	SAIC		ASHRAE 90.1-2010	Product Literature	Product Literature	Product Literature			
Average Life (yrs)	System life 25 years, ground loop life 50 years (DOE); system life 25 years (ASHRAE RP 1237-TRP)								
Retail Equipment Cost ($)	Distributors/SAIC								
Total Installed Cost ($)	US DOD/IGSHPA/MA DOER/CEFIA/ASHRAE								
Annual Maintenance Cost ($)	Geothermal Heat Pump Consortium, Inc. (US DOE Contract DE-FG07-95ID13347)								

Data Sources » Commercial Electric Resistance Heaters

SOURCES	2003		2012		2013		2020	2030	2040
	Small	Large	Small	Large	Small	Large	Small / Large		
Typical Capacity (kBTU/h)	Distributors/Navigant						SAIC		
Efficiency (%)	Navigant								
Average Life (yrs)	Technology Cost and Performance File for Commercial Model for AEO2010								
Retail Equipment Cost ($)	RS Means/Distributors/SAIC								
Total Installed Cost ($)	RS Means/Distributors/SAIC								
Annual Maintenance Cost ($)	Navigant								

Data Sources » Commercial Gas-Fired Water Heaters

<table>
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<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td colspan="2">Arthur D. Little / Distributors / AHRI</td><td colspan="3">AHRI</td><td colspan="3" rowspan="7">Navigant</td></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>Arthur D. Little / AHRI</td><td>AHRI</td><td colspan="3">AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="2">EERE / ASHRAE Standard 90.1-2004 / Navigant</td><td>EERE</td><td>AHRI</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors / CEC / Navigant</td><td colspan="3">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Distributors / CEC / Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">Navigant</td></tr>
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Data Sources » Commercial Electric Resistance Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="2">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th colspan="3">Typical</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td colspan="2">Navigant / Product Literature</td><td colspan="2">AHRI</td><td colspan="3" rowspan="7">Navigant</td></tr>
<tr><td>Typical Input Capacity (kW)</td><td colspan="2">Product Literature</td><td colspan="2">AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>Product Literature</td><td>ASHRAE Standard 90.1-2004</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors/ Navigant</td><td>Distributors</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors/ Navigant</td><td>Navigant</td><td colspan="2">Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="4">Navigant</td></tr>
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Data Sources » Commercial Oil-Fired Water Heaters

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Storage Capacity (gal)	Navigant	AHRI / Navigant	AHRI / Navigant			Navigant		
Typical Input Capacity (kBtu/h)	Navigant	AHRI / Navigant	AHRI / Navigant					
Thermal Efficiency (%)	Navigant	Navigant	AHRI / Navigant					
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Navigant	Distributors / Navigant	Distributors					
Total Installed Cost ($)	Navigant	Distributors / Navigant	Navigant					
Annual Maintenance Cost ($)	Navigant	Distributors / Navigant	Navigant					

Data Sources » Commercial Gas-Fired Instantaneous Water Heaters

<table>
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<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="2">Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / AHRI</td><td colspan="3">AHRI</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>AHRI</td><td>Navigant</td><td>EERE</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>CEC / Navigant / Distributors</td><td>Distributors / Navigant</td><td colspan="3">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">CEC / Navigant / Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">CEC / Navigant / Distributors</td></tr>
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Data Sources » Commercial Electric Booster Water Heaters

SOURCES	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical		
Typical Capacity (gal)	Product Literature/SAIC			SAIC		
Thermal Efficiency (%)	Product Literature					
Average Life (yrs)	Product Literature					
Retail Equipment Cost ($)	Distributors/SAIC					
Total Installed Cost ($)	Distributors/SAIC					
Annual Maintenance Cost ($)	Distributors/SAIC					

Data Sources » Commercial Gas Booster Water Heaters

<table>
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<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td colspan="5">Distributors/SAIC</td><td colspan="3" rowspan="6">SAIC</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="5">Product Literature</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">Product Literature/SAIC</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="5">Distributors/SAIC</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Distributors/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">Distributors/SAIC</td></tr>
</table>

Data Sources » Commercial Gas Griddles

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Typical	ENERGY STAR	High	Typical / High		
Cooking Surface (ft^2)	FSTC, 2013					Navigant		
Cooking Energy Efficiency (%)	FSTC, 2002	Navigant		ENERGY STAR	ENERGY STAR QPL			
Normalized Idle Energy Rate ($Btu/h/ft^2$)	FSTC, 2002	Navigant		ENERGY STAR	ENERGY STAR QPL			
Average Life (yrs)	FSTC, 2013							
Retail Equipment Cost ($)	Distributors / ENERGY STAR Savings Calculator / Navigant							
Total Installed Cost ($)	FSTC, 2013							
Annual Maintenance Cost ($)	FSTC, 2013							

Data Sources » Commercial Electric Griddles

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Typical	ENERGY STAR	High	Typical / High		
Cooking Surface (ft^2)	FSTC, 2013					Navigant		
Cooking Energy Efficiency (%)	FSTC, 2002	Navigant		ENERGY STAR	ENERGY STAR QPL			
Normalized Idle Energy Rate (W/ft^2)	FSTC, 2002	Navigant		ENERGY STAR	ENERGY STAR QPL			
Average Life (yrs)	FSTC, 2013							
Retail Equipment Cost ($)	Distributors / ENERGY STAR Savings Calculator / Navigant							
Total Installed Cost ($)	FSTC, 2013							
Annual Maintenance Cost ($)	FSTC, 2013							

Data Sources » Commercial Hot Food Holding Cabinets

<table>
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<tr><td>Interior Volume (ft^3)</td><td colspan="6">FEMP</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Maximum Idle Energy Rate (W)</td><td colspan="2">CEE / Navigant</td><td colspan="3">ENERGY STAR Savings Calculator</td><td>FEMP</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">ENERGY STAR Savings Calculator</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="6">Distributors / ENERGY STAR Savings Calculator / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="6">Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">FSTC</td></tr>
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Appendix B
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Washington, D.C. 20036
(202) 973-2400

www.navigantconsulting.com

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APPENDIX B

FINAL

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case

Presented to:

U.S. Energy Information Administration

Prepared by

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March 2014

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March 2014

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Objective

The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

- 2003 and 2012 baselines (or 2009 for residential products), as well as today's (2013)
  - Review of literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
- Forecast of technology improvements that are projected to be available through 2040
  - Review of trends in standards, product enhancements, and Research and Development (R&D).
  - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- All cost forecasts are shown in 2013 dollars.

Definitions

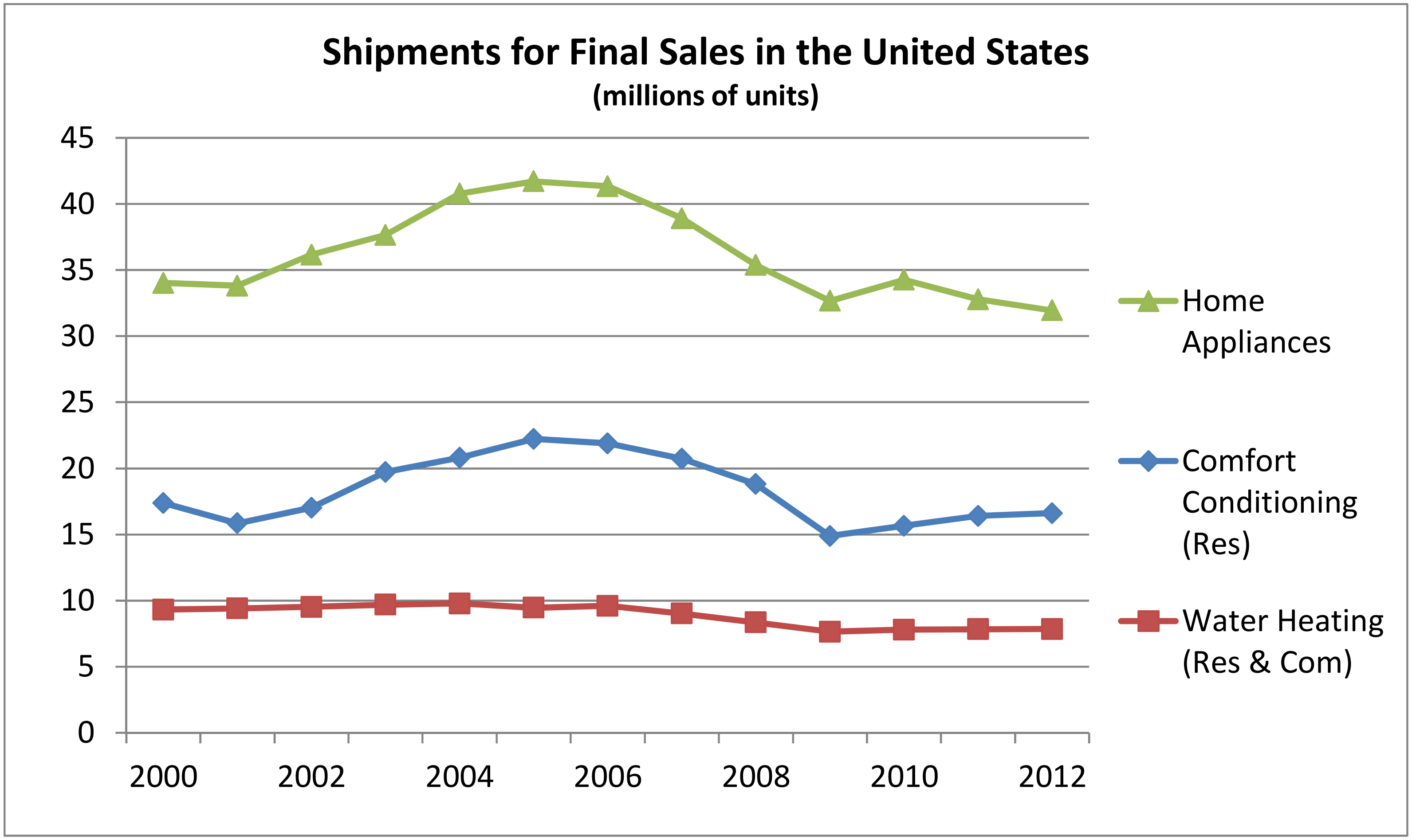
The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (or 2009 for residential products) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming advanced adoption. Below are definitions for the terms used in characterizing the status of each technology.

- 2003/2009/2012 Installed Base: Efficiency values are for those units installed and "in use" in that year. Cost values are for the typical new unit sold in that year.
- 2013 Current Standard: the minimum efficiency required by current standards.
- Typical: the average, or "typical" product being sold in the particular timeframe.
- ENERGY STAR: the minimum efficiency required to meet the ENERGY STAR criteria, where applicable.
- Mid-Level: middle tier high-efficiency product available in the particular timeframe.
- High: the product with the highest efficiency available in the particular timeframe.
- Advanced adoption assumes increases in market incentives, market adoption, and/or technology research and development (R&D).

The market for the reviewed products has changed since the analysis performed in 2011 and is reflected in the efficiency and cost characteristics.

- In some categories the typical new product purchased today is significantly more efficient than the average product in the installed base in 2003 (comm.) or 2009 (res.):
  - Residential sector: room and central air conditioners, heat pumps, refrigerators, freezers, clothes washers
  - Commercial sector: rooftop air conditioners and hot food holding cabinets
- More stringent Federal standards are taking effect for the following products:
  - residential and commercial boilers in 2012
  - residential furnaces and dishwashers in 2013
  - room air conditioners, refrigerators, and freezers in 2014
  - residential central air conditioners, air-source heat pumps, water heaters, clothes washers, and clothes dryers in 2015
- ENERGY STAR continues to raise the bar with revised criteria for residential furnaces and new criteria for commercial water heaters, both effective in early 2013.

Shipments of home appliances and comfort conditioning (heating and cooling) equipment peaked during the housing boom in 2005 then declined. Shipment volumes bottomed out in 2009 and have changed little since.



Source: Analysis by Navigant Consulting of data from *Appliance Magazine*.

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Residential Gas-Fired Water Heaters

Higher typical efficiency and lower costs for a given efficiency level.

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	40	40	40	40	50	40	50	40	50	40	50
Energy Factor	0.6	0.59	0.62	0.67	0.80	0.67	0.85	0.74	0.86	0.80	0.87
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	500	500	510	830	1,500	700	1,470	800	1,330	900	1,280
	540	540	540	860	3,000	800	3,100	900	2,930	1,000	2,870
Total Installed Cost ($)	980	980	990	1,310	1,980	1,180	1,950	1,280	1,810	1,380	1,760
	1,020	1,020	1,020	1,340	3,480	1,280	3,580	1,380	3,410	1,480	3,350
Annual Maintenance Cost ($)	-	-	14	18	18	18	18	18	18	18	18

Residential Gas-Fired Water Heaters

- The current Federal standard, which came into effect in January 2004 mandates an EF of 0.59 for a 40-gallon water heater. The equation for the Federal standard is:

  EF=0.67-(0.0019*Gal), which is used to expand the analysis to a greater range of storage capacities.

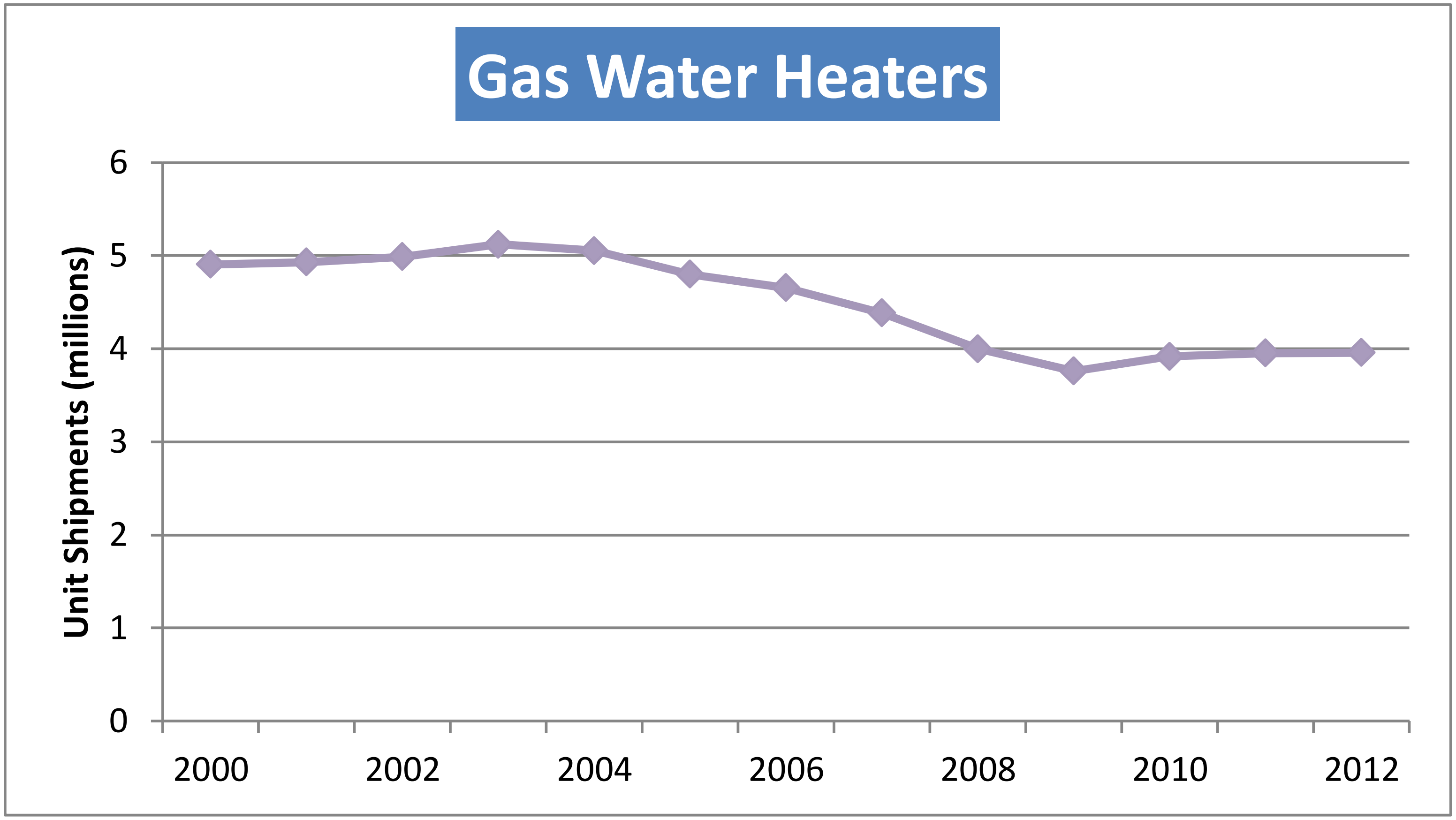
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  EF=0.675-(0.0015*Gal) for a volume ≤ 55 gallons and

  EF=0.8012-(0.00078*Gal) for a volume > 55 gallons

- The current minimum EF for ENERGY STAR qualification is 0.67.
- Per discussions with National Labs, there is a potential trend towards a capacity of 50 gallons as efficiency increases.
- Gas-fired water heater capacities typically fall between 30 and 75 gallons.
- As part of the heating products Federal standards rulemaking, a high efficiency model was examined, EF=0.77 at 40 gallons, which represents a condensing unit with two inches of insulation and a power vent.
- The cost of installation is approximately $450, which is higher than electric water heaters for a number of reasons, which includes an extra 1.5 hours of labor for 2 plumbers that is required for gas units.

Shipments were flat at 5 million units per year through 2004, then declined gradually over 4 years to a new plateau at 4 million units.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

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Residential Oil–Fired Water Heaters

Higher typical efficiencies than ref. case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	30	30	30	30	32	30	30	30	30	30	30
Energy Factor	0.50	0.53	0.54	0.62	0.68	0.62	0.68	0.65	0.68	0.68	0.68
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	1,280	1,380	1,440	1,540	1,700	1,540	1,700	1,620	1,700	1,700	1,700
	1,380	1,490	1,540	1,650	1,810	1,650	1,810	1,730	1,810	1,810	1,810
Total Installed Cost ($)	1,920	2,020	2,080	2,180	2,340	2,180	2,340	2,260	2,340	2,340	2,340
	2,020	2,130	2,180	2,290	2,450	2,290	2,450	2,370	2,450	2,450	2,450
Annual Maintenance Cost ($)	-	-	167	167	167	167	167	167	167	167	167

Residential Oil-Fired Water Heaters

- The current Federal standard, which came into effect in January 2004 mandates an EF of 0.53 for a 30-gallon water heater. The equation for the Federal standard is:

  EF=0.59-(0.0019*Gal), which is used to expand the analysis to a greater range of storage capacities.

- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  EF=0.68-(0.0019*Gal)

- Oil-fired water heaters often have small tanks with larger input ratings, relative to natural gas and electric residential water heaters.
- No condensing oil-fired, storage residential water heaters currently exist on the U.S. market. The range of efficiencies currently reach their peak at near-condensing efficiency levels.
- The max-tech model on the market is achieved using a proprietary "turbo flue" design.

Final

Residential Electric Resistance Water Heaters

Higher efficiencies than ref. case

DATA	2009	2013			2020		2030		2040	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	40	50	40	50	40
Energy Factor	0.9	0.904	0.92	0.95	0.95	0.96	0.96	0.97	0.96	0.97
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	270	270	290	350	290	350	350	410	350	410
	320	320	350	470	350	470	470	530	470	530
Total Installed Cost ($)	590	590	610	670	610	670	670	730	670	730
	640	640	670	790	670	790	790	850	790	850
Annual Maintenance Cost ($)	-	-	6	6	6	6	6	6	6	6

Residential Electric Resistance Water Heaters

- The current Federal minimum efficiency standard, which went into effect in January 2004, requires an EF of 0.90 for a 50-gallon electric resistance water heater. The equation for the Federal standard is:

  $EF=0.97-(0.00132*volume)$, which is used to expand the analysis to a greater range of storage capacities.

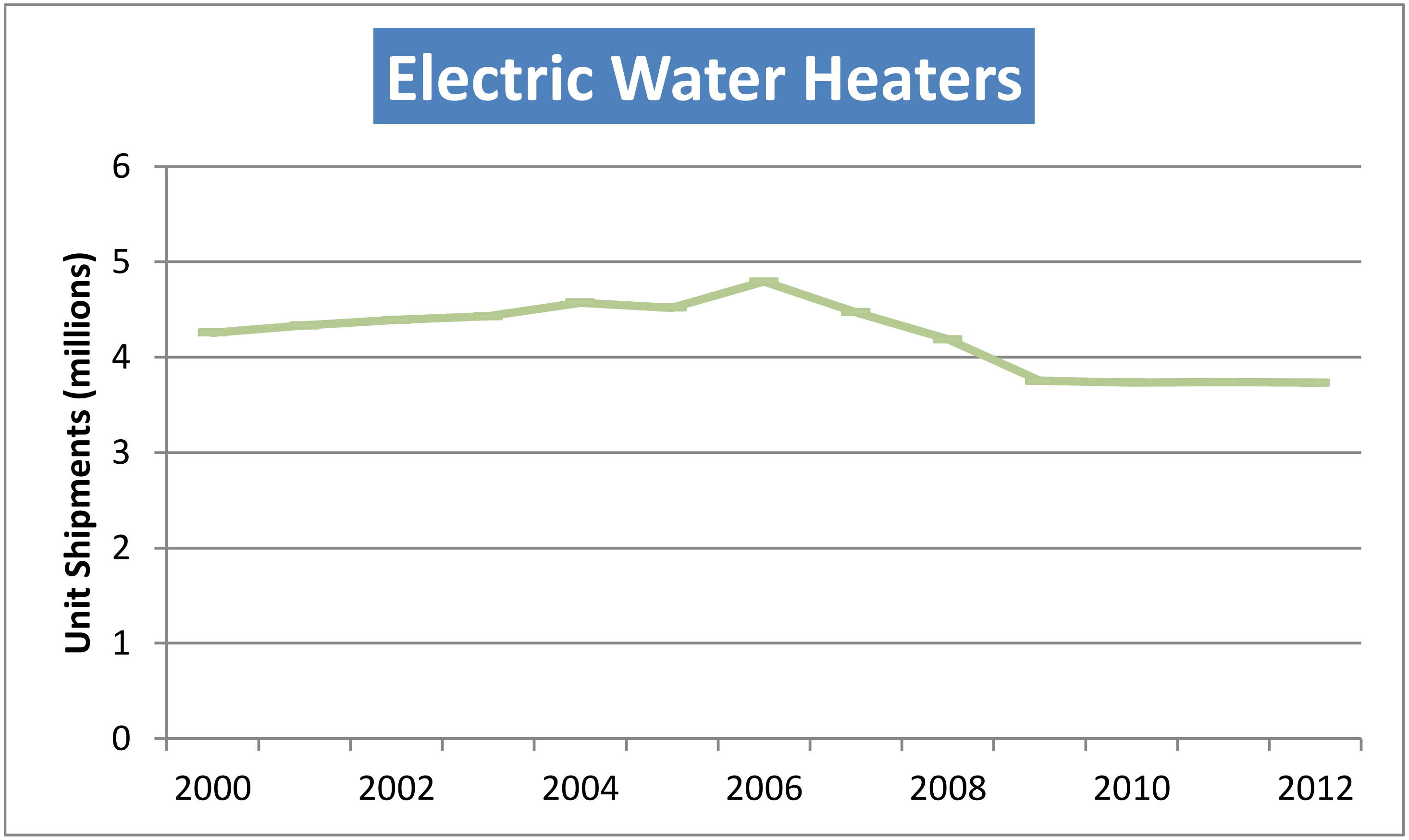
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  $EF=0.96-(0.0003*Gal)$ for a volume $\leq$ 55 gallons, and

  $EF=2.057-(0.00113*Gal)$ for a volume $>$ 55 gallons.

- Residential electric resistance water heater capacities usually range between 30 and 119 gallons.

Shipments peaked in 2006 then dropped a total of 22 percent over three years and leveled off at 3.7 million units per year.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

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Residential Heat Pump Water Heaters

Higher typical efficiencies than ref. case

DATA	2009	2013		2020		2030		2040	
	Installed Base	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50
Energy Factor	2	2	2.45	2.3	2.75	2.5	3.6	2.75	2.45
Average Life (yrs)	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	1,500	1,500	1,600	1,500	1,600	1,550	5,250	1,600	3,500
	1,800	1,800	2,100	1,800	2,100	1,950	6,000	2,100	4,000
Total Installed Cost ($)	1,610	1,610	1,710	1,610	1,710	1,660	5,360	1,710	3,610
	2,330	2,330	2,630	2,330	2,630	2,480	6,530	2,630	4,530
Annual Maintenance Cost ($)	16	16	16	16	16	16	16	16	16

Residential Heat Pump Water Heaters

- The minimum EF for ENERGY STAR qualification is 2.0 for heat pump water heaters (HPWH). All HPWH products on the market meet ENERGY STAR minimums and no HPWH products are being offered below the ENERGY STAR efficiency level.
- There is no unique Federal standard HPWH, but integrated HPWHs are in the same product class as electric resistance water heaters, so the Federal electric resistance water heaters standard also applies to HPWH.
- Technology improvements have advanced efficiency and reliability, but the high first-cost still precludes high-volume market penetration. Although there is an installed base listed for 2009, the market penetration of HPWHs was quite low at that time.
- Several major water heater manufacturers have an integrated HPWH model on the market, and other competitors offer integrated or retrofit units (for existing electric or indirect storage water heaters).
- Stiebel Eltron has an 80 gallon, 2.51 EF HPWH. This unit was not included in this analysis because it has a significantly larger capacity than the units included on the previous slide.
- Sales are estimated to be driven partly by rebates and tax credits at the utility, local, state, and Federal level.
- Resistive heating elements are virtually 100% efficient, but there is a jump in efficiency when heat pump technology is adopted because heat pumps' COP are usually between 2 and 3.
- Heat pumps raise the water temperature at a slow rate, so it is usual for these systems to use resistive heat for some of the water heating process. All HPWH systems examined by DOE allow the consumer to adjust the HPWH behavior.
- First-hour ratings range from 57 to 68 gallons.

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Residential Instantaneous Water Heaters

Higher typical efficiencies than ref. case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	185	117	178	178	150	178	150	185	185	185	150
Energy Factor	0.82	0.62	0.82	0.82	0.98	0.87	0.98	0.93	0.98	0.98	0.98
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8
	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	1,120	900	900	900	2,300	1,350	2,300	1,850	2,300	2,300	2,300
	1,220	1,400	1,400	1,400	2,400	1,550	2,400	2,000	2,400	2,400	2,400
Total Installed Cost ($)	1,650	1,430	1,430	1,430	2,830	1,880	2,830	2,380	2,830	2,830	2,830
	1,750	1,930	1,930	1,930	2,930	2,080	2,930	2,530	2,930	2,930	2,930
Annual Maintenance Cost ($)	85	85	85	85	85	85	85	85	85	85	85

Residential Instantaneous Water Heaters

- The current minimum EF for ENERGY STAR qualification is 0.80 EF or higher. Most instantaneous water heaters sold in 2013 are gas-fired and qualify for ENERGY STAR. In July 2013, the criteria will increase to 0.82 EF, which many existing models qualify for.
- Navien manufactures the highest efficiency gas-fired models currently available on the market, which have an EF of 0.98. This is achieved through the use of electronic ignition, powered direct venting, and through condensing the flue gases.
- All of the major water heater manufacturers now offer an instantaneous model.
- The maintenance cost includes cleaning the water inlet filter and the heat exchanger of mineral deposits and replacing the water valve approximately once every five years for all energy efficiency levels of instantaneous water heaters.
- When replacing a storage water heater with an instantaneous water heater, there are significant additional costs to upsize the gas supply line to ¾ inch from the typical ½ inch and change the venting.

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Residential Solar Water Heaters

DATA	2009	2013		2020	2030	2040
	Installed Base	Current Standard	Typical / ENERGY STAR	Typical	Typical	Typical
Typical Capacity (sq. ft.)	42	NA	42	42	42	42
	63	NA	63	63	63	63
Overall Efficiency (Solar Fraction)	0.5	NA	0.5	0.5	0.5	0.5
Solar Energy Factor	2.5	NA	2.5	3	3.5	3.5
Average Life (yrs)	20	NA	20	20	20	20
Retail Equipment Cost ($)	3,300	NA	3,300	3,000	2,600	2,600
	5,200	NA	5,200	4,700	4,100	4,100
Total Installed Cost ($)	7,600	NA	7,600	7,300	6,900	6,900
	10,000	NA	10,000	9,500	8,900	8,900
Annual Maintenance Cost ($)	25	NA	25	25	25	25

[1] Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.
[2] ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

Residential Solar Water Heaters

- ENERGY STAR requires an OG-300 rating from the Solar Rating and Certification Corporation (SRCC). Most installations use SRCC rated collectors, so there is no high efficiency category.
- Solar water heaters (SWHs) can be either active or passive. An active system uses an electric pump to circulate the heat transfer fluid; a passive system has no pump. Most solar water heaters in the United States are the active type.
- Solar water heaters are also characterized as open loop (also called "direct") or closed loop (also called "indirect"). An open-loop system circulates household (potable) water through the collector. A closed-loop system uses a heat transfer fluid (water or diluted antifreeze, for example) to collect heat and a heat exchanger to transfer the heat to household water.
- Solar fraction represents the fraction of total annual water heating energy met by the solar water heater. A backup water heating system is required with SWHs, and it is typically most economical to size the system to provide about 50% of water heating energy (solar fraction = 0.5).
- Solar Energy Factor (SEF) is defined by the SRCC as the useful energy delivered by the system divided by the total electrical and/or fossil fuel required for backup heating, pumping, and controls (the free solar energy input is neglected).
- Over 2/3 of the current SWH market is in the southern or western US (including Hawaii). The collector area of 42 ft^2 would be typical for these areas. Colder areas of the US would require a larger collector (63 ft^2).
- Installed costs are higher for colder areas where larger collectors are required. Costs also vary widely depending on collector quality, type of system, and site-specific characteristics.

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Residential Gas-Fired Furnaces

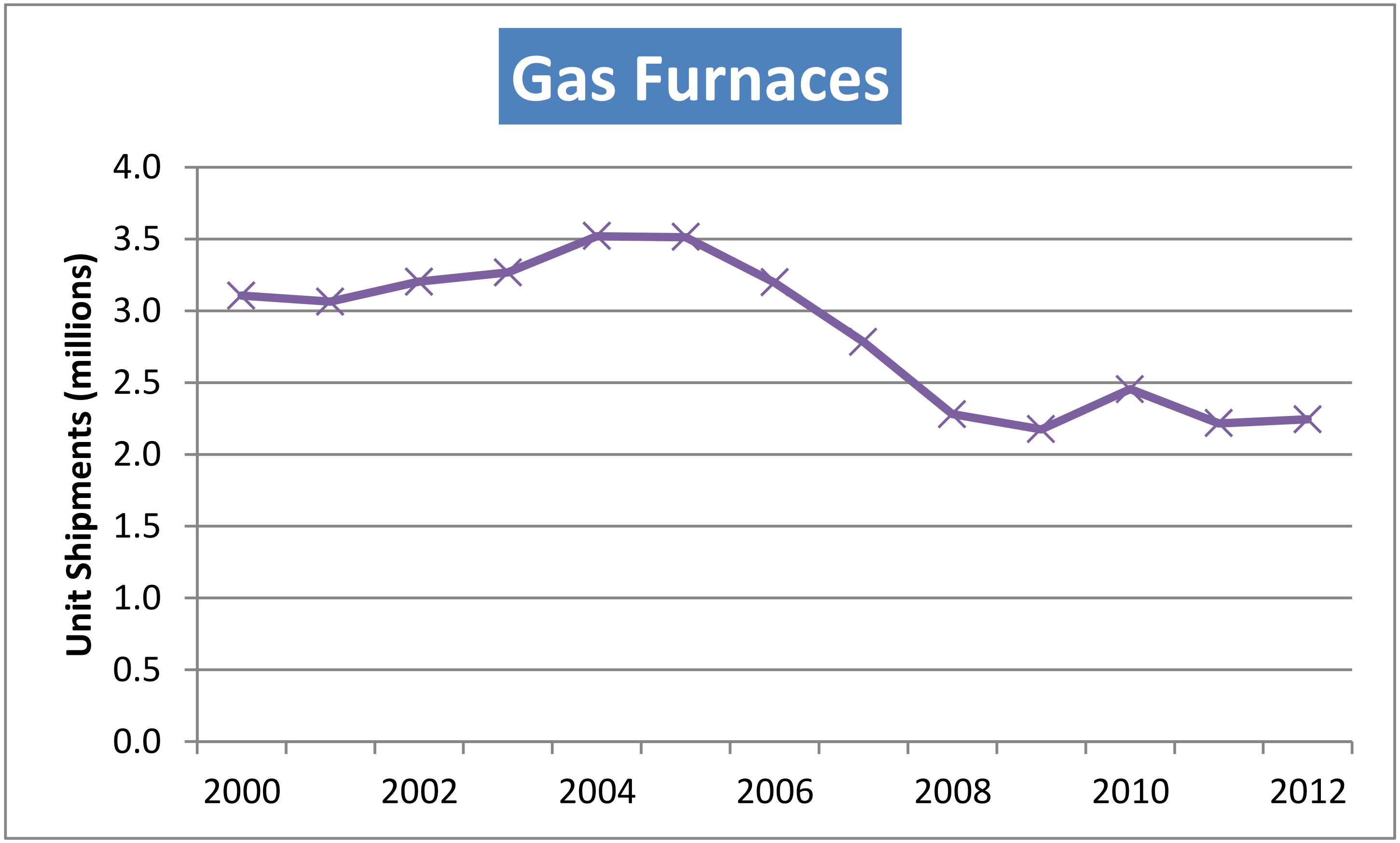
Higher typical efficiencies and lower costs for a given efficiency level

DATA	2009	2013					2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR (South)	ENERGY STAR (North)	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	75	75	75	75	75	75	75	75	75	75	75	75
AFUE (%)	80	80	80	90	95	98	90	98	94	98	96	98
Electric Consumption (kWh/yr)	312	312	312	289	275	363	289	275	283	275	283	275
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
	17	17	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost ($)	750	750	750	1,000	1,200	1,500	1,000	1,500	1,100	1,500	1,200	1,500
	1,100	1,100	1,100	1,300	1,500	1,700	1,300	1,700	1,300	1,700	1,400	1,700
Total Installed Cost ($)	1,500	1,500	1,500	2,200	2,400	2,700	2,200	2,700	2,300	2,700	2,400	2,700
	2,300	2,300	2,300	2,800	3,000	3,200	2,800	3,200	2,800	3,200	2,900	3,200
Annual Maintenance Cost ($)	45	45	45	45	45	45	45	45	45	45	45	45

Residential Gas-Fired Furnaces

- Current Federal standards for non-weatherized units:
  - South: AFUE ≥ 80%
  - North: AFUE ≥ 90%
  - ≤ 10 watts of electrical power when in standby and off modes
  - Contested in court and not being enforced by DOE
- ENERGY STAR criteria:
  - South: AFUE ≥ 90%
  - North: AFUE ≥ 95%
- Most efficient available: 98% AFUE. The market is nearly evenly split between non-condensing units (AFUE≤85) and condensing units (AFUE≥90).
- Condensing furnaces use an additional heat exchanger to extract additional energy from the flue gases; some models also have variable speed blowers, which decrease electrical energy consumption, and inducer fan systems, which usually have modulating gas valves to allow the furnace to modulate in very small increments, providing an AFUE boost of a few percentage points.
- Non-condensing AFUE levels for natural gas top out at around 81%; above this level, the potential for exhaust gas condensation increases. This condensate is corrosive and requires cost restrictive corrosion resistant venting.
- High-efficiency condensing furnaces typically have aluminized steel heat exchangers and low NO_x emissions, flexible installation, direct vent, and sealed combustion systems. Direct vent furnaces do not use room air for combustion, but instead draws combustion air directly from outdoors.
- Depending on the location of the home, piping materials in use, and other considerations, condensing furnaces may need an acid neutralizer and/or lift pump for the condensate.
- Furnaces may contain permanent split capacitor (PSC) or electronically commutated motor (ECM) fan motors, though the type of motor has no impact on the AFUE measurement. It only impacts SEER/EER of the associated air conditioner.

Annual shipments peaked at 3.5 million units in 2005 then declined each year until 2009 and leveled off at about 2.25 million units.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

Final

Residential Oil-Fired Furnaces

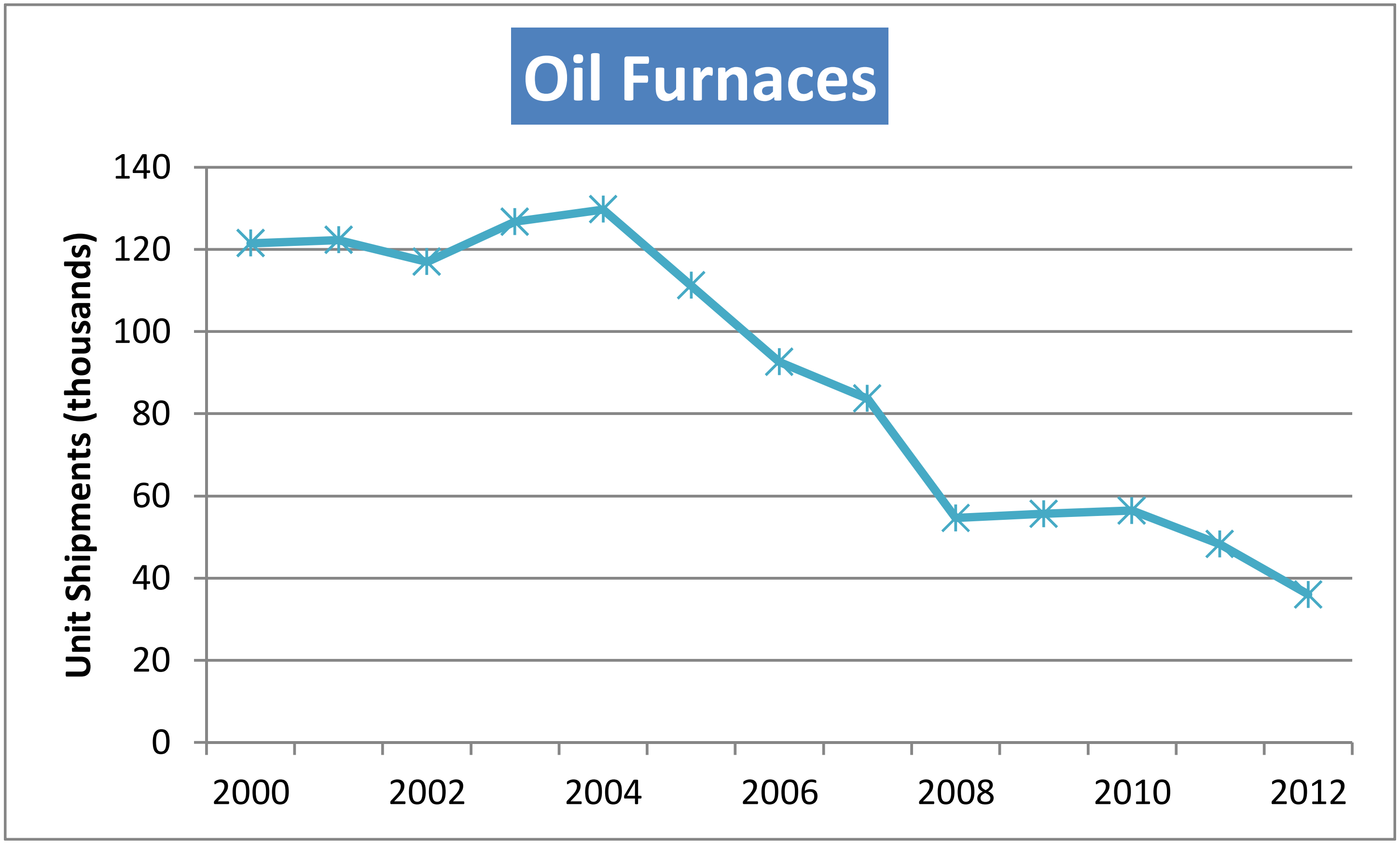
Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	83	83	85	97	84	97	84	97	85	97
Electric Consumption (kWh/yr)	490	477	477	460	410	472	410	472	410	460	410
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15
	19	19	19	19	19	19	19	19	19	19	19
Retail Equipment Cost ($)	2,050	2,300	2,300	2,300	2,700	2,300	2,700	2,300	2,700	2,300	2,700
	2,250	2,400	2,400	2,400	2,900	2,400	2,900	2,400	2,900	2,400	2,900
Total Installed Cost ($)	2,600	3,050	3,050	3,150	4,550	3,050	4,550	3,050	4,550	3,050	4,550
	3,250	3,550	3,550	4,650	5,200	3,550	5,200	4,350	5,200	4,350	5,200
Annual Maintenance Cost ($)	65	65	65	65	65	65	65	65	65	65	65

Residential Oil-Fired Furnaces

- Current Federal standards:
  - AFUE ≥ 83%
  - ≤ 11 watts of electrical power when in standby and off modes (non-weatherized models only)
- ENERGY STAR criteria: AFUE ≥ 85%
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Most efficient available: 96% AFUE – condensing units with tiny market share (<1%), due to market acceptance issues.
- Condensate from condensing oil furnaces is typically even more corrosive than that of gas-fired systems due to the higher sulfur content in fuel oil. Hence, condensing oil furnaces also likely require the use of an acid neutralizer.
- Oil-fired furnaces, like gas-fired furnaces, achieve condensing conditions through the use of a secondary heat exchanger. Typically, these heat exchangers use a high-grade stainless steel (Al29-4C) as the primary heat exchange surface.
- Sooting is an issue for all oil-fired appliances, but secondary heat exchangers, with their narrow passages, are even more prone to be plugged by soot. Because of this, oil furnaces require frequent cleaning and maintenance.

Annual shipments declined rapidly after 2004, likely due at least in part to an increase in fuel oil prices, which more than tripled from 2002 to 2008.



Source: *Appliance Magazine* (also available from http://www.ahrinet.org/historical+data.aspx)

Final

Residential Gas-Fired Boilers

Higher typical efficiencies and lower costs for a given efficiency level

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	82	82	85	96	90	96	93	96	95	96
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17
	24	24	24	24	24	24	24	24	24	24	24
Retail Equipment Cost ($)	1,950	2,100	2,100	2,300	3,450	3,000	3,450	3,100	3,400	3,200	3,350
	2,550	2,900	2,900	3,100	4,500	3,800	4,500	3,900	4,450	4,000	4,400
Total Installed Cost ($)	3,900	4,050	4,050	4,700	6,350	5,900	6,350	6,000	6,300	6,100	6,250
	4,500	4,850	4,850	5,500	7,600	6,900	7,600	7,000	7,550	7,100	7,500
Annual Maintenance Cost ($)	50	50	50	50	50	50	50	50	50	50	50

Final

Residential Gas-Fired Boilers

- Federal standard for hot-water gas-fired boilers (more common than steam):
  - AFUE ≥ 82%
  - Design requirements that took effect on September 1, 2012 prohibit a constant burning pilot and require an automatic means for adjusting water temperature
- ENERGY STAR criteria: AFUE ≥ 85%
- Most efficient available: 96% AFUE
- Have lost market share to furnaces and heat pumps over the past 30 years
- The bulk of U.S. boiler sales are non-condensing boilers, which are primarily manufactured in North America. These are typically high-mass systems whose heat exchangers are made of cast iron.
- Due to incentives and market pressure, the U.S. boiler industry has been shifting towards also providing condensing boilers. Most of these boilers are private-labeled products sourced from Europe, where the hydronic market is much bigger and condensing appliances are much more common and/or required by law.
- Typically, condensing boilers are low-mass in construction with modulating burners, variable-speed inducer fan systems, sealed powered direct-vent combustion, multiple sensor technologies, and electronic ignition and control.
- Most value-added components for condensing boilers are sourced abroad, even when the condensing boiler is assembled in North America (i.e. heat exchanger, gas valve, burner, blower systems, sensors, and/or controls).

Final

Residential Oil-Fired Boilers

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	140	140	140	140	140	140	140	140	140	140	140
AFUE (%)	80	84	84	85	91	84	91	85	91	86	91
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	2,300	2,300	2,300	2,300	3,300	2,300	3,300	2,300	3,300	2,300	3,300
	2,900	2,900	2,900	3,350	4,150	2,900	4,150	2,900	4,150	2,900	4,150
Total Installed Cost ($)	4,150	4,150	4,150	4,700	6,200	4,150	6,200	4,150	6,200	4,150	6,200
	4,750	4,750	4,750	5,900	7,250	4,750	7,250	4,750	7,250	4,750	7,250
Annual Maintenance Cost ($)	135	135	135	135	135	135	135	135	135	135	135

Residential Oil-Fired Boilers

- Federal standard for hot-water oil-fired boilers (more common than steam):
  - AFUE ≥ 84%
  - Design requirements that took effect on September 1, 2012 require an automatic means for adjusting water temperature
- ENERGY STAR criteria: AFUE ≥ 85%
- Most efficient available: 91% AFUE
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Oil boilers have heat exchangers comprised of cast iron or steel.

Final

Residential Room Air Conditioners

Higher typical efficiencies and lower costs for a given efficiency level

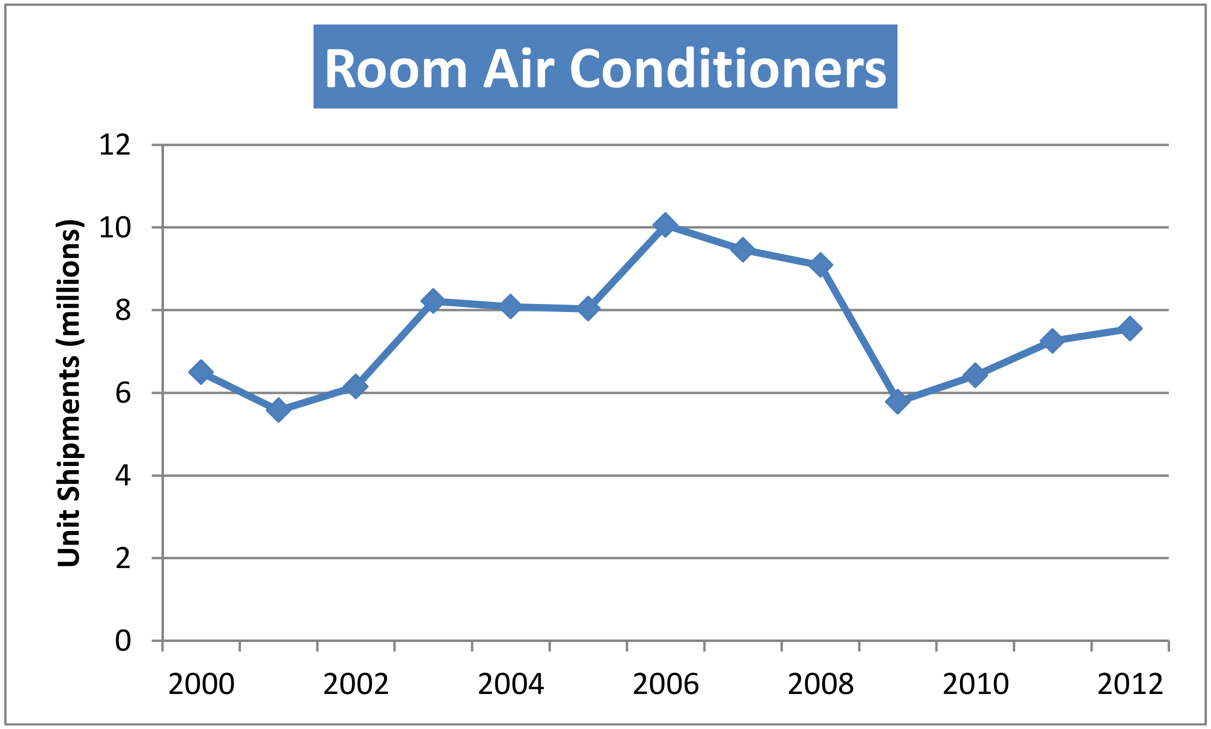
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)*	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
EER**	9.2	9.8	10.8	10.8	11.5	*11.4*	*11.9*	*11.9*	*12.9*	*11.9*	*12.9*
CEER**	*9.3*	*9.9*	*10.9*	*10.9*	*11.6*	11.5	12.0	12.0	13.0	12.0	13.0
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6
	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost ($)	220	250	270	270	430	370	480	430	510	430	510
	300	320	340	340	500	440	550	500	590	500	590
Total Installed Cost ($)	320	350	370	370	530	470	580	530	610	530	610
	400	420	440	440	600	540	650	600	690	600	690
Annual Maintenance Cost ($)	-	-	-	-	-	-	-	-	-	-	-

* All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).
** Italicized values are estimated. The federal standard is expressed in EER, but will be expressed in CEER beginning in 2014. The two metrics are not strictly comparable, but both values are shown here to facilitate longitudinal analyses.
*** Maintenance costs are negligible.

Residential Room Air Conditioners

- Focus on most common type: louvered sides (window air conditioners) without reverse cycle and having cooling capacity of 8,000–13,999 Btu/h (DOE Product Class 3).
- Federal standards for Product Class 3:
  - EER ≥ 9.8 (until May 31, 2014)
  - CEER ≥ 10.9 (beginning June 1, 2014)
- Combined Energy Efficiency Ratio (CEER) is a new metric that incorporates energy use in all operating modes, including standby and off modes.
- Of the 538 models in Product Class 3 listed in DOE's CCMS database:
  - 1/3 are at the standard level (9.8 EER)
  - 2/3 are at the ENERGY STAR level (10.8 EER)
  - Most efficient model is at 11.8 EER
- New ENERGY STAR criteria take effect on 10/1/2013: EER ≥ 11.3.
- Most efficient product in 2030: 13.0 EER, based on Building Technologies Program R&D.
- Efficiency improvements are attained by:
  - Higher efficiency compressor and fan motors, and
  - An increased heat transfer area in the evaporator and condenser through the use of larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.

Sales were down in 2009, likely due to the recession and an unusually cool summer in the Northeast. Sales have increased each year since.



Source: *Appliance Magazine*.

South (Hot-Dry and Hot-Humid)

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	13.0	13.5	14.5	24.0	14.5	24.0	15.0	24.0	15.5	24.0
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	1,700	1,700	1,750	1,900	4,550	1,900	4,550	1,900	4,550	1,900	4,550
Total Installed Cost ($)	2,100	2,100	2,150	2,300	5,100	2,300	5,100	2,300	5,100	2,300	5,100
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22
	130	130	130	130	130	130	130	130	130	130	130

* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs are for "coil-only" systems, meaning they do not include a blower.

North (Rest of Country)

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	13.0	13.0	14.5	24.0	14.0	24.0	14.5	24.0	15.0	24.0
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	1,700	1,700	1,700	1,900	4,500	1,800	4,500	1,900	4,500	1,900	4,500
Total Installed Cost ($)	2,300	2,300	2,300	2,500	5,300	2,400	5,300	2,500	5,300	2,500	5,300
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22
	130	130	130	130	130	130	130	130	130	130	130

* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs are for "coil-only" systems, meaning they do not include a blower.

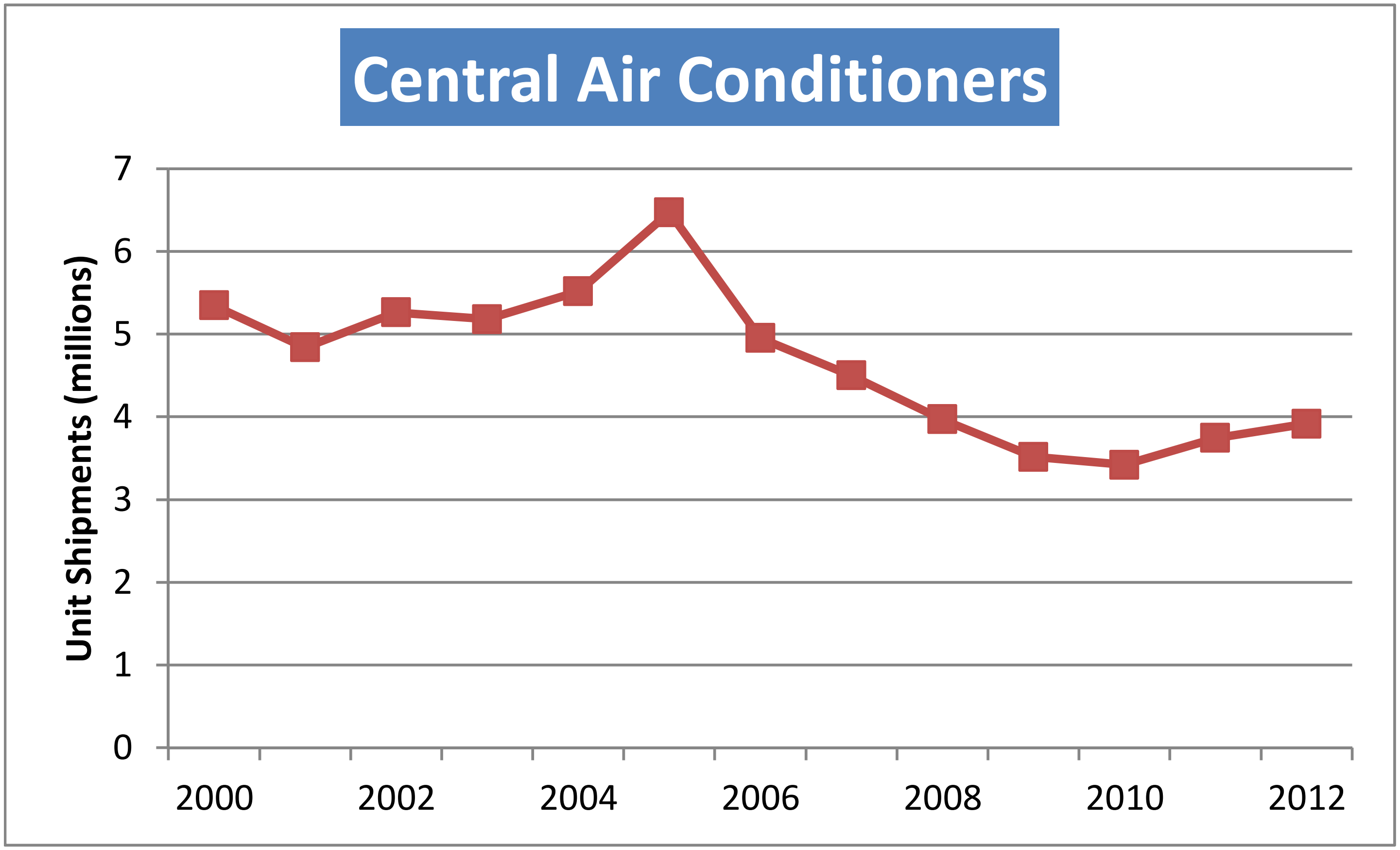
Final

Residential Central Air Conditioners

Residential Central Air Conditioner Product Class	Current Standard	Current ENERGY STAR Criteria		Future Standards (Jan. 1, 2015)		
	Min. SEER	Min. SEER	Min. EER	Min. SEER in North	Min. SEER in South	Max. Off Mode Power (W)
Split-System AC	13	14.5	12	13	14	30
Single-Package AC	13	14	11	14	14	30
Small-Duct, High-Velocity	13	–	–	13	13	30
Space-Constrained	12	–	–	12	12	30

- Current standards, which took effect in 2006, represent a significant improvement in efficiency from 10 SEER for split systems and 9.7 SEER for single-package units.
- Typical new units today are at the standard level of 13 SEER (for most product classes).
- Effective Jan. 1, 2015, the standard for split systems will increase to 14 SEER in the South and the standard for single-package units will increase to 14 SEER nationwide.
- Beginning in 2015, central AC units installed in the Southwest (CA, AZ, NM, and NV) will also have to meet a new energy efficiency ratio (EER) standard that varies by cooling capacity.

Annual shipments spiked at 6.5 million units in 2005 at the peak of the housing boom and just before more stringent Federal standards took effect in 2006.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

Final

Residential Air Source Heat Pumps

Same as reference case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
SEER (Cooling)*	12.0	13.0	14.0	14.5	22.0	14.5	23.0	15.5	24.0	16.0	25.0
HSPF (Heating)*	7	7.7	8.3	8.2	9	8.4	10.8	8.6	10.9	8.7	11
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)*	2,700	2,700	2,850	2,900	4,000	2,900	4,150	3,150	4,250	3,250	4,400
Total Installed Cost ($)*	3,150	3,150	3,300	3,400	4,500	3,400	4,600	3,650	4,750	3,750	4,900
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22
	130	130	130	130	130	130	130	130	130	130	130

* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. "High" units were selected for maximum cooling, not heating, efficiency.

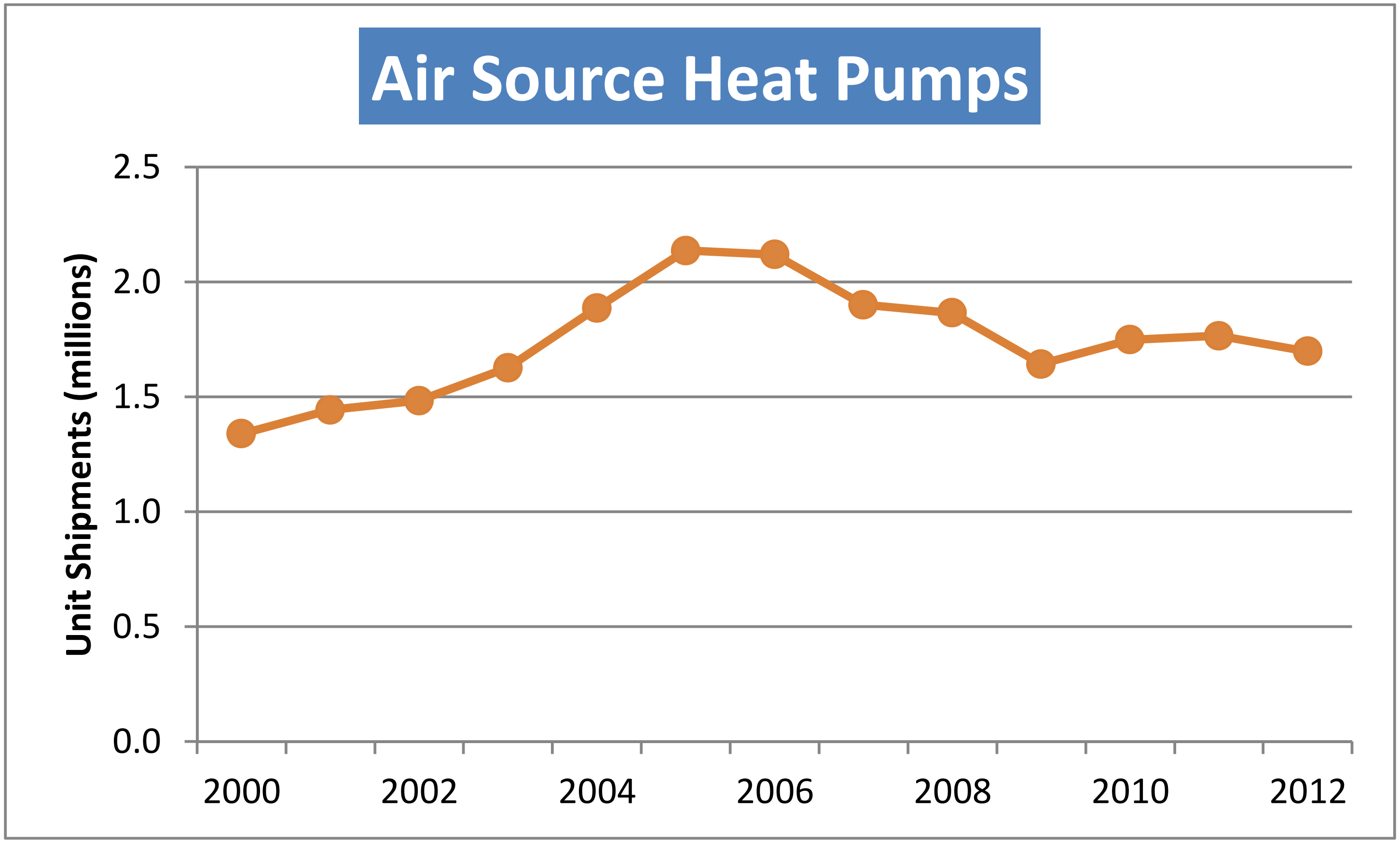
Final

Residential Air Source Heat Pumps

Residential Heat Pump Product Class	Current Standard		Current ENERGY STAR Criteria			Future Standards (Jan. 1, 2015)		
	Min. SEER	Min. HSPF	Min. SEER	Min. EER	Min. HSPF	Min. SEER	Min. HSPF	Max. Off Mode Power
Split-System	13	7.7	14.5	12	8.2	14	8.2	33 W
Single-Package	13	7.7	14	11	8.0	14	8	33 W
Small-Duct, High-Velocity	13	7.7	–	–	–	13	7.7	30 W
Space-Constrained	12	7.4	–	–	–	12	7.4	33 W

- High efficiency cooling does not necessarily correlate with high efficiency heating. The range of SEER–HSPF combinations is very broad.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, electric resistance heat is used to supplement.
- When the heat pump's heating capacity exceeds the heating load, the heat pump starts and stops more frequently, causing wear and tear on the components and an overall loss of efficiency. Multi-stage and/or variable-speed compressors can help, as does sophisticated refrigerant management.

From 2000 to 2005 annual shipments increased nearly 60% to 2.1 million units, then dropped and leveled off around 1.7 million units.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

- Principal energy efficiency drivers for central air conditioners and heat pumps :
  - Heat exchanger (surface area, number of tube rows)
  - Compressor (type and single-stage vs. two-stage vs. variable-speed operation)
  - Fan motor choices (PSC vs. ECM fan motors on inside and outside)
  - Control choices (i.e., piston, thermal, and electronic expansion valves)
- Typical high-efficiency unit (≥16 SEER) has very large heat exchanger, ECM evaporator fan motor, and two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, making possible high-SEER condensing units with smaller enclosures.
- Efficiency levels >21 SEER made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and electronic expansion valves.

Final

Residential Ground Source Heat Pumps

Higher typical efficiencies and lower costs than reference case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36
COP (Heating)	3	3.1	3.2	3.6	4.5	3.8	4.9	4.1	5.2	4.4	5.4
EER (Cooling)	12.3	13.4	14.2	17.1	28	22	36	29	42	33	46
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	5,000	3,000	3,000	5,000	7,000	4,900	7,000	4,800	7,000	4,700	7,000
	7,000	5,000	5,000	7,000	9,000	6,900	9,000	6,800	9,000	6,700	9,000
Total Installed Cost ($)	15,000	10,000	10,000	15,000	20,000	14,900	20,000	14,800	20,000	14,700	20,000
	20,000	15,000	15,000	20,000	27,000	19,900	27,000	19,800	27,000	19,700	27,000
Annual Maintenance Cost ($)	75	75	75	75	75	75	75	75	75	75	75

Residential Ground Source Heat Pumps

- There are currently over 20 ground source heat pump manufacturers/OEMs in the US.
- Heating COP does not correlate with cooling EER (coefficient of determination, $R^2 = 0.59$ for ENERGY STAR certified products). The highest efficiency GSHP is the 7 Series by WaterFurnace International, Inc. (41 EER & 5.3 COP). Note that these are equipment-level thermal ratings tested according to standardized lab conditions and do not necessarily represent system-level or "real-world" performance.
- The ENERGY STAR® criteria for water-to-air ground source heat pumps are:

Type	Tier 1 (12/1/2009)		Tier 2 (1/1/2011)		Tier 3 (1/1/2012)	
	Heating COP	Cooling EER	Heating COP	Cooling EER	Heating COP	Cooling EER
Closed Loop	3.3	14.1	3.5	16.1	3.6	17.1
Open Loop	3.6	16.2	3.8	18.2	4.1	21.1
Direct Expansion	3.5	15	3.6	16	3.6	16

- The most common ground source heat pump is a closed-loop system in which water or an anti-freeze solution is circulated through plastic pipes buried underground. Open loop systems that employ ground water or surface water (e.g., open well, pond, lake) are used in some parts of the country, but water supply and water quality issues impose limitations on such applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger represents a majority of the installation cost. Installed costs for these systems vary widely.
- Variable speed electronically commutated motors (ECMs) improve performance on high end models.

Residential Gas Heat Pumps

Higher efficiencies and lower costs than reference case

DATA	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	60	60	60	60	60
Heating (COP)	1.3	1.3	1.4	1.45	1.5
Cooling (COP)	0.6	0.6	0.7	0.8	0.9
Annual Electric Use (kWh/yr)	2,000	1,500	1,500	1,500	1,500
Average Life (yrs)	15	15	15	15	15
Retail Equipment Cost ($)	10,500	10,500	10,400	10,300	10,200
	11,700	11,700	11,600	11,500	11,400
Total Installed Cost ($)	12,000	12,000	11,900	11,800	11,700
	14,200	14,200	14,100	14,000	13,900
Annual Maintenance Cost ($)	160	160	160	160	160

NAECA does not cover residential gas heat pumps, but the CEC Title 24, Part 6 Section 112 does indicate minimum cooling efficiency for gas heat pumps.

Residential Gas Heat Pumps

- Residential Gas Heat Pumps are not currently covered by NAECA. CEC Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for gas heat pumps.
- Gas heat pumps are much more popular in Europe and Asia. Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market in the U.S.
- Currently, Robur is the predominant manufacturer of residential-sized gas heat pumps with sales to the US. Robur units are 5-ton cooling capacity, a size typically associated with larger homes. Since only one product is available, no mid-level or high efficiency categories are included.
- The data represents air-source absorption heat pumps. Gas engine-driven vapor compression heat pumps are available in other parts of the world; York formerly offered the Triathlon gas engine-driven heat pump in the US. It is possible to couple either technology to the ground (ground source) rather than the atmosphere (air source).
- The absorption heat pump is a gas-fired, ammonia-water absorption cycle, combined with a high-efficiency low-pressure boiler integrated into one outdoor unit.
- The cooling efficiency of a gas-fired air source absorption heat pump is considerably lower than for an electric air source heat pump. Heating efficiency of an air source heat pump (electric or gas-fired absorption) decreases as outdoor temperature decreases; however the gas-fired absorption heat pump recovers waste heat from the combustion process to improve heating efficiency.

Final

Residential Electric Resistance Furnaces

Same as reference case

DATA	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	68	68	68	68	68
AFUE (%)	99	99	99	99	99
Average Life (yrs)	20	20	20	20	20
	30	30	30	30	30
Retail Equipment Cost ($)	600	600	600	600	600
	700	700	700	700	700
Total Installed Cost ($)	1,000	1,000	1,000	1,000	1,000
	1,200	1,200	1,200	1,200	1,200
Annual Maintenance Cost ($)	40	40	40	40	40

Residential Electric Resistance Furnaces

- This analysis examined non-weatherized (installed indoors) electric resistance central warm-air furnaces.
- There are currently no federal requirements on electric resistance furnaces. ASHRAE 90.1-2010 unit heater requirements only capture gas and oil-fired units.
- According to RECS 2009 data, electric central warm-air furnaces are the main source of space heating in approximately 19.1 million US homes or about 17%.
- Electric furnaces range in capacity from 10 to 25 kW (34 to 85 kBtu/hr), with 20 kW (68 kBtu/hr) being the typical for units on the market.
- Electric resistance furnaces are considered near 100% efficient because there is no flue heat loss and any jacket losses are contained within the home. For this analysis, the efficiency is 99% to account for IR losses. Furnace fans or blowers have no impact on AFUE measurements.

Final

Residential Electric Resistance Unit Heaters

Same as reference case

DATA	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBTU/h)	3.5	3.5	3.5	3.5	3.5
Efficiency (%)	0.98	0.98	0.98	0.98	0.98
Average Life (yrs)	18	18	18	18	18
Retail Equipment Cost ($)	75	75	75	75	75
	200	200	200	200	200
Total Installed Cost ($)	125	125	125	125	125
	275	275	275	275	275
Annual Maintenance Cost ($)*	-	-	-	-	-

* Annual Maintenance Cost is negligible

Residential Electric Resistance Unit Heaters

- This analysis examined electric wall and baseboard heaters. Plug-in space heaters are considered plug loads and, therefore, not included.
- There are currently no federal requirements on electric resistance unit heaters. ASHRAE 90.1-2010 unit heater requirements only capture gas and oil-fired units.
- According to RECS 2009 data, electric resistance unit heaters are the main source of space heating in approximately 5.7 million US homes or about 5%.
- Electric heaters range in capacity from 500 to 2,500 watts (1.7 to 8.5 kBtu/hr), with 1,000 watts (3.5 kBtu/hr) being the most typical for units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion. For this analysis, the efficiency is 98% to account for IR losses and fan inefficiency.

Final

Residential Cordwood Stoves

Same as reference case

DATA	2009	2013			2020		2030		2040	
	Installed Base	EPA Certified (Default)	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (Non-Catalytic) (HHV)	58	63	63	74	70	77	73	78	74	79
Efficiency (Catalytic) (HHV)	68	72	72	81	78	84	81	85	82	86
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($) (Non-Catalytic)	2,400	2,400	2,400	3,200	2,600	3,400	2,800	3,600	3,000	3,800
Retail Equipment Cost ($) (Catalytic)	3,300	3,300	3,300	4,100	3,500	4,300	3,700	4,500	3,700	4,700
Total Installed Cost ($) (Non-Catalytic)	7,000	7,000	7,000	7,800	7,200	8,000	7,400	8,200	7,400	8,400
Total Installed Cost ($) (Catalytic)	7,900	7,900	7,500	8,700	8,100	8,900	8,300	9,100	8,500	9,300
Annual Maintenance Cost ($) (Non Catalytic)	150	150	150	150	150	150	150	150	150	150
Annual Maintenance Cost ($) (Catalytic)	225	225	225	225	225	225	225	225	225	225

*Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
**Installed cost includes cost of hearth and stainless steel chimney liner - materials and labor.
***Annual maintenance cost of catalytic stove includes periodic cost of replacing the catalytic combustor.

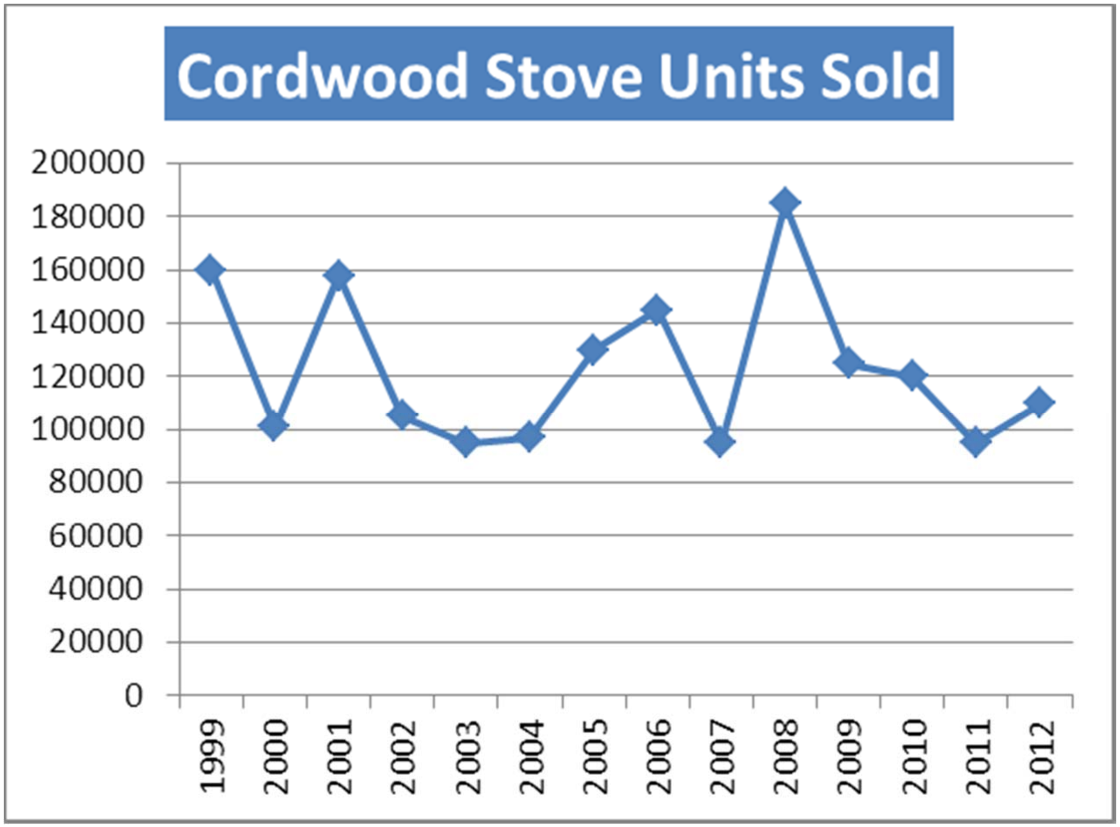
Residential Cordwood Stoves

- Residential cordwood stoves that must meet EPA particulate limits fall into two broad classes based on whether or not they use a catalyst for air treatment. Catalytic wood stoves use a catalytic combustor to reduce emissions from the combustion air. Non-catalytic wood stoves use baffles and introduce secondary air above the flames for more complete combustion to help reduce emissions.
- There are no efficiency standards for wood stoves. EPA publishes a list of stoves that have met emission limits for particulates and includes default efficiencies by type (non-catalytic and catalytic wood stoves). The emission limits are 7.5 grams/hr. for EPA certified non-catalytic wood stoves and 4.1 grams/hr. for catalytic wood stoves.
- The EPA default efficiencies are 63% for certified non-catalytic wood stoves and 72% for catalytic wood stoves. Manufacturers may submit efficiency data from laboratory testing to EPA, to include with the default values, but very few have done so.
- Data from product literature does not generally identify the efficiency test method. It's not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies.

Residential Cordwood Stoves

- Some states have instituted tighter emission standards along with minimum efficiency requirements (e.g., Oregon).
- EPA is considering updates to its New Source Performance Standards (NSPS) which would tighten the emissions limits and may include minimum efficiency requirements. However, the timing remains uncertain.
- Cordwood stoves require chimneys for venting combustion gases. Whether conventional masonry chimneys are used or metal chimney liners, these add considerable cost to the overall system. Installed costs can be double that of the wood stove itself.

Cordwood stove shipments have averaged 123,000 per year since 1999, and have rebounded somewhat since 2011.



Source: HPBA

Final

Residential Wood Pellet Stoves

Same as reference case

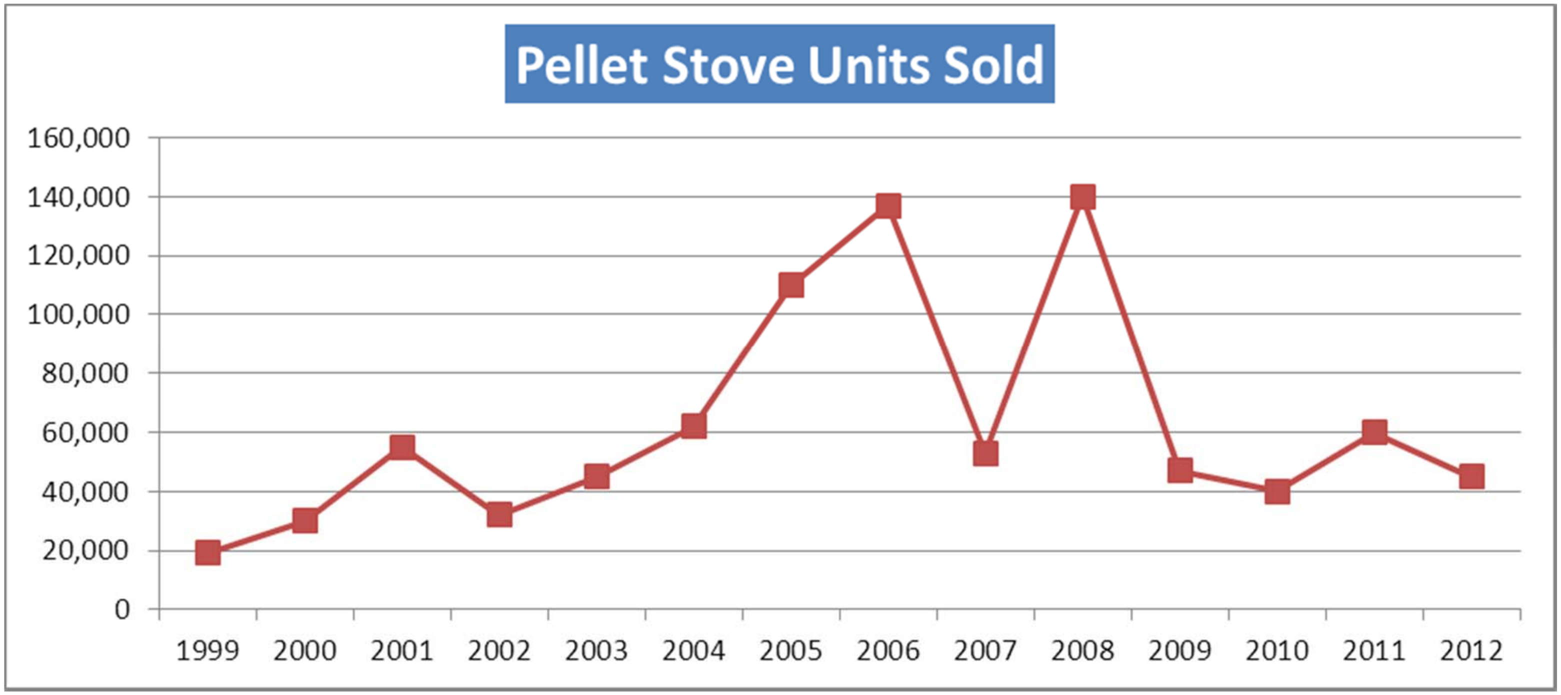
DATA	2009	2013			2020		2030		2040	
	Installed Base	EPA Certified (Default)	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)	65	78	78	81	81	84	83	86	84	87
Annual Electricity Consumption (kWh)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	3,300	3,300	3,300	4,200	3,500	4,400	3,700	4,600	3,900	4,800
Total Installed Cost ($)	4,700	4,700	4,700	5,600	4,900	5,800	5,100	6,000	5,300	6,200
Annual Maintenance Cost ($)	250	250	250	250	250	250	250	250	250	250

*Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
**Electricity consumption is for combustion air fan, distribution blower, and pellet feeder.
***Installed cost includes cost of hearth and vent pipe - materials and labor.

Residential Wood Pellet Stoves

- There are no efficiency standards for wood pellet stoves and they are not required to be certified by EPA. However, manufacturers that wish to be certified must meet an emission limit of 2.5 grams/hr.
- The EPA default efficiency for wood pellet stoves is 72%. Manufacturers may submit efficiency data from laboratory testing to EPA, to include with the default values, but very few have done so.
- Data from product literature does not generally identify the efficiency test method
- Some states have instituted tighter emission standards along with minimum efficiency requirements (e.g., Oregon).
- EPA is considering updates to its New Source Performance Standards (NSPS) which would tighten the emissions limits and may include minimum efficiency requirements. However, the timing remains uncertain.
- Wood pellet stoves may be able to be direct vented to the outdoors, eliminating the need for a chimney. This reduces the overall system cost as compared to a cord wood stove. However, they do use electricity to power the pellet feeder, the combustion air fan, and the blower. In the event of a power outage, a pellet stove can not operate without some back-up source of electricity (e.g., battery) .

Wood pellet stove shipments grew substantially in the 2005 – 2008 time period, but have averaged only 40,000 – 60,000 units since that time.



Source: HPBA

Top-Mount (Product Class 3)

Higher typical efficiencies than ref. case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/yr)**	586	482	407	385	311	385	311	365	311	345	311
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	550	530	570	620	880	620	880	700	880	780	880
Total Installed Cost ($)	550	530	570	620	880	620	880	700	880	780	880
Annual Maintenance Cost ($)	9	9	9	9	9	9	9	9	9	9	9

* The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 21 ft^3.

Bottom-Mount (Product Class 5)

Higher typical efficiencies than ref. case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	21	21	21	21	21	21	21	21	21	21	21
Energy Consumption (kWh/yr)**	574	574	540	459	457	500	457	459	457	459	457
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	935	930	940	980	980	960	980	980	980	980	980
Total Installed Cost ($)	935	930	940	980	980	960	980	980	980	980	980
Annual Maintenance Cost ($)	22	22	22	22	22	22	22	22	22	22	22

* The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 25 ft3.

Side-Mount (Product Class 7)

Higher typical efficiencies than ref. case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	26	26	26	26	26	26	26	26	26	26	26
Energy Consumption (kWh/yr)**	889	729	596	583	509	575	509	550	509	525	509
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	1,150	1,130	1,170	1,180	1,380	1,200	1,380	1,250	1,380	1,300	1,380
Total Installed Cost ($)	1,150	1,130	1,170	1,180	1,380	1,200	1,380	1,250	1,380	1,300	1,380
Annual Maintenance Cost ($)	24	24	24	24	24	24	24	24	24	24	24

* The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 32 ft3.

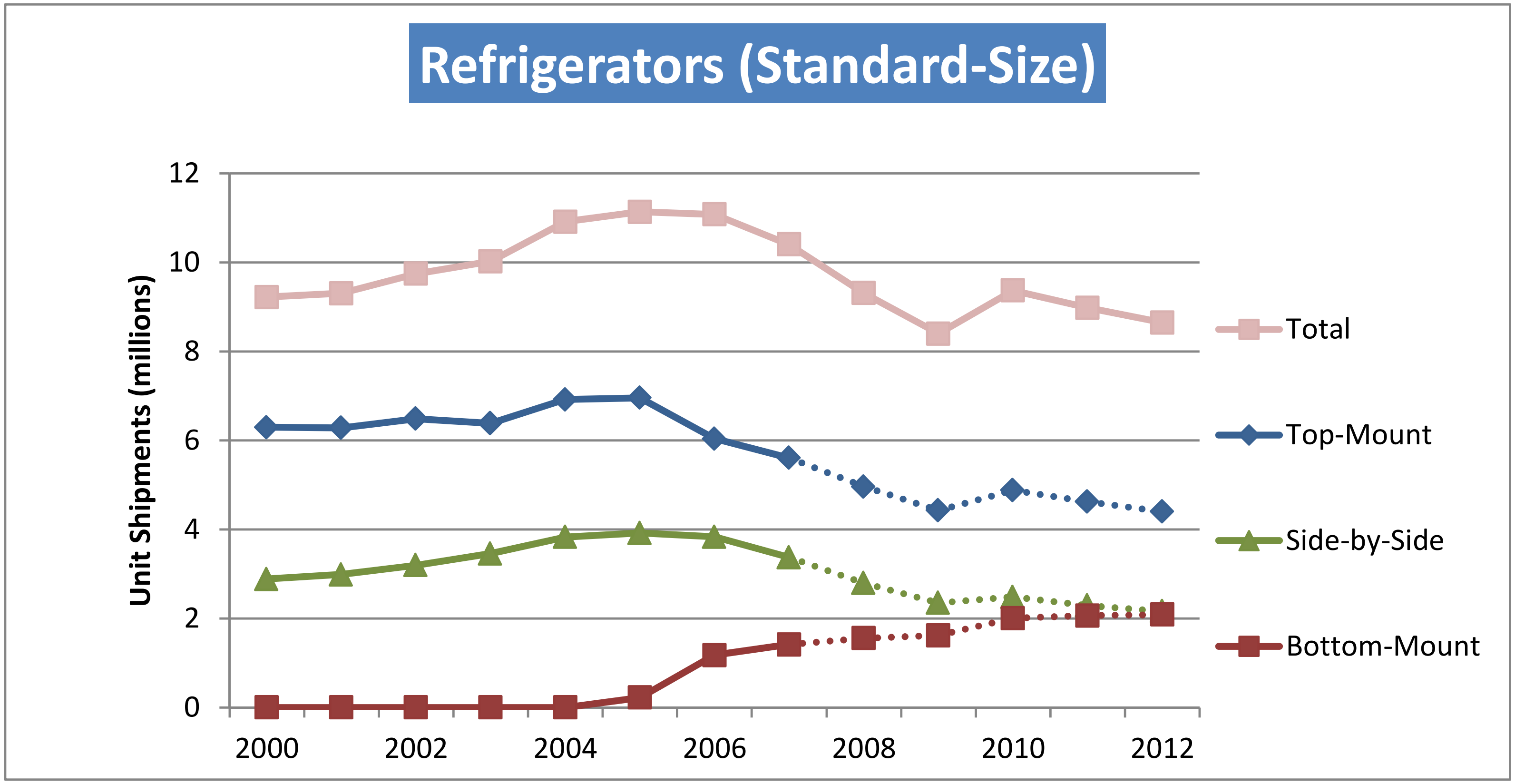
Final

Residential Refrigerator-Freezers

- Current Federal standards:
  - Compliance required beginning July 1, 2001
  - Models divided into 12 product classes based on size (standard or compact), location of freezer (top, bottom, or side), type of defrost (automatic or manual), and presence of through-the-door ice
  - Limits on annual electricity consumption expressed as functions of adjusted volume[1]
- ENERGY STAR criteria limit annual electricity consumption to 20% less than the Federal standard.
- More stringent Federal standards:
  - Compliance required beginning September 15, 2014
  - New product classes for built-in units
  - Amount by which standards are tightened varies by product class
- Current analysis focuses on the three representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Better gasketing
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating

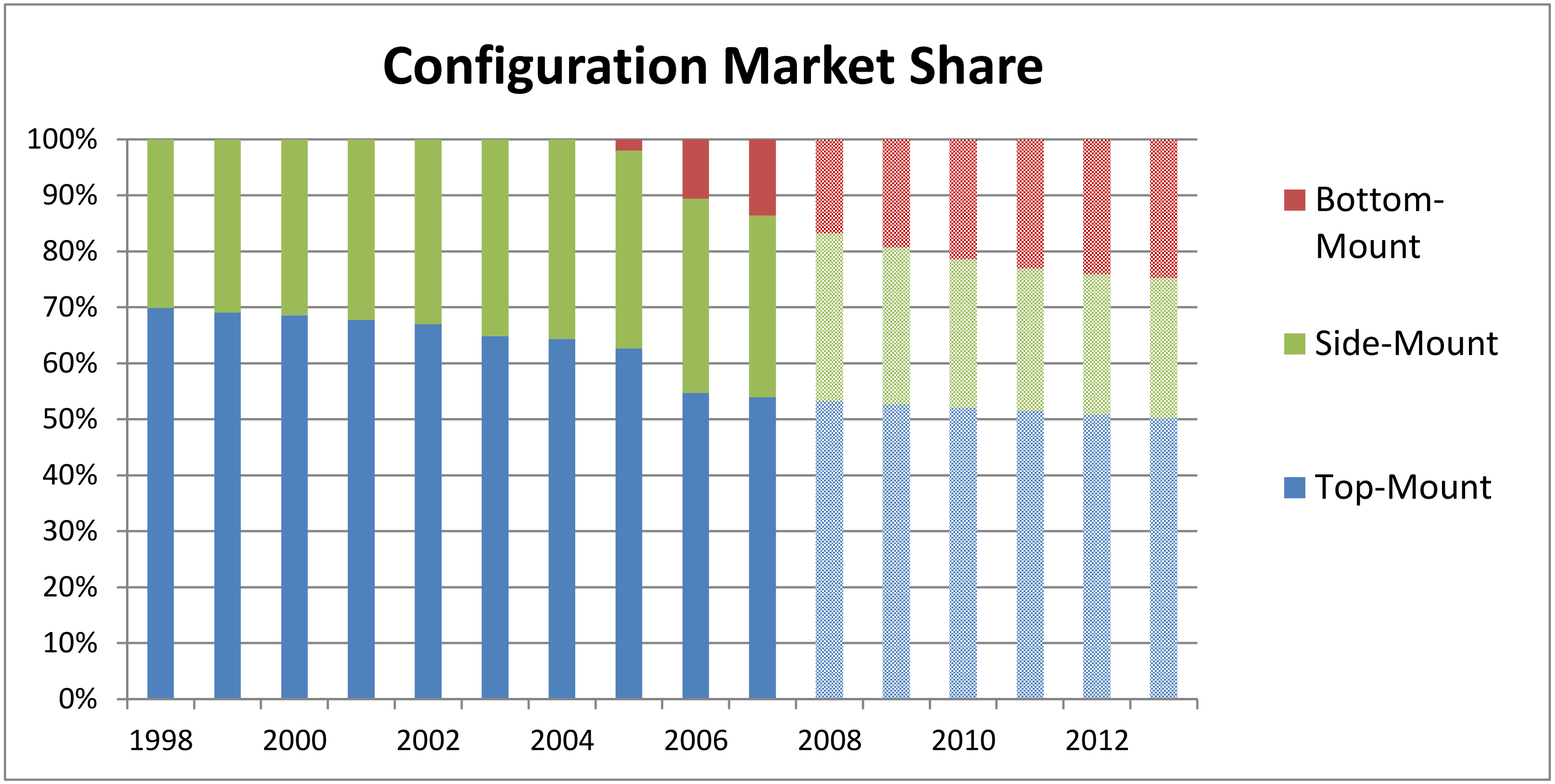
[1]Adjusted Volume (AV) = (Fresh Volume) + 1.63 × (Freezer Volume). Beginning in 2004, the 1.63 coefficient will change to 1.76.

Annual shipment volumes declined 25% from 2006 to 2009, rebounded slightly in 2010, then declined again to 8.6 million units in 2012.



Source: *Appliance Magazine*; data provided by AHAM and Navigant analysis for configuration shares.

Bottom-mount units likely have captured somewhere between 15 and 35 percent of the market, based on shipment-weighted data through 2007, DOE analysis, and counts of currently available models.



Sources: AHAM data; August 2011 Refrigerator Final Rule TSD; Navigant analysis.

Upright Freezers (Product Class 9)

Same as reference case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	17	17	17	17	17	17	17	17	17	17	17
Energy Consumption (kWh/yr)**	775	687	642	618	615	487	487	487	487	487	487
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost ($)	550	550	555	560	560	660	660	660	660	660	660
Total Installed Cost ($)	550	550	555	560	560	660	660	660	660	660	660
Annual Maintenance Cost ($)	5	5	5	5	5	5	5	5	5	5	5

* The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 29 ft^3 (30 ft^3 beginning in 2014).

Chest Freezers (Product Class 10)

Same as reference case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)*	17	17	17	17	17	17	17	17	17	17	17
Energy Consumption (kWh/yr)**	430	401	370	361	354	327	327	327	327	327	327
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost ($)	400	400	405	410	410	425	425	425	425	425	425
Total Installed Cost ($)	400	400	405	410	410	425	425	425	425	425	425
Annual Maintenance Cost ($)	3	3	3	3	3	3	3	3	3	3	3

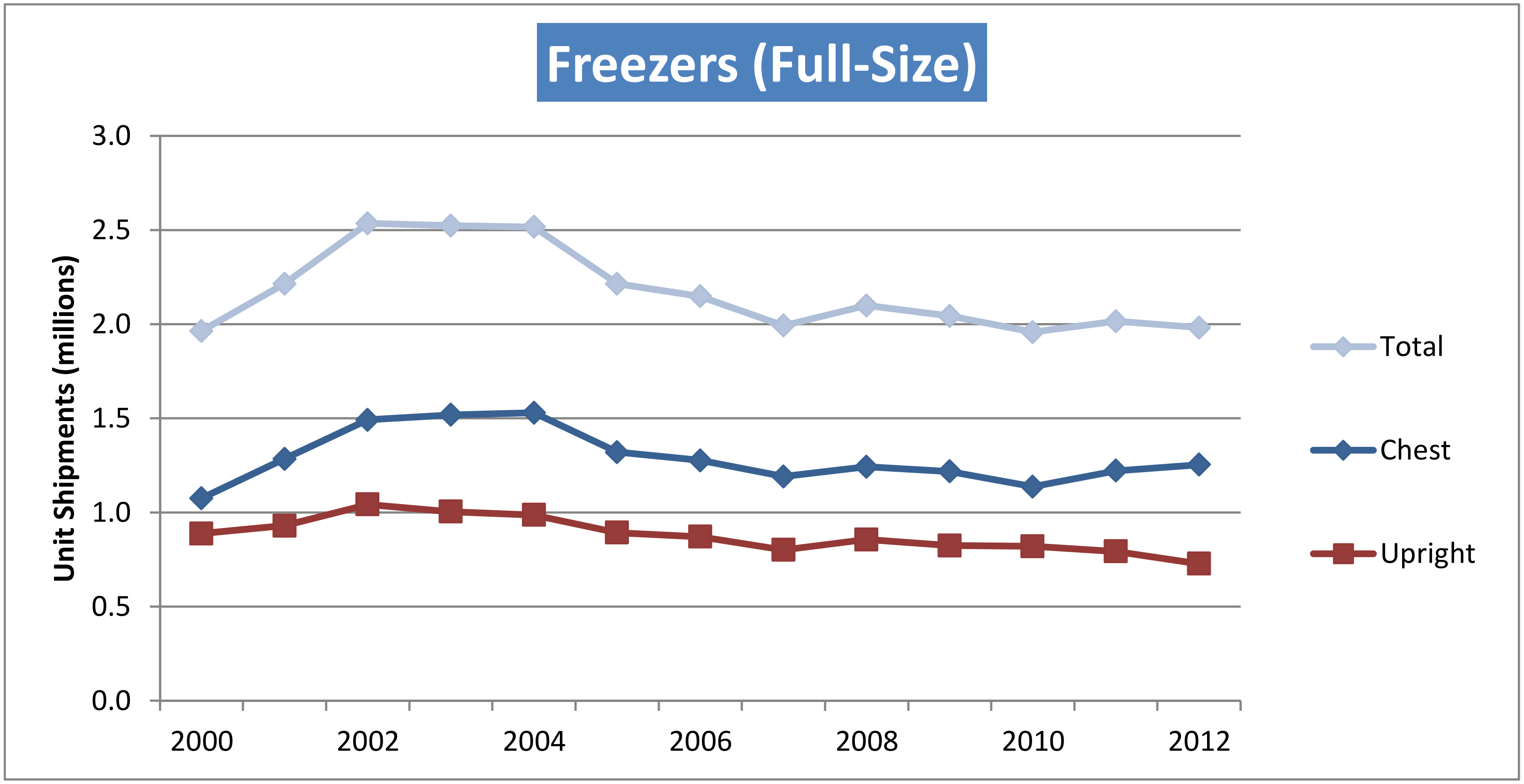
* The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 26 ft^3 (30 ft^3 beginning in 2014).

Residential Freezers

- Current Federal standards:
  - Compliance required beginning July 1, 2001
  - Models divided into 6 product classes based on size (standard or compact), orientation (chest or upright), and type of defrost (automatic or manual).
  - Limits on annual electricity consumption expressed as functions of adjusted volume[1]
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard.
- More stringent Federal standards:
  - Compliance required beginning September 15, 2014
  - New product classes for built-in freezers and freezers with an automatic icemaker
  - Amount by which standards are tightened varies by product class
- Current analysis focuses on the two representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Better gasketing
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating
  - Use of forced convection condenser (for upright freezers)

[1]Adjusted Volume (AV) = (Fresh Volume) + 1.63 × (Freezer Volume). Beginning in 2004, the 1.63 coefficient will change to 1.76.

Shipment volumes have held steady since 2007 at about 2 million units per year. Chest freezers represent about 60% of the market .



Source: *Appliance Magazine.*

Final

Residential Natural Gas Cooktops and Stoves

Same as reference case

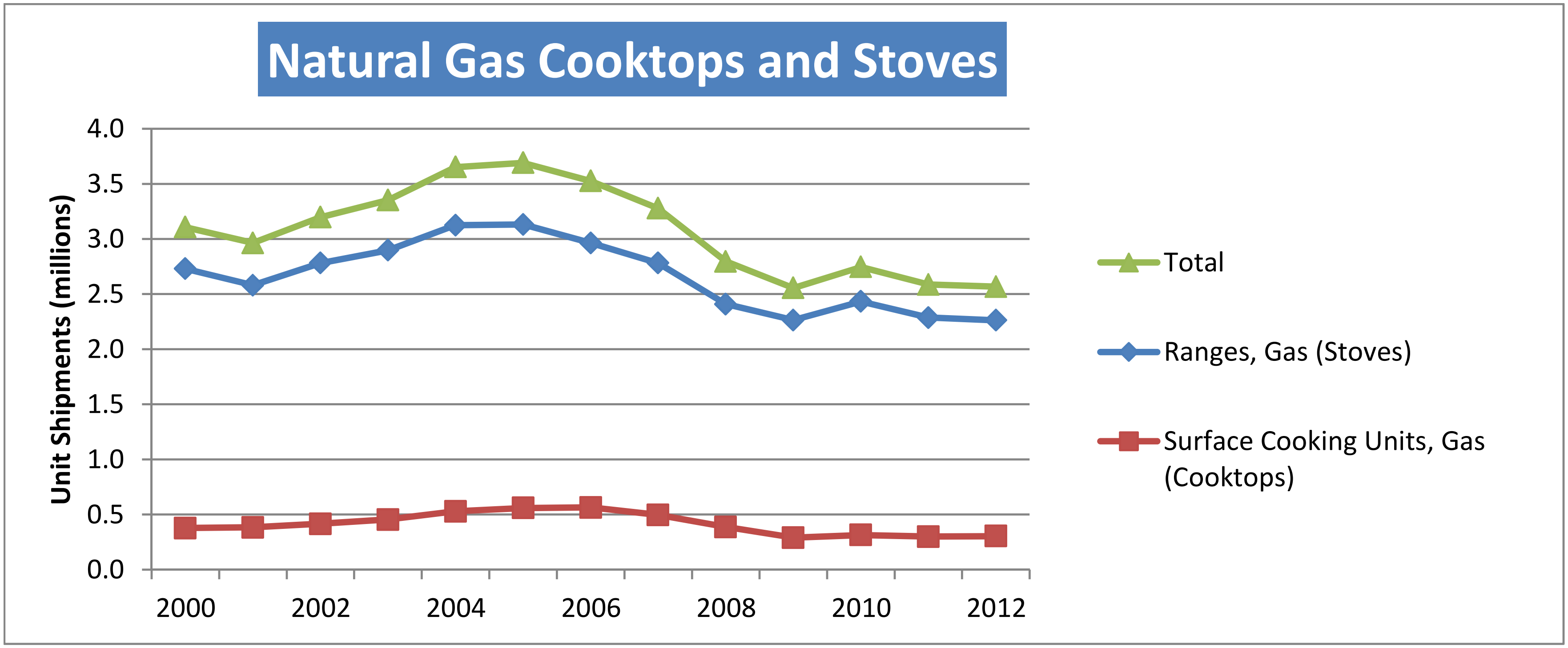
DATA	2009	2013		2020		2030		2040	
	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9
	12	12	12	12	12	12	12	12	12
Cooking Efficiency (%)	38.5	39.9	42	39.9	42	39.9	42	39.9	42
Average Life (yrs)	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)*	225	250	300	250	300	250	300	250	300
	300	350	400	350	400	350	400	350	400
Total Installed Cost ($)*	275	300	350	300	350	300	350	300	350
	350	400	450	400	450	400	450	400	450
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-

* Equipment and installed costs are for stand-alone cooktops only (not stoves).
** Maintenance costs are negligible.

Residential Natural Gas Cooktops and Stoves

- Since January 1, 1990, gas cooking products *with* an electrical supply cord have been required to <u>not</u> be equipped with a constant burning pilot light. This requirement extended to gas cooking products *without* an electrical supply cord, as of April 9, 2012.
- Little variation in cooking efficiency among gas cooktops and stoves (or "ranges").
- DOE final rule published in 2009: no standard for cooking efficiency is cost-justified.

Shipments are down from their peak in 2005 and appear to have leveled off in the past five years.



Note: Excludes separate ovens, which were categorized as "built-in" units prior to 2007.
Source: *Appliance Magazine*.

Final

Residential Clothes Washers – Front-Loading

Same as reference case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.09	3.00	3.90	3.00	5.20	3.90	5.20	3.90	5.20	3.90	5.20
Modified Energy Factor (ft3/kWh/cycle)	2.07	1.26	3.09	2.00	3.45	3.09	3.45	3.09	3.45	3.09	3.45
Water Factor (gal/cycle/ft^3)	6.2	9.5	3.1	6.0	3.0	3.1	3.0	3.1	3.0	3.1	3.0
Average Life (yrs)	7	7	7	7	7	7	7	7	7	7	7
	14	14	14	14	14	14	14	14	14	14	14
Water Consumption (gal/cycle)	19	29	12	18	15	12	15	12	15	12	15
Hot Water Energy (kWh/cycle)	0.32	0.82	0.16	0.29	0.27	0.16	0.27	0.16	0.27	0.16	0.27
Machine Energy (kWh/cycle)	0.15	0.2	0.12	0.15	0.11	0.12	0.11	0.12	0.11	0.12	0.11
Dryer Energy (kWh/cycle)	1.02	1.37	0.99	1.03	1.13	0.99	1.13	0.99	1.13	0.99	1.13
Retail Equipment Cost ($)	550	550	900	800	1,200	900	1,200	900	1,200	900	1,200
	700	700	1,000	900	1,500	1,000	1,500	1,000	1,500	1,000	1,500
Total Installed Cost ($)	650	650	1,000	900	1,300	1,000	1,300	1,000	1,300	1,000	1,300
	800	800	1,100	1,000	1,600	1,100	1,600	1,100	1,600	1,100	1,600
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Maintenance costs are negligible.

Final

Residential Clothes Washers – Top-Loading

Same as reference case

DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.0	3.2	3.5	3.6	4.8	3.6	4.8	3.6	4.8	3.6	4.8
Modified Energy Factor (ft3/kWh/cycle)	1.20	1.26	1.40	2.00	2.87	2.00	2.87	2.00	2.87	2.00	2.87
Water Factor (gal/cycle/ft^3)	12.0	9.5	8.5	6.0	3.65	6.0	3.65	6.0	3.65	6.0	3.65
Average Life (yrs)	7	7	7	7	7	7	7	7	7	7	7
	14	14	14	14	14	14	14	14	14	14	14
Water Consumption (gal/cycle)	36	30	30	22	18	22	18	22	18	22	18
Hot Water Energy (kWh/cycle)	0.91	0.87	0.64	0.51	0.39	0.51	0.39	0.51	0.39	0.51	0.39
Machine Energy (kWh/cycle)	0.28	0.28	0.28	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Dryer Energy (kWh/cycle)	1.31	1.39	1.58	1.21	1.20	1.21	1.20	1.21	1.20	1.21	1.20
Retail Equipment Cost ($)	550	350	450	550	850	550	850	550	850	550	850
	700	450	550	650	950	650	950	650	950	650	950
Total Installed Cost ($)	650	450	550	650	950	650	950	650	950	650	950
	800	550	650	750	1,050	750	1,050	750	1,050	750	1,050
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Maintenance costs are negligible.

Residential Clothes Washers

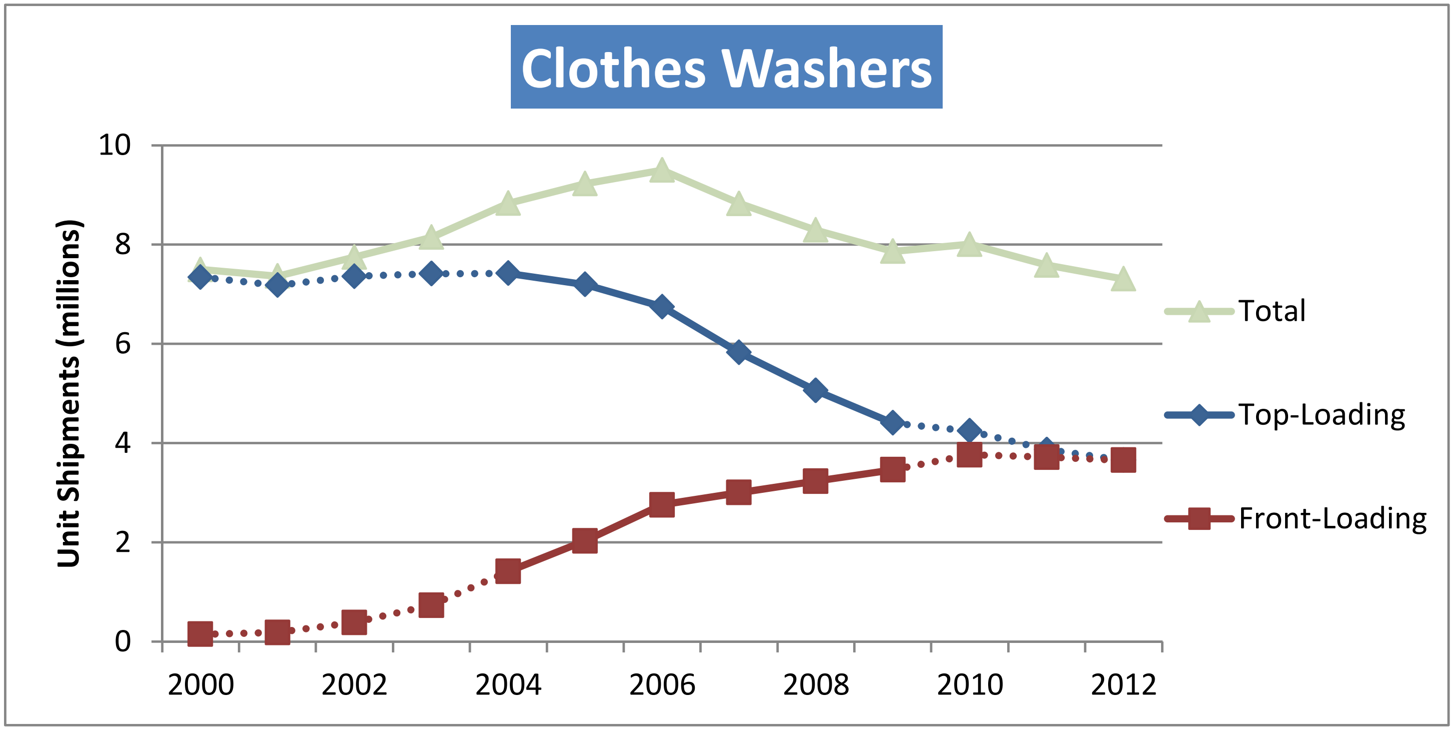
- Present analysis treats front- and top-loading models separately. Past analyses did not consider the two types separately.
- Federal standards for standard-capacity clothes washers (≥ 1.6 cubic feet):

	Modified Energy Factor		Water Factor	
	Top-Loading	Front-Loading	Top-Loading	Front-Loading
Current DOE Standard	≥ 1.26 (effective 1/1/2007)		≤ 9.5 (effective 1/1/2011)	
Current ENERGY STAR	≥ 2.00		≤ 6.0	
	Integrated Modified Energy Factor[1]		**Integrated Water Factor[2]**	
March 7, 2015	≥ 1.29	≥ 1.84	≤ 8.4	≤ 4.7
January 1, 2018	≥ 1.57	≥ 1.84 (no change)	≤ 6.5	≤ 4.7 (no change)

1. IMEF differs from MEF as follows: (a) includes standby power energy; (b) smaller capacity measurement for top-loaders; (c) higher drying energy estimate; and (d) additional wash cycles required for testing.
2. IWF differs from WF as follows: WF incorporates water usage from cold water cycles only while IWF incorporates water usage from all wash temperatures.

- Most front-loading models on the market today surpass the ENERGY STAR levels by a comfortable margin; typical new front-loading unit has MEF = 3.09 and WF = 3.1
- Energy efficiency improvement opportunities include:
  - Higher efficiency motors and higher spin speeds
  - Better load sensing for adaptive water fill control
  - Reduced water temperature and quantity, while providing equivalent cleaning and rinsing performance

Shipment volumes have returned to pre-housing boom levels. Front-loaders' market share grew from 5% to about 50% in 10 years.



Source: *Appliance Magazine* and Residential Clothes Washer Direct Final Rule TSD, EERE, April 2012.

Electric

Same as reference case

DATA	2009	2013			2020		2030		2040	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7
EF (lb/kWh)*	3.01	3.01	3.10	3.16	*3.10*	*4.51*	*3.16*	*4.51*	*3.16*	*4.51*
CEF (lb/kWh)*	*3.55*	*3.55*	*3.73*	*3.81*	3.73	5.42	3.81	5.42	3.81	5.42
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8
	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	400	400	450	500	450	650	500	650	500	650
	500	500	550	600	550	750	600	750	600	750
Total Installed Cost ($)	510	510	560	610	560	780	610	780	610	780
	610	610	660	710	660	880	710	880	710	880
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-

* Italicized values are estimated. The federal standard is expressed in EF, but will be expressed in CEF beginning in 2015. The two metrics are not strictly comparable, but both values are shown here to facilitate longitudinal analyses.
** Maintenance costs are negligible.

Natural Gas

Same as reference case

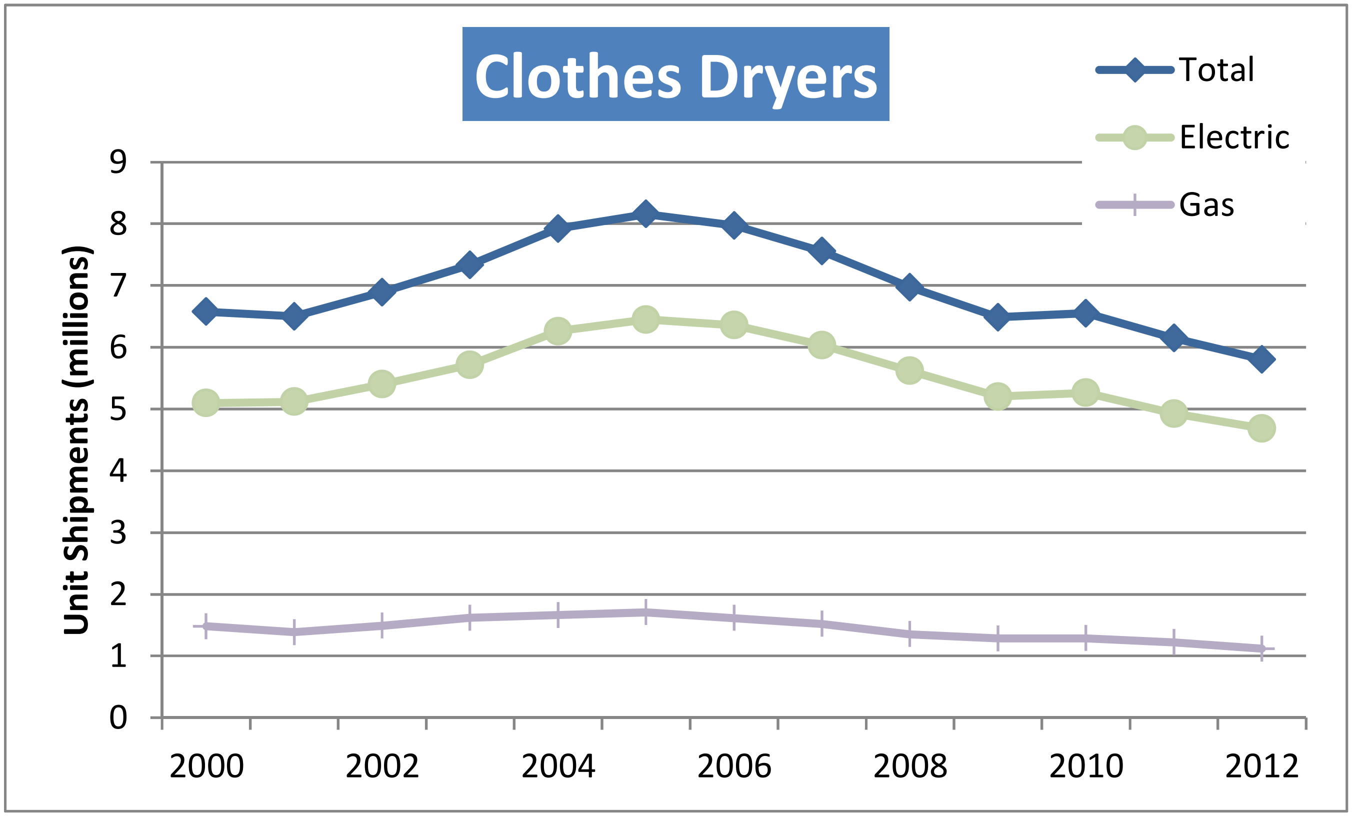
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7
EF (lb/kWh)*	2.67	2.67	2.75	2.85	3.02	*2.81*	*3.02*	*2.81*	*3.02*	*2.81*	*3.02*
CEF (lb/kWh)*	*3.14*	*3.14*	*3.24*	*3.35*	*3.61*	3.30	3.61	3.30	3.61	3.30	3.61
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8
	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	450	400	425	450	550	400	550	400	550	400	550
	550	450	475	550	650	500	650	500	650	500	650
Total Installed Cost ($)	610	560	585	610	710	560	710	560	710	560	710
	710	610	635	710	810	660	810	660	810	660	810
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-

* Italicized values are estimated. The federal standard is expressed in EF, but will be expressed in CEF beginning in 2015. The two metrics are not strictly comparable, but both values are shown here to facilitate longitudinal analyses.
** Maintenance costs are negligible.

Residential Clothes Dryers

- Current standards in effect since 1994:
  - For standard-size electric units : EF ≥ 3.01 lb/kWh
  - For gas units: EF ≥ 2.67 lb/kWh
- New standards announced in April 2011 with compliance date of Jan. 1, 2015. Efficiency metric will change from energy factor (EF) to combined energy factor (CEF), which incorporates standby mode power consumption:
  - For standard-size vented electric units : CEF ≥ 3.73 lb/kWh (≅3.17 EF)
  - For vented gas units: CEF ≥ 3.30 lb/kWh (≅2.81 EF)
- Remaining efficiency improvement opportunities include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Better control systems for cycle termination (not reflected per the current test procedure, however)
  - Heat pump (for electric clothes dryers)
- Heat pump clothes dryers with EF around 4.5 currently available in Europe. High initial cost and potential reliability issues have kept them out of the U.S. market, but anticipated to arrive by 2020.
- In 2012, EPA announced the Emerging Technology Award for Clothes Dryers, which would be awarded to a manufacturer that introduces a high-efficiency clothes dryer to the U.S. market.

Shipment volumes are now slightly below pre-housing boom levels. Gas dryers continue to account for about one-fifth of the market.



Source: *Appliance Magazine.*

Final

Residential Dishwashers

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

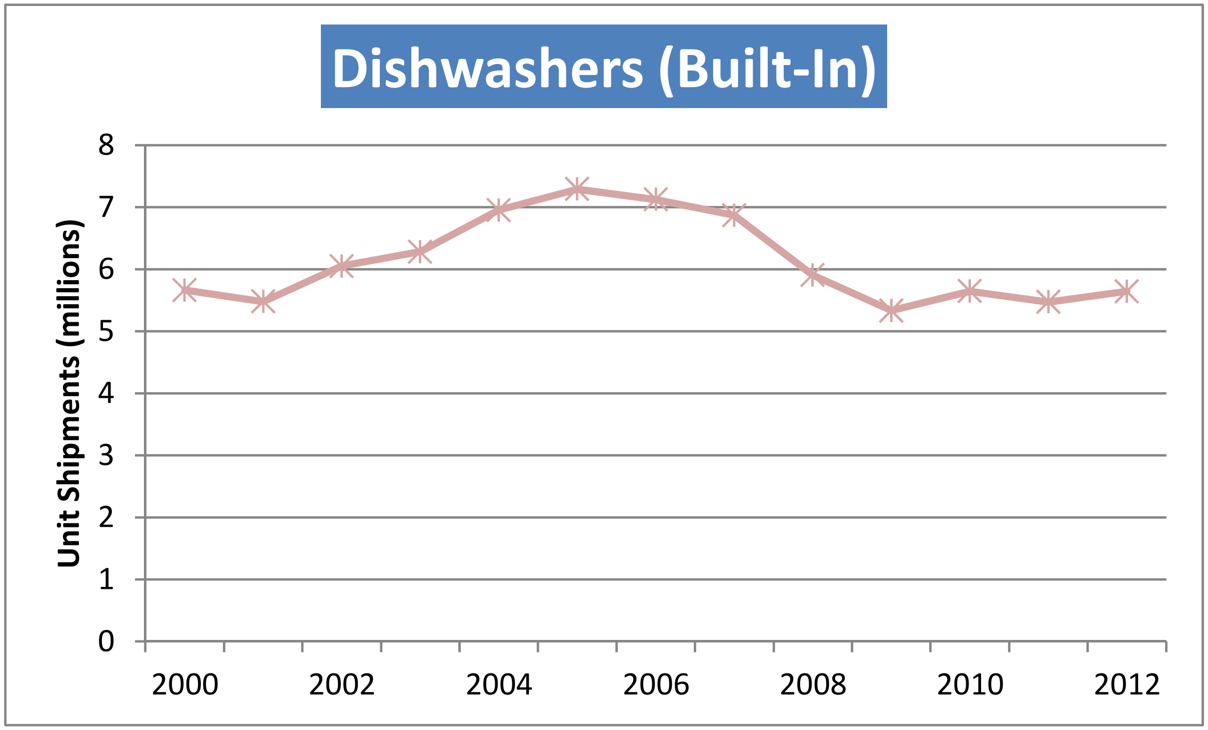
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/yr)	312	307	295	295	180	275	180	275	180	275	180
Water Consumption (gal/cycle)	4.50	5.00	4.25	4.25	2.22	4.00	2.22	4.00	2.22	4.00	2.22
Water Heating Energy Use (kWh/yr)*	163	181	153	153	80	140	80	140	80	140	80
Average Life (yrs)	14	14	14	14	14	14	14	14	14	14	14
	24	24	24	24	24	24	24	24	24	24	24
Retail Equipment Cost ($)	390	395	450	450	470	450	470	450	470	450	470
Total Installed Cost ($)	710	715	770	770	790	770	790	770	790	770	790
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-

* Refers to that portion of "Typical Annual Energy Use" that is the energy used to heat water in a separate water heater before it enters the dishwasher. The energy used to heat water inside the dishwasher cannot be disaggregated from the total.
** Maintenance costs are negligible.

Residential Dishwashers

- Performance criteria for standard-capacity dishwashers (assumes 215 cycles/year):
  - Federal Standards:
    - Jan. 1, 2010: ≤ **355** kWh/yr, ≤ **6.5** gal/cycle (EISA 2007)
    - May 30, 2013: ≤ **307** kWh/yr, ≤ **5.0** gal/cycle (DOE Direct Final Rule, published May 2012)
  - ENERGY STAR Criteria:
    - Aug. 11, 2009 : ≤ **324** kWh/yr, ≤ **5.8** gal/cycle (version 4.0, announced Nov. 2008)
    - Jan. 20, 2012: ≤ **295** kWh/yr, ≤ **4.25** gal/cycle (version 5.0, announced April 2011)
- ENERGY STAR has maintained a very high market share for several years, so sales-weighted-average efficiency has tracked ENERGY STAR levels.
- Test procedures:
  - Accounts for motor, dryer, booster heater (if present), and hot water from separate water heater
  - Amended test procedure, enters into force May 30, 2013, includes standby and off-mode energy
  - Cleaning performance test method expected to be part of future ENERGY STAR requirements
- Efficiency improvement opportunities include:
  - Better soil sensing in the water, the filter, and the controls to make use of that
  - Water distribution (small pipes, fine filter, small sump, alternating water use)
  - Inline water heater (to minimize sump volume)
  - High-efficiency, variable-speed pump motor
  - Vent assembly to help drying of dishes

Shipments peaked in 2005 during the housing boom then declined and appear to have leveled off at between 5 and 6 million units per year.



Source: *Appliance Magazine*

Final

Commercial Gas-Fired Furnaces

Higher typical efficiencies than ref. case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400	400	400	400	400
Thermal Efficiency (%)*	76	80	80	80	90	81	90	81	90	81	90
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	1,920	2,370	2,910	2,910	3,590	3,000	3,590	3,000	3,590	3,000	3,590
	2,130	2,580	3,120	3,120	3,900	3,200	3,900	3,200	3,900	3,200	3,900
Total Installed Cost ($)	2,300	2,750	3,290	3,290	3,970	3,380	3,970	3,380	3,970	3,380	3,970
	2,510	2,960	3,500	3,500	4,280	3,580	4,280	3,580	4,280	3,580	4,280
Annual Maintenance Cost ($)**	320	320	320	320	930	320	930	320	930	320	930

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Commercial Gas-Fired Furnaces

- Current Federal standard requires minimum 80% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- The Federal standard applies to all units manufactured on or after January 1, 1994 with maximum rated heat input ≥ 225,000 Btu per hour.
- Commercial furnace efficiency ranges are as wide as those for residential, and the technology options are similar (though usually scaled up).
- Besides scale, commercial units can differ in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies) and they may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Final

Commercial Oil-Fired Furnaces

Same as reference case

DATA	2003	2012	2013		2020	2030	2040
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400
Thermal Efficiency (%)*	81	81	81	82	82	82	82
Average Life (yrs)	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3,200	3,400	4,000	4,000	4,000	4,000	4,000
	3,800	3,900	4,200	4,200	4,200	4,200	4,200
Total Installed Cost ($)	3,800	3,800	4,380	4,380	4,380	4,380	4,380
	4,400	4,400	4,580	4,580	4,580	4,580	4,580
Annual Maintenance ($)	320	320	320	320	320	320	320

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Commercial Oil-Fired Furnaces

- Current Federal standard requires minimum 81% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- The Federal standard applies to all units manufactured on or after January 1, 1994 with maximum rated heat input ≥ 225,000 Btu per hour.
- Commercial furnace efficiency ranges are as wide as those for residential, and the technology options are similar (though usually scaled up).
- Besides scale, commercial units can differ in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies) and they may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Final

Commercial Electric Boilers

Same as reference case

DATA	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (kW)*	165	165	165	165	165	165
Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($)	$6,400	$7,000	$7,000	$7,000	$7,000	$7,000
	$7,500	$7,800	$7,800	$7,800	$7,800	$7,800
Total Installed Cost ($)	$8,000	$10,500	$10,500	$10,500	$10,500	$10,500
	$9,600	$11,800	$11,800	$11,800	$11,800	$11,800
Annual Maintenance Cost ($)	110	110	110	110	110	110
	160	160	160	160	160	160

* Capacity is *output*

- There are currently no federal standards associated with electric boilers.
- The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/hr.
- Service life is determined mainly by water quality. Water conditioning (e.g., filters, softeners, de-alkizers, chemical feeders) may be necessary for a given application.
- Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.
- Minor end-use inefficiencies for electric boilers result from heat loss through the boiler (jacket losses).

Final

Commercial Gas-Fired Boilers

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard*	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)**	76	77	80	80	85	98	83	98	84	98	85	98
Average Life (yrs)	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	10,650	11,350	13,050	13,050	15,900	18,150	14,700	18,150	15,250	18,150	15,750	18,150
	12,750	13,400	15,100	15,100	18,000	20,200	16,750	20,200	17,300	20,200	17,800	20,200
Total Installed Cost ($)	17,850	18,550	20,250	20,250	23,100	25,350	21,900	25,350	22,450	25,350	22,950	25,350
	19,950	20,600	22,300	22,300	25,200	27,400	23,950	27,400	24,500	27,400	25,000	27,400
Annual Maintenance Cost ($)**	480	480	480	480	480	480	480	480	480	480	480	480

* The standard level shown here is for small hot water boilers, the most common type of boiler.
** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.
*** Installed Base costs have been adjusted to reflect the cost of two 427 kBtu/h boilers rather than one, as was reported in prior editions.

Commercial Gas-Fired Boilers

- Commercial packaged gas-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
  - Draft type (natural draft or not)
- Most common type is small hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Federal standards require thermal efficiency ≥ 77%, 79%, or 80%, depending on type.
- Exception is large hot water boilers, which must have *combustion* efficiency ≥ 82%.
- Similar technologies to the those used in the residential market can be leveraged in the commercial arena. The higher efficiency units typically include electronic ignition, power burners, and improved heat exchangers. They may even condense and/or pre-heat incoming air.

Final

Commercial Oil-Fired Boilers

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard*	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Thermal Efficiency (%)**	79	81	82	83	98	84	98	85	98	86	98
Average Life (yrs)	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	11,700	12,400	13,400	14,400	24,700	14,900	25,200	16,000	24,700	16,500	24,700
	12,800	14,400	15,400	16,500	26,800	17,000	27,300	18,000	26,800	18,500	26,800
Total Installed Cost ($)	15,800	16,500	17,500	18,500	30,900	19,000	30,900	20,100	30,900	20,600	30,900
	16,900	18,500	19,500	20,600	33,000	21,100	33,000	22,100	33,000	22,600	33,000
Annual Maintenance Cost ($)	115	115	115	115	115	115	115	115	115	115	115
	165	165	165	165	165	165	165	165	165	165	165

* The standard level shown here is for small hot water boilers, the most common type of boiler.
** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.

Commercial Oil-Fired Boilers

- Commercial packaged oil-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
- Most common type is small hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Federal standards require thermal efficiency ≥ 81% for steam boilers and ≥ 82% for hot water boilers.
- Exception is large hot water boilers, which must have *combustion* efficiency ≥ 84%.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.

Final

Commercial Gas-Fired Chillers[1]

Higher efficiencies and costs than reference case

DATA	2003		2012		2013		2020		2030		2040	
	Installed Base				Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven
	Absorption	Engine-Driven	Absorption	Engine-Driven								
Typical Capacity (tons)*	150	150	150	150	150	150	150	150	150	150	150	150
	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400
COP	1.0	1.5	1.1	1.7	1.1	1.7	1.3	1.8	1.5	1.9	1.6	2.0
Average Life (yrs)	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost ($/ton)	650	750	700	700	700	700	700	700	1,000	700	1,000	700
	800	850	850	800	850	800	850	800	1,300	800	1,300	800
Total Installed Cost ($/ton)	800	900	800	800	800	800	800	800	1,150	800	1,150	800
	950	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,600	1,000	1,600	1,000
Annual Maintenance Cost ($/ton)	16	37	16	31	16	31	16	31	16	31	16	31
	32	48	32	47	32	47	32	47	32	47	32	47

* Capacity is *output*

[1] This analysis assumes a water-cooled chiller; both gas-fired chiller types (absorption and engine-driven) are shown.

Commercial Gas-Fired Chillers

- Gas-fired chillers are available as either air-cooled (~25-50 tons) or water-cooled (150+ tons). This analysis includes only water-cooled chillers. Two direct-fired gas chiller technologies are in the market; absorption and engine-driven.
- Direct gas firing provides high enough temperatures to operate double effect absorption chillers, which operate at a 50-60% higher COP than single effect absorption chillers. Triple effect absorption chillers are expected to boost cooling COP 30-50% beyond double effect chillers. Prototype direct-fired triple effect absorption chillers have been tested by York and Trane, but are not commercially available. Due to the prohibitively high cost of advanced high heat/corrosion-resistant materials required for triple effect absorption chillers, it is expected that this technology will not likely have a commercial market impact in the near-term. Some absorption chillers can be operated in reverse to provide heating; these are referred to as chiller/heaters.
- Gas-fired engine-driven chillers pair conventional vapor compression technologies (typically screw or centrifugal compressors) with natural gas powered reciprocating engines. Gas-fired engine-driven chillers exhibit higher peak cooling COP than absorbers, and engine modulation results in even better part load performance. Future efficiency improvements for engine-driven chillers are not anticipated. Engine driven chillers allow the opportunity to recover waste heat useful purposes.
- Sales dropped by nearly 75 percent in the US from 2006 to 2010. Most new gas-fired chillers sales in the US are for replacement, not for new installations. The increase in electric chiller efficiency has narrowed the operating cost differential with gas chillers. Gas chiller technologies remain popular and development will in other markets, such as Asia, which currently has 80 percent of the gas-fired chiller market.
- Gas-fired chiller installations hold value in niche applications such as where electric demand charges are high, electrical capacity is limited, alternative energy sources are available (such as digester or landfill gas) or where waste heat is available (such as from an industrial process or microturbine CHP system) that could be used with a hybrid direct/indirect-fired absorption chiller to offset the use of natural gas.

Final

Commercial Centrifugal Chillers

Higher typical efficiencies than reference case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	400	400	400	400	400	400	400	400	400	400	400
	600	600	600	600	600	600	600	600	600	600	600
Efficiency [full-load] (kW/ton)	0.70	0.66	0.58	0.56	0.45	0.54	0.44	0.52	0.43	0.50	0.42
Efficiency [IPLV] (kW/ton)	0.67	0.61	0.40	0.36	0.33	0.35	0.32	0.34	0.31	0.33	0.30
COP [full-load]	5.0	5.4	6.1	6.3	7.8	6.5	8.0	6.8	8.2	7.0	8.4
COP [IPLV]	5.2	5.9	8.8	9.8	10.7	10.0	11.0	10.3	11.3	10.7	11.7
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($/ton)	250	250	250	300	400	300	400	300	400	300	400
	350	350	350	400	500	400	500	400	500	400	500
Total Installed Cost ($/ton)	300	300	300	350	450	350	450	350	450	350	450
	450	450	450	500	600	500	600	500	600	500	600
Annual Maintenance Cost ($/ton)	16	16	16	16	16	16	16	16	16	16	16
	32	32	32	32	32	32	32	32	32	32	32

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.
[2] 2013 typical efficiency based on ASHRAE 90.1-2010.
[3] 2013 mid efficiency based on FEMP recommendations.

Commercial Centrifugal Chillers

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- ASHRAE 90.1-2010 and Addendum M of 90.1-2007 became effective 1/1/10 and instituted the following Separate compliance paths for applications that spend a significant amount of time at full load versus part load (encourages the use of chillers with better IPLVs in part-load applications and full-load efficiencies in full-load applications; for either path, minimum requirements for both full load and IPLV must still be met). The Addendum also added a new size category for centrifugal chillers ≥600 tons, strengthened minimum efficiency requirements for centrifugal chillers <150 tons and ≥600 tons, and changed how efficiency is expressed, from coefficient of performance (COP) to kW/ton to reflect industry practice.
- The Federal Energy Management Program (FEMP) requires separate minimum efficiencies for full-load optimized and part-load optimized applications. For full-load optimized applications, a full-load efficiency less than 0.56 kW/ton and an IPLV efficiency less than 0.55 kW/ton. For full-load optimized applications, a full-load efficiency less than 0.60 kW/ton and an IPLV efficiency less than 0.36 kW/ton.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed drive (VSD) compressors
  - Dedicated heat recovery (heat pump chiller)
  - Magnetic bearing technology (oil-free operation)
  - Greater heat exchanger surface areas; enhanced tube configurations (counterflow)
  - Optimized fluid flow velocities
  - High efficiency electric motors
  - Improved turbomachinery design, resulting in higher compressor efficiency
  - Better piping and valving, including electronic expansion valves
  - Evaporative condenser for the heat rejection equipment
- Installed costs vary widely depending on equipment needed for installation (e .g. crane) and size of system. This is a mature market with centrifugal chillers representing 75% of commercial chiller sales larger than 200 tons.

Final

Commercial Reciprocating Chillers

Same as reference case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	100	100	100	100	100	100	100	100	100	100	100
	200	200	200	200	200	200	200	200	200	200	200
Efficiency [full-load] (kW/ton)[1]	1.26	1.26	1.25	1.15	1.00	1.15	1.00	1.15	1.00	1.15	1.00
Efficiency [IPLV] (kW/ton)[1]	1.15	1.13	0.96	0.80	0.79	0.80	0.79	0.80	0.79	0.80	0.79
COP [full-load][1]	2.80	2.80	2.81	3.06	3.52	3.06	3.52	3.06	3.52	3.06	3.52
COP [IPLV][1]	3.05	3.12	3.66	4.40	4.45	4.40	4.45	4.40	4.45	4.40	4.45
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	400	575	550	650	750	650	750	650	750	650	750
	500	675	650	750	850	750	850	750	850	750	850
Total Installed Cost ($/ton)	475	650	675	775	875	775	875	775	875	775	875
	600	775	825	925	1025	925	1025	925	1025	925	1025
Annual Maintenance Cost ($/ton)	27	27	27	27	27	27	27	27	27	27	27
	43	43	43	43	43	43	43	43	43	43	43

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.
[2] 2013 typical efficiency based on ASHRAE 90.1-2010.
[3] 2013 mid efficiency based on FEMP recommendations.

Commercial Reciprocating Chillers

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- Reciprocating chillers are most cost effective for small loads. Reciprocating chiller market share continues to be supplanted by screw and scroll chillers. Large manufacturers no longer manufacture reciprocating chillers since most packaged reciprocating chillers under 80 tons utilize R-22 which is being phased out under the Montreal Protocol.
- Reciprocating chillers can be used in either air-cooled or water cooled applications. Reciprocating chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use (as required for compliance with ASHRAE 90.1-2010).
- ASHRAE 90.1-2010 instituted separate minimum efficiency requirements for air-cooled chillers more and less than 150 tons and both sets of requirements are more stringent than 90.1-2007. The 90.1-2007 minimum efficiency requirements were the same as 90.1-2004.
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (updated December 2012) include a full-load efficiency of 1.15 or less kW/ton for base-loaded chillers or an IPLV efficiency of 0.78 kW/ton and 0.80 kW/ton for chillers with seasonally variable loads that are less than 150 tons and more than 150 tons, respectively.
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Final

Commercial Screw Chillers

Higher typical efficiencies than reference case

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	100	100	100	100	100	100	100	100	100	100	100	100
	300	300	300	300	300	300	300	300	300	300	300	300
Efficiency [full-load] (kW/ton)	1.26	1.26	1.25	1.24	1.13	1.02	1.08	0.99	1.04	0.96	1.02	0.94
Efficiency [IPLV] (kW/ton)	1.15	1.13	0.94	0.94	0.77	0.61	0.70	0.58	0.65	0.56	0.63	0.55
COP [full-load]	2.80	2.80	2.81	2.84	3.10	3.46	3.26	3.55	3.38	3.66	3.45	3.74
COP [IPLV]	3.05	3.12	3.74	3.74	4.58	5.80	5.02	6.06	5.41	6.28	5.58	6.39
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	300	500	500	500	600	700	600	700	600	700	600	700
	400	600	600	600	700	800	700	800	700	800	700	800
Total Installed Cost ($/ton)	375	625	625	625	725	825	725	825	725	825	725	825
	500	800	800	800	900	1,000	900	1,000	900	1,000	900	1,000
Annual Maintenance Cost ($/ton)	11	11	11	11	11	11	11	11	11	11	11	11
	53	53	53	53	53	53	53	53	53	53	53	53

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.
[2] 2013 typical, mid, and high efficiency levels determined base on the range of products currently available on the market.

Commercial Screw Chillers

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- Screw chillers are available from ~50-1100 tons but are most cost effective for small (<300 tons) loads. Screw chillers dominate the current market for small to mid-size chillers.
- Screw chillers can be used in either air-cooled or water cooled applications. Screw chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use (as required for compliance with ASHRAE 90.1-2010).
- ASHRAE 90.1-2010 instituted separate minimum efficiency requirements for air-cooled chillers more and less than 150 tons and both sets of requirements are more stringent than 90.1-2007. The 90.1-2007 requirements were the same as 90.1-2004.
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (updated December 2012) include a full-load efficiency of 1.15 or less kW/ton for base-loaded chillers or an IPLV efficiency of 0.78 kW/ton and 0.80 kW/ton for chillers with seasonally variable loads that are less than 150 tons and more than 150 tons, respectively.
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Economizers
  - Improved heat-exchangers

Final

Commercial Scroll Chillers

Same as reference case

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical[2]	Mid[2]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	20	20	20	20	20	20	20	20	20	20	20	20
	140	140	140	140	140	140	140	140	140	140	140	140
Efficiency [full-load] (kW/ton)[1]	1.26	1.23	1.25	1.17	1.14	1.11	1.14	1.09	1.11	1.07	1.09	1.06
Efficiency [IPLV] (kW/ton)[1]	1.15	0.99	0.94	0.77	0.75	0.72	0.75	0.71	0.73	0.69	0.71	0.68
COP [full-load][1]	2.80	2.88	2.81	3.02	3.08	3.17	3.08	3.23	3.17	3.29	3.23	3.32
COP [IPLV] [1]	3.05	3.67	3.74	4.54	4.67	4.86	4.67	4.99	4.82	5.10	4.95	5.17
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	320	450	450	450	550	650	550	650	550	650	550	650
	420	550	550	550	650	800	650	800	650	800	650	800
Total Installed Cost ($/ton)	420	700	700	700	800	900	800	900	800	900	800	900
	530	800	800	800	900	1050	900	1050	900	1050	900	1050
Annual Maintenance Cost ($/ton)	37	37	37	37	37	37	37	37	37	37	37	37
	53	53	53	53	53	53	53	53	53	53	53	53

* Capacity is *output*

[1] COP and kW/ton efficiencies listed are for full load rated conditions as well as integrated part load value (IPLV), which is more indicative of annual performance.

[2] 2013 typical, mid, and high efficiency levels determined base on the range of products currently available on the market.

Commercial Scroll Chillers

- For most chiller applications the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of performance than the full-load performance at rated conditions. The IPLV does not necessarily correlate well to the full-load efficiency, so both efficiency parameters are listed in the comparison table.
- Scroll chillers can be used in either air-cooled or water cooled applications. Scroll chillers shown in the data are air-cooled, which is most common. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use (as required for compliance with ASHRAE 90.1-2010).
- ASHRAE 90.1-2010 instituted separate minimum efficiency requirements for air-cooled chillers more and less than 150 tons and both sets of requirements are more stringent than 90.1-2007. The 90.1-2007 requirements were the same as 90.1-2004.
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (updated December 2012) include a full-load efficiency of 1.15 or less kW/ton for base-loaded chillers or an IPLV efficiency of 0.78 kW/ton and 0.80 kW/ton for chillers with seasonally variable loads that are less than 150 tons and more than 150 tons, respectively.
- The highest efficiency scroll chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Final

Commercial Rooftop Air Conditioners

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Output Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	9.2	10.6	11.2	11.2	11.7	13.9	11.5	13.9	11.7	13.9	11.9	13.9
Part Load Efficiecny (IEER)	-	12.4	-	12.4	11.8	20.8	12.7	20.8	14.0	20.8	16.0	20.8
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3,500	5,850	5,850	5,850	6,450	21,500	6,250	21,500	6,250	21,500	6,250	21,500
	4,800	6,900	6,900	6,900	7,500	22,500	7,300	22,500	7,300	22,500	7,300	22,500
Total Installed Cost ($)	5,300	8,000	8,000	8,000	8,600	23,500	8,400	23,500	8,400	23,500	8,400	23,500
	6,600	9,050	9,050	9,050	9,650	25,500	9,450	25,500	9,450	25,500	9,450	25,500
Annual Maintenance Cost ($)	160	160	160	160	160	160	160	160	160	160	160	160
	320	320	320	320	320	320	320	320	320	320	320	320

* Values shown are for air-cooled units with either electric resistance heating or no heating within the same enclosure.

Air-Cooled Commercial Packaged Air Conditioners

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010 Min. EER	ENERGY STAR version 2.2 Effective 1/1/2011	
			Min. EER	Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	11.2	11.7	11.8
	Any other type	11.0	11.5	11.6
Large (≥ 135 and < 240)	Electric resistance or none	11.0	11.7	11.8
	Any other type	10.8	11.5	11.6

- This analysis focused on small air-cooled commercial packaged air conditioners (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial air conditioners.
- The high efficiency unit includes a variable capacity digital scroll compressor, which saves energy during off-design hours—approximately 17% annual energy savings over a typical unit.

Final

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners

Same as reference case

DATA	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	25	18	11	11	11	11
Heating COP	NA	1.4	1.4	1.4	1.4	1.4
Cooling COP	0.7	0.9	1.1	1.1	1.1	1.1
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($/ton)	800	2,700	2,700	2,700	2,700	2,700
	900	3,300	3,300	3,300	3,300	3,300
Total Installed Cost ($/ton)	1,300	3,100	3,100	3,100	3,100	3,100
	1,400	4,100	4,100	4,100	4,100	4,100
Annual Maintenance Cost ($)	59	59	59	59	59	59

* Capacity is *output*

Final

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners/Heat Pumps

- The only gas-fired engine-driven rooftop unit currently available in the US market is by NextAire (an Aisin Seiki product line). It is an 11 ton packaged heat pump with dual scroll compressors, variable refrigerant flow, and a variable speed supply fan. Engine coolant heat recovery improves the heating mode COP. This heat pump was introduced in 2010.
- There are currently no Federal requirements on gas-fired engine-driven rooftop air conditioners or heat pumps.
- Annual sales of the engine-driven rooftop heat pump are estimated at less than 5,000 units per year.

Final

Commercial Rooftop Heat Pumps

Higher typical efficiencies and lower costs for a given efficiency level

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	ENERGY STAR**	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	9.3	10.2	11.0	11.0	11.3	12.0	11.3	12.0	11.7	12.0	12.0	12.0
Part Load Efficiecny (IEER)	-	12.0	-	12.0	11.4	20.2	12.0	20.2	14.0	20.2	16.0	20.2
COP (Heating)	3.1	3.25	3.3	3.3	3.35	3.4	3.35	3.4	3.35	3.4	3.35	3.4
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3,700	5,300	5,300	5,300	5,500	5,850	5,400	5,750	5,500	5,650	5,600	5,600
	4,800	6,400	6,400	6,400	6,600	6,900	6,500	6,800	6,600	6,700	6,650	6,650
Total Installed Cost ($)	5,300	6,900	6,900	6,900	7,100	8,400	6,900	8,250	7,200	7,850	7,500	7,500
	6,900	7,750	7,750	7,750	7,950	10,100	8,000	9,300	8,300	8,900	8,550	8,550
Annual Maintenance Cost ($)	105	105	105	105	105	105	105	105	105	105	105	105
	160	160	160	160	160	160	160	160	160	160	160	160

* Values shown are for air-cooled units with either electric resistance heating or no heating within the same enclosure.
** ENERGY STAR qualified products must also have IEER of 11.4 or greater.

Air-Cooled Commercial Packaged Heat Pumps

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010		ENERGY STAR version 2.2 Effective 1/1/2011		
		Min. EER	Min. COP at 47°F	Min. EER	Min. IEER	Min. COP at 47°F
Small (≥ 65 and < 135)	Electric resistance or none	11.0	3.3	11.3	11.4	3.35
	Any other type	10.8	3.3	–	–	–
Large (≥ 135 and < 240)	Electric resistance or none	10.6	3.2	10.9	11.0	3.25
	Any other type	10.4	3.2	–	–	–

- This analysis focused on small air-cooled commercial packaged heat pumps (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial heat pumps.

Final

Commercial Ground Source Heat Pumps

Higher typical efficiencies and lower costs than ref. case

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		Current Standard	Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	48	48	48	48	48	48	48	48	48	48	48	48
COP (Heating)	3.4	3.5	3.1	3.6	3.7	4	4	4.2	4.2	4.4	4.4	4.5
EER (Cooling)	13.8	14	13.4	17.1	17.6	20.6	20	22	22	24	24	26
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	6,000	6,000	6,000	6,500	7,000	8,500	6,400	8,500	6,300	8,500	6,200	8,500
	11,000	11,000	7,000	7,500	8,500	11,000	7,400	11,000	7,300	11,000	7,200	11,000
Total Installed Cost ($)	16,000	16,000	16,000	16,500	17,000	18,500	16,400	18,500	16,300	18,500	16,200	18,500
	36,400	36,400	32,400	32,900	33,900	36,400	32,800	36,400	32,700	36,400	32,600	36,400
Annual Maintenance Cost ($)	150	150	150	150	150	150	150	150	150	150	150	150

Commercial Ground Source Heat Pumps

- The most common commercial ground source heat pump systems are closed-loop in which water or anti-freeze solution is circulated through plastic pipes buried underground. Commercial water-to-air heat pumps (WAHPs) range in size from 1 ton or less to over 500 tons depending on whether a distributed or centralized architecture is used. Distributed systems are more prevalent.
- Most geothermal WAHPs are rated for capacity and efficiency based on the ISO 13256-1 standard. Heating and cooling efficiency measurements under this standard include input energy for fans and pumps on a proportional basis that only includes that power required to transport air and liquid through the heat pump. The reason for this method is to simplify comparisons between heat pumps and to allow equipment to be optimized for real world conditions without suffering rating penalties. Real world energy use will exceed ratings predictions as a result of higher fluid static pressure requirements.
- ISO 13256-1 cooling rating conditions call for 77F entering water temperature and 80.6F entering air temperature. More typical peak design criteria would be 80-90F entering water temperature and 75F entering air temperature. As a result, ISO 13256-1 rated cooling efficiency would be higher than typical design peak operation.
- Some WAHPs include efficiency data for a part load operating condition as allowed by ISO 13256-1 for multiple stage or variable speed compressors. No seasonal energy efficiency metric (analogous to SEER or IEER) currently applies to WAHPs. The annual performance of a geothermal WAHP system can vary more widely than for other system types due to the large influence of ground loop design and characteristics.
- The ENERGY STAR® criteria for ground source heat pumps apply only to residential applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger and distribution pumping systems represent a majority of the installation cost.
- Low end WAHPs utilize single stage compressors. Higher efficiency units incorporate multiple stage or variable speed compressor controls to improve efficiency as well as humidity and temperature control. Variable speed electronically commutated (EC) fan motors also improve overall energy efficiency.

Final

Commercial Electric Resistance Heaters

Same as reference case

DATA	2003		2012		2013		2020		2030		2040	
	Installed Base				Small	Large	Small	Large	Small	Large	Small	Large
	Small	Large	Small	Large								
Typical Capacity (kBtu/h)*	17	170	17	170	17	170	17	170	17	170	17	170
Efficiency (%)	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Average Life (yrs)	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost ($)	500	3,400	500	3,400	500	3,500	500	3,500	500	3,500	500	3,500
	700	3,800	700	3,800	700	3,900	700	3,900	700	3,900	700	3,900
Total Installed Cost ($)	600	3,500	600	3,500	650	4,000	650	4,000	650	4,000	650	4,000
	800	3,900	800	3,900	850	4,500	850	4,500	850	4,500	850	4,500
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-	-

* Capacity is *output*
** Annual Maintenance Cost is negligible

Commercial Electric Resistance Heaters

- This analysis examined electric unit heaters.
- Electric unit heaters range in capacity from 2 to 100 kW (7 to 340 kBtu/hr), with 5 to 50 kW (17 to 170 kBtu/hr) being the most typical units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion. For this analysis, the efficiency is 98% to account for IR losses and fan inefficiency.
- Installation time and costs are estimated to be minimal.

Final

Commercial Gas Storage Water Heaters

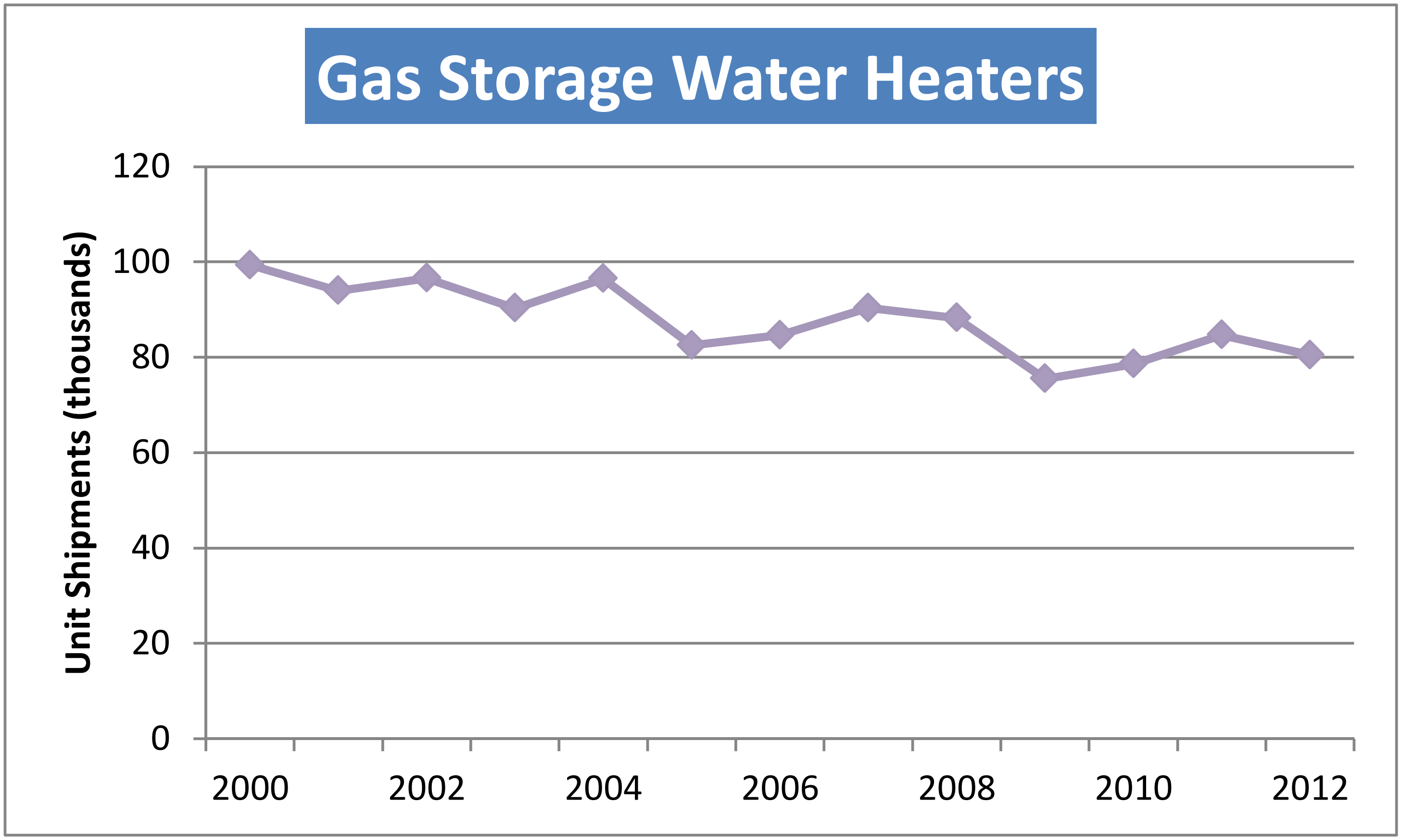
Higher typical efficiencies than ref. case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	100	100	100	100	100	100	100	100	100	100	100
Typical Input Capacity (kBtu/h)	200	200	200	200	200	200	200	200	200	200	200
Thermal Efficiency (%)	77	79	80	80	99	85	99	92	99	99	99
Average Life (yrs)	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2013$)	3,000	3,200	3,700	3,700	5,300	4,000	5,121	4,500	4,866	4,611	4,611
	4,500	4,800	6,100	6,100	6,900	6,150	6,667	6,200	6,335	6,003	6,003
Total Installed Cost (2013$)	3,530	3,730	4,230	4,230	5,830	4,530	5,651	5,030	5,396	5,141	5,141
	5,030	5,330	6,630	6,630	7,430	6,680	7,197	6,730	6,865	6,533	6,533
Annual Maintenance Cost (2013$)	110	110	110	110	110	110	110	110	110	110	110
	210	210	210	210	210	210	210	210	210	210	210

Commercial Gas Storage Water Heaters

- Input capacity ≥ 75,000 Btu/h
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss: Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss: 0.84 × [(Input Rate/800) + 110 × (Rated Volume)$^{1/2}$]
- Baseline units are constructed similarly to residential units, though typically with greater storage and/or input capacities.
- High-efficiency integrated units feature condensing heat exchangers, consisting of either stainless or enameled tubing and an inducer fan system or power burner. Other designs incorporate an external heating module with a storage tank assembly. Either design approach can yield a condensing appliance.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $100–$200 per year for one or two cleanings performed by a plumber.

Annual shipments dropped almost 20 percent over 12 years from 99 thousand units in 2000 to 80 thousand units in 2012.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

Final

Commercial Electric Resistance Water Heaters

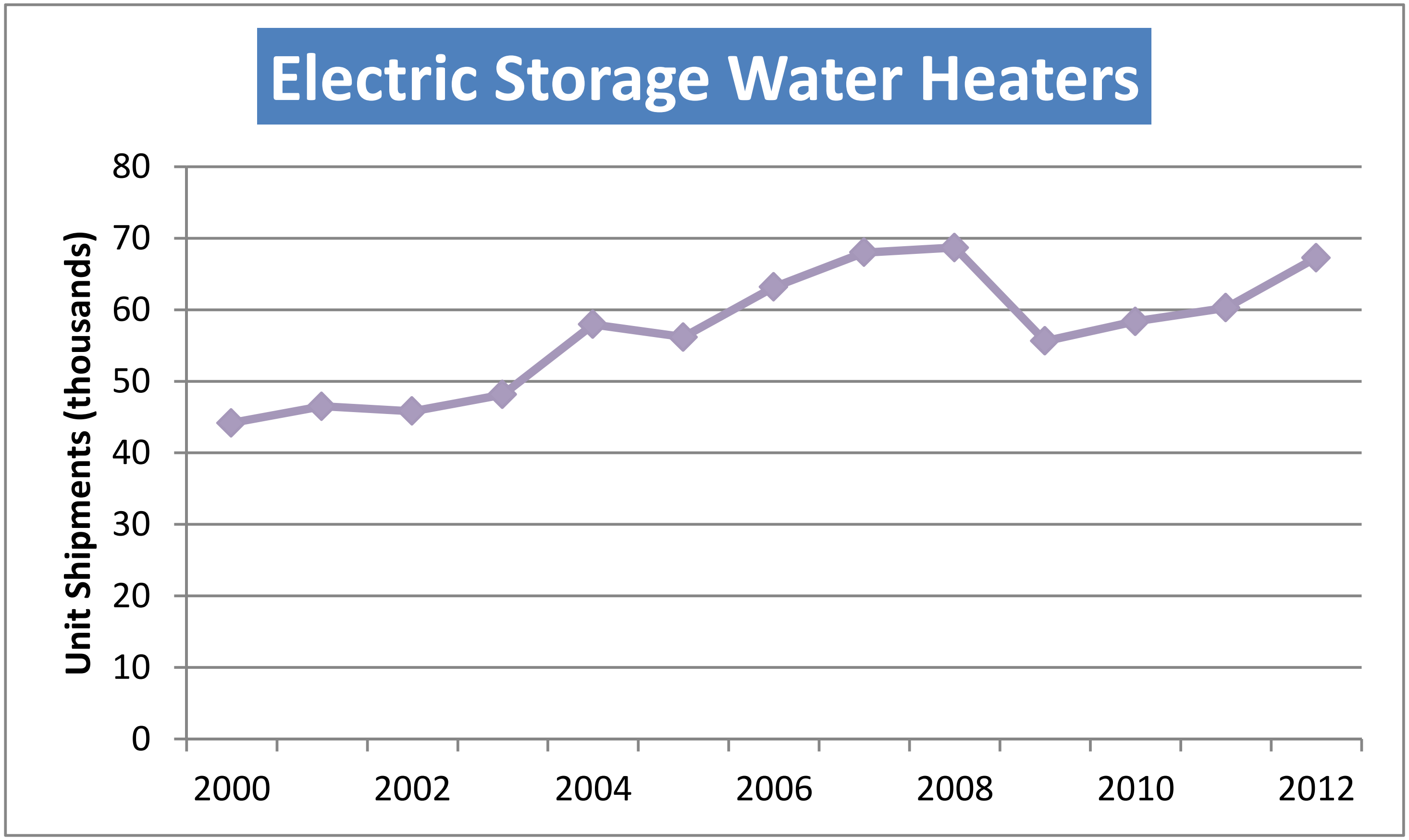
Same as reference case

DATA	2003	2012	2013		2020	2030	2040
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	120	120	120	120	120	120	120
Typical Input Capacity (kW)	45	45	54	54	54	54	54
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (yrs)	13	13	13	13	13	13	13
Retail Equipment Cost ($)	3600	3600	3600	3600	3600	3600	3600
	5600	5600	5600	5600	5600	5600	5600
Total Installed Cost ($)	4240	4240	4240	4240	4240	4240	4240
	6340	6340	6340	6340	6340	6340	6340
Annual Maintenance Cost ($)	110	110	110	110	110	110	110
	210	210	210	210	210	210	210

Commercial Electric Resistance Water Heaters

- Federal standard:
  - Maximum standby loss: 0.30 + 27/Measured Storage Volume
  - Minimum thermal efficiency: no standard, but all units ≥ 98% anyway
- Storage capacity: typically 50 to 120 gallons, though larger units exist for specialized applications
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $100–$200 per year for one or two cleanings performed by a plumber.

Annual shipments increased more than 50 percent over 12 years from 44 thousand units in 2000 to 67 thousand units in 2012.



Source: *Appliance Magazine*. (Also available from http://www.ahrinet.org/historical+data.aspx)

Final

Commercial Oil-Fired Water Heaters

Higher typical efficiencies than ref. case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	70	70	70	70	70	70	70	70	70	70	70
Typical Input Capacity (kBtu/h)	300	300	140	140	140	140	140	140	140	140	140
Thermal Efficiency (%)	78	79	78	80	85	82	85	84	85	85	85
Average Life (yrs)	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost ($)	4,360	4,420	4,360	6,500	8,500	7,250	8,500	8,000	8,500	8,500	8,500
Total Installed Cost ($)	4,890	4,950	4,890	7,030	9,030	7,780	9,030	8,530	9,030	9,030	9,030
Annual Maintenance Cost ($)	110	110	110	110	110	110	110	110	110	110	110
	210	210	210	210	210	210	210	210	210	210	210

Commercial Oil-Fired Water Heaters

- Input capacity ≥ 105,000 Btu/h
- Federal standard:
  - — Minimum thermal efficiency: 78%
  - — Maximum standby loss: Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- Condensing units do not exist, thus the highest attainable thermal efficiency is ≅ 86%.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $100–$200 per year for one or two cleanings performed by a plumber.

Final

Commercial Gas-Fired Instantaneous Water Heaters

Higher typical efficiencies than ref. case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	180	180	180	180	180	180	180	180	180	180	180
	230	230	250	250	250	250	250	250	250	250	250
Thermal Efficiency (%)	76	78	80	89	97	91	97	94	97	97	97
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	530	640	850	1,300	1,500	1,350	1,500	1,425	1,500	1,500	1,500
	800	900	1,050	1,650	1,850	1,700	1,850	1,775	1,850	1,850	1,850
Total Installed Cost ($)	680	790	1,000	1,550	1,750	1,600	1,750	1,675	1,750	1,750	1,750
	950	1,050	1,200	2,200	2,400	2,250	2,400	2,325	2,400	2,400	2,400
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Maintenance costs are negligible.

Commercial Gas-Fired Instantaneous Water Heaters

- Input capacity ≥ 200,000 Btu/h
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss: Input Rate/800 + 110 x (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss: 0.84 x [(Input Rate/800) + 110 x (Rated Volume)$^{1/2}$]
- Use similar technologies for improving energy efficiency as residential systems; however, unlike condensing residential systems, condensing commercial systems typically do not use multiple heat exchangers.
- Depending on the manufacturer, input ratings for condensing systems usually top out at 800,000 Btu/h, requiring the use of multiple units for staging purposes; however, there are reliability, comfort, and efficiency benefits to staging multiple units.
- When replacing a storage water heater with an instantaneous water heater, there may be significant additional costs to upsize the gas supply line and change the venting.

Final

Commercial Electric Booster Water Heaters

Same as reference case

DATA	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (gal)	6	6	6	6	6	6
	16	16	16	16	16	16
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	3	3	3	3	3	3
	10	10	10	10	10	10
Retail Equipment Cost ($)	1300	1250	1250	1250	1250	1250
	1600	2700	2700	2700	2700	2700
Total Installed Cost ($)	1500	1450	1450	1450	1450	1450
	1800	2900	2900	2900	2900	2900
Annual Maintenance Cost ($)*	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

Final

Commercial Gas Booster Water Heaters

Same as reference case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	6	3	3	3	3	3	3	3	3	3	3
	10	5	5	5	5	5	5	5	5	5	5
Thermal Efficiency (%)	79	80	80	80	91	82	93	85	95	85	95
Average Life (yrs)	3	3	3	3	3	3	3	3	3	3	3
	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost ($)	5,300	4,500	4,500	4,500	8,000	4,500	8,000	4,500	8,000	4,500	8,000
	6,400	6,500	6,500	6,500	10,000	6,500	10,000	6,500	10,000	6,500	10,000
Total Installed Cost ($)	5,600	4,800	4,800	4,800	8,300	4,800	8,300	4,800	8,300	4,800	8,300
	6,700	6,800	6,800	6,800	10,300	6,800	10,300	6,800	10,300	6,800	10,300
Annual Maintenance Cost ($)	160	160	160	160	160	160	160	160	160	160	160

Commercial Booster Water Heaters

- Booster water heaters are installed, often at the point of use, in series with the main service water heating system to boost service water temperatures. The main service water heating system may provide 110-140°F water, and the booster water heater may increase that temperature to 180-195°F. Typical commercial applications for booster water heaters include commercial dishwashers, laundromats, hospitals, and car washes.
- There is currently no energy efficiency standard for electric booster water heaters. Gas booster water heater minimum efficiency is dictated by ASHRAE Standard 90.1-2010 under the "gas instantaneous water heaters" category.
- Booster water heaters typically have short lifetimes because of high usage and extreme temperatures.
- Typical sales are small due to the limited number of applications.

Final

Commercial Gas Griddles

Higher typical efficiencies than ref. case

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Cooking Surface (ft^2)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Cooking Energy Efficiency (%)	30	30	30	38	52	33	52	37	52	41	52
Normalized Idle Energy Rate ($Btu/h/ft^2$)	3,000	3,000	3,000	2,650	1,180	2,760	1,180	2,430	1,180	2,090	1,180
Average Life (yrs)	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	5,000	5,000	5,000	5,360	6,160	5,150	6,160	5,365	6,160	5,580	6,160
Total Installed Cost ($)	5,150	5,150	5,150	5,510	6,310	5,300	6,310	5,515	6,310	5,730	6,310
Annual Maintenance Cost ($)*	–	–	–	–	–	–	–	–	–	–	–

* Maintenance costs are negligible.

Final

Commercial Electric Griddles

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2003	2012	2013			2020		2030		2040	
	Installed Base		Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Cooking Surface (ft^2)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Cooking Energy Efficiency (%)	65	65	65	70	82	67	82	70	82	73	82
Normalized Idle Energy Rate (W/ft^2)	440	440	440	320	210	410	210	370	210	320	210
Average Life (yrs)	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)	7,800	7,800	7,800	7,800	9,000	7,800	9,000	7,800	9,000	7,800	9,000
Total Installed Cost ($)	7,950	7,950	7,950	7,950	9,150	7,950	9,150	7,950	9,150	7,950	9,150
Annual Maintenance Cost ($)*	–	–	–	–	–	–	–	–	–	–	–

* Maintenance costs are negligible.

Final

Commercial Gas and Electric Griddles

- Used throughout the hospitality industry to crisp, brown, sear, warm, and toast foods.
- Transfers heat to food by direct contact with a hot plate, usually made of polished steel.
- Energy performance metrics are "Cooking Efficiency" (%) and "Normalized Idle Energy Consumption Rate" (Watts/ft^2), measured using ASTM F1275-03 and ASTM F1605-01.
- No Federal standards, but ENERGY STAR criteria version 1.1 took effect May 8, 2009 and became more stringent on January 1, 2011 for electric griddles.

ENERGY STAR Requirements	Gas	Electric
Cooking Energy Efficiency	≥ 38%	≥ 70%
Normalized Idle Energy Rate	≤ 2,650 Btu/h per ft^2	≤ 320 Watts per ft^2

- Price premiums for ENERGY STAR qualified products: estimated at $0 for electric and $360 for gas models.
- Incentives ranging from $25 to $600 per unit available from more than 30 utilities in 19 states.
- Energy savings achieved by using highly conductive or reflective plate materials, improved thermostatic controls, sub-griddle insulation (electric only), and through the strategic placement of thermocouples to better regulate temperature.

Final

Commercial Hot Food Holding Cabinets

Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2003	2012	2013				2020		2030		2040	
	Installed Base		State Standards	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4
Maximum Idle Energy Rate (W)	1,400	900	856	856	297	154	700	154	500	154	300	154
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost ($)	2,400	2,400	2,400	2,400	2,400	2,800	2,400	2,800	2,400	2,800	2,400	2,800
Total Installed Cost ($)	2,400	2,400	2,400	2,400	2,400	2,800	2,400	2,800	2,400	2,800	2,400	2,800
Annual Maintenance Cost ($)*	–	–	–	–	–	–	–	–	–	–	–	–

* Maintenance costs are negligible.

Commercial Hot Food Holding Cabinets

- Used in commercial kitchens to keep food warm until it is served.
- Many shapes and sizes, but interior volumes around 21.4 ft^3 typical in many settings.
- Annual unit energy consumption can range from < 1,000 to > 30,000 kWh/y, depending on size, efficiency, and usage.
- Energy performance metric is "Idle Energy Consumption Rate" in Watts, measured using ASTM Standard F2140-11.
- No Federal standards, but eight identical State standards, first took effect in California in 2006, now considered the typical or "baseline" product. ENERGY STAR version 2.0 took effect October 1, 2011.
- Maximum Idle Energy Consumption Rate for products $12 \le V < 28$:
  - State standards: $\boldsymbol{\le 40 \times V}$ (baseline)
  - ENERGY STAR: $\boldsymbol{\le 2.0 \times V + 254}$ (about 65% below baseline)

  where V is interior volume in ft^3.
- Small, if any, price premium for ENERGY STAR qualified products, yet incentives ranging from $110 to $900 per unit are available from more than 25 utilities in 7 states.
- The most efficient products are about 80% below baseline.
- Energy savings achieved with insulation, automatic door closers, magnetic door gaskets, and Dutch doors (half-doors).

Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19 St. NW, Suite 700
Washington, D.C. 20036
(202) 973-2400

www.navigantconsulting.com

Data Sources » Residential Gas-Fired Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td>EERE</td><td>AHRI</td><td>ENERGY STAR</td><td>AHRI</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Energy Factor</td><td>AHRI</td><td>EERE</td><td>AHRI</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors</td><td colspan="3">EERE</td><td>Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors / RS Means 2010</td><td colspan="4">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE</td><td colspan="4">EERE</td></tr>
</table>

Data Sources » Residential Oil Water Heaters

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical / High		
Typical Capacity (gal)	AHRI / Distributors	EERE	AHRI	AHRI	AHRI	Navigant		
Energy Factor	AHRI	EERE	AHRI					
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Distributors	EERE						
Total Installed Cost ($)	Distributors / RS Means 2007	EERE						
Annual Maintenance Cost ($)	EERE	EERE						

Data Sources » Residential Electric Resistance Water Heaters

SOURCES	2009	2013			2020	2030	2040
	Installed Base	Current Standard	Typical	High	Typical / High		
Typical Capacity (gal)	AHRI / Distributors	EERE	AHRI	AHRI	Navigant		
Energy Factor	AHRI	EERE	AHRI	AHRI			
Average Life (yrs)	EERE						
Retail Equipment Cost ($)	Distributors	EERE		Distributors			
Total Installed Cost ($)	Distributors / RS Means 2010	EERE					
Annual Maintenance Cost ($)	EERE	EERE					

Data Sources » Residential Heat Pump Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="2">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
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<tr><td>Energy Factor</td><td>AHRI</td><td colspan="2">ENERGY STAR</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>RS Means 2010 / ACEEE, 2007</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>RS Means 2010 / ACEEE, 2007</td><td colspan="2">Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td></td><td colspan="2">EERE</td></tr>
</table>

Data Sources » Residential Instantaneous Water Heaters

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/hr)	EERE	AHRI	ENERGY STAR / AHRI		ENERGY STAR	Navigant		
Energy Factor	Distributors	EERE	AHRI		ENERGY STAR			
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Distributors / RS Means 2010	Distributors						
Total Installed Cost ($)	DEER, 2008	Distributors						
Annual Maintenance Cost ($)	Navigant	EERE						

SOURCES	2009	2013		2020	2030	2040
	Installed Base	Current Standard	Typical	Typical		
Typical Capacity (sq. ft.)	SRCC			SAIC		
Overall Efficiency (Solar Fraction)	0.3-0.5 (RETScreen); 0.58-0.83 (SRCC); 0.5-0.75 (EERE)					
Solar Energy Factor	ENERGY STAR range=0.53-47, median=2, average=2.83					
Average Life (yrs)	20 year system life (EERE); Collector warranties are 10 years (ENERGY STAR/SRCC)					
Retail Equipment Cost[1] ($)	RS Means					
Total Installed Cost[1] ($)	RS Means					

[1] Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.
[2] ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

Data Sources » Residential Gas-Fired Furnaces

SOURCES	2009	2013					2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR		High	Typical / High		
Typical Input Capacity (kBtu/h)	Navigant	EERE					Navigant		
AFUE (%)	Navigant	EERE	EERE	ENERGY STAR	ENERGY STAR	AHRI			
Electric Consumption (kWh/yr)	EERE	EERE							
Average Life (yrs)	Appliance Magazine, 2012								
Retail Equipment Cost ($)	EERE	EERE							
Total Installed Cost ($)	EERE	EERE							
Annual Maintenance Cost ($)	EERE	EERE							

Data Sources » Residential Oil-Fired Furnaces

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Input Capacity (kBtu/h)	Navigant	EERE						
AFUE (%)	Navigant	EERE	EERE	ENERGY STAR	AHRI			
Electric Consumption (kWh)	EERE							
Average Life (yrs)	Appliance Magazine, 2012					Navigant		
Retail Equipment Cost ($)	EERE							
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Gas-Fired Boilers

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
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<tr><td>AFUE (%)</td><td>EERE 2007 / Navigant</td><td>EERE 2007</td><td>EERE 2007 / Navigant</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">Appliance Magazine, 2012</td></tr>
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<tr><td>Total Installed Cost ($)</td><td colspan="5">EERE 2007</td></tr>
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Data Sources » Residential Oil-Fired Boilers

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<tr><td>AFUE (%)</td><td>EERE / Navigant</td><td>EERE</td><td>EERE / Navigant</td><td>ENERGY STAR</td><td>AHRI</td></tr>
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<tr><td>Total Installed Cost ($)</td><td colspan="5">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE</td></tr>
</table>

Data Sources » Residential Room Air Conditioners

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/hr)	Distributors	AHAM				Navigant		
EER and CEER	Navigant	EERE	CCMS	ENERGY STAR	CCMS			
Average Life (yrs)	Appliance Magazine, 2012	Appliance Magazine, 2012						
Retail Equipment Cost ($)	Distributors	EERE						
Total Installed Cost ($)	Distributors	EERE						
Annual Maintenance Cost ($)	Navigant	Navigant						

South (Hot-Dry and Hot-Humid)

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	EERE					Navigant		
SEER	Navigant	eCFR	EERE	ENERGY STAR	AHRI			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE / Navigant				Navigant			
Total Installed Cost ($)	EERE / Navigant				Navigant			
Annual Maintenance Cost ($)	EERE							

North (Rest of Country)

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	EERE					Navigant		
SEER	Navigant	eCFR	EERE	ENERGY STAR	AHRI			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE				Navigant			
Total Installed Cost ($)	EERE				Navigant			
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Air Source Heat Pumps

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	EERE / AHRI					Navigant		
SEER (Cooling)	Navigant	eCFR	CCMS	ENERGY STAR	CCMS			
HSPF (Heating)	Navigant	eCFR	EERE	ENERGY STAR	CCMS			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE							
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Ground Source Heat Pumps

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI/SAIC					SAIC		
COP (Heating)	SAIC	ASHRAE 90.1-2010	SAIC	ENERGY STAR	ENERGY STAR Product Finder/ Product Literature			
EER (Cooling)	SAIC	ASHRAE 90.1-2010	SAIC	ENERGY STAR	ENERGY STAR Product Finder/ Product Literature			
Average Life (yrs)	System life 25 years, ground loop life 50 years (DOE)							
Retail Equipment Cost ($)	Distributors/IGSHPA/EERE/SAIC							
Total Installed Cost ($)	Distributors/IGSHPA/EERE/SAIC							
Annual Maintenance Cost ($)	SAIC							

Data Sources » Residential Gas Heat Pumps

SOURCES	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical		
Typical Capacity (kBTU/h)	Manufacturer		SAIC		
Heating (COP)	Product Literature				
Cooling (COP)	Product Literature				
Annual Electric Use (kWh/yr)	Product Literature/SAIC				
Average Life (yrs)	SAIC				
Retail Equipment Cost ($)	PERC/SAIC				
Total Installed Cost ($)	SAIC				
Annual Maintenance Cost ($)	SAIC				

Data Sources » Residential Electric Resistance Furnaces

SOURCES	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical		
Typical Capacity (kBTU/h)	Distributor/SAIC		SAIC		
Efficiency (%)	DOE/SAIC				
Average Life (yrs)	Distributors				
Retail Equipment Cost ($)	RS Means 2013/SAIC				
Total Installed Cost ($)	RS Means 2013/SAIC				
Annual Maintenance Cost ($)	SAIC				

Data Sources » Residential Electric Resistance Heaters

SOURCES	2009	2013	2020	2030	2040
	Installed Base	Typical	Typical		
Typical Capacity (kBTU/h)	Distributors/SAIC		SAIC		
Efficiency (%)	SAIC				
Average Life (yrs)	Technology Cost and Performance File for Commercial Model for AEO2010 (adapted for residential)				
Retail Equipment Cost ($)	Distributors/RS Means 2013/SAIC				
Total Installed Cost ($)	Distributors/RS Means 2013/SAIC				
Annual Maintenance Cost ($)	SAIC				

Data Sources » Residential Cord Wood Stoves

SOURCES	2009	2013			2020	2030	2040
	Installed Base	EPA Certified	Typical	High	Typical / High		
Typical Capacity (kBTU/h)	Distributors / Product Literature	Distributors / Product Literature	Distributors / Product Literature		SAIC		
Efficiency (Non-Catalytic) (HHV)	SAIC/Lit.	EPA Default	EPA Default	Product Lit./SAIC			
Thermal Efficiency (Catalytic) (HHV)	SAIC/Lit.	EPA Default	EPA Default	Product Lit./SAIC			
Average Life (yrs)	SAIC						
Retail Equipment Cost ($)	Product Lit./Dealers	Product Literature/Dealers					
Total Installed Cost ($)	Dealers	Dealers/SAIC					
Annual Maintenance Cost ($)	Dealers/SAIC	Dealers/SAIC					

Data Sources » Residential Wood Pellet Stoves

SOURCES	2009	2013			2020	2030	2040
	Installed Base	EPA Certified	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Distributors / Product Literature	Distributors / Product Literature	Distributors / Product Literature	Distributors / Product Literature	SAIC		
Efficiency (HHV)	SAIC/Lit.	EPA Default	EPA Default	Product Lit./ SAIC			
Average Life (yrs)	SAIC						
Retail Equipment Cost ($)	Product Lit./Dealers	Product Lit./Dealers					
Total Installed Cost ($)	Dealers	Dealers/SAIC					
Annual Maintenance Cost ($)	Dealers	Dealers/SAIC					

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (ft^3)	EERE / Navigant					Navigant		
Energy Consumption (kWh/yr)	Navigant							
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE / Navigant							
Total Installed Cost ($)	Navigant							
Annual Maintenance Cost ($)	EERE / Navigant							

Data Sources » Residential Natural Gas Cooktops

SOURCES	2009	2013		2020	2030	2040
	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Distributors / Product Literature	EERE		Navigant		
Cooking Efficiency (%)	Distributors / Product Literature	EERE				
Average Life (yrs)	Appliance Magazine, 2012					
Retail Equipment Cost ($)	EERE	EERE / Distributors				
Total Installed Cost ($)	EERE	EERE / Distributors				
Annual Maintenance Cost ($)	Navigant / EERE	Navigant / EERE				

Front-Loading

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (ft3)	Navigant	CCMS	Distributors	CCMS	CCMS	Navigant		
Modified Energy Factor (ft3/kWh/cycle)	Navigant	EERE	CCMS	ENERGY STAR	CCMS			
Water Factor (gal/cycle/ft^3)	Navigant	EERE	CCMS	ENERGY STAR	CCMS			
Average Life (yrs)	Appliance Magazine, 2012							
Water Consumption (gal/cycle)	[calculated]							
Hot Water Energy (kWh/cycle)	Navigant							
Machine Energy (kWh/cycle)	Navigant							
Dryer Energy (kWh/cycle)	Navigant							
Retail Equipment Cost ($)	EERE / Distributors							
Total Installed Cost ($)	RS Means 2010							
Annual Maintenance Cost ($)	Navigant							

Top-Loading

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (ft3)	Navigant	EERE			CCMS	Navigant		
Modified Energy Factor (ft3/kWh/cycle)	Navigant	EERE			CCMS			
Water Factor (gal/cycle/ft^3)	Navigant	EERE			CCMS			
Average Life (yrs)	Appliance Magazine, 2012							
Water Consumption (gal/cycle)	[calculated]							
Hot Water Energy (kWh/cycle)	Navigant							
Machine Energy (kWh/cycle)	Navigant							
Dryer Energy (kWh/cycle)	Navigant							
Retail Equipment Cost ($)	EERE / Distributors							
Total Installed Cost ($)	RS Means 2010							
Annual Maintenance Cost ($)	Navigant							

SOURCES	2009	2013			2020	2030	2040
	Installed Base	Current Standard	Typical	High	Typical / High		
Typical Capacity (ft3)	Navigant	CEC		CEC / Distributors	Navigant		
EF and CEF (lb/kWh)	Navigant	EERE / Navigant					
Average Life (yrs)	Appliance Magazine, 2012						
Retail Equipment Cost ($)	Navigant	EERE					
Total Installed Cost ($)	Navigant	EERE					
Annual Maintenance Cost ($)	EERE	EERE					

Data Sources » Residential Dishwashers

SOURCES	2009	2013				2020	2030	2040
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Annual Energy Use (kWh/yr)	EERE	EERE	Distributors / CCMS / EPA	EPA	CCMS	Navigant		
Water Consumption (gal/cycle)	EERE	EERE	Distributors / CCMS / EPA	EPA	CCMS			
Water Heating Energy Use (kWh/yr)	EERE							
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	EERE							
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	Navigant							

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Input Capacity (kBtu/h)	Arthur D. Little, 1997	AHRI	AHRI			Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004	AHRI	10 CFR 431.77	AHRI	Modine/ Reznor			
Average Life (yrs)	EERE / Navigant							
Retail Equipment Cost ($)	RS Means 2010 / Navigant / Distributors	RS Means 2011	RS Means 2011					
Total Installed Cost ($)	RS Means 2011	RS Means 2011	RS Means 2011					
Annual Maintenance Cost $)	RS Means 2010/ Navigant / Distributors		Public Comments from Stakeholders					

Data Sources » Commercial Oil-Fired Furnaces

SOURCES	2003	2012	2013		2020	2030	2040
	Installed Base		Current Standard	Typical	Typical		
Typical Input Capacity (kBtu/h)	Navigant / Distributors / AHRI	AHRI			Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004	AHRI	10 CFR 431.77	AHRI			
Average Life (yrs)	EERE / Navigant						
Retail Equipment Cost ($)	RS Means 2010	Navigant	RS Means 2011				
Total Installed Cost ($)	RS Means 2010	Navigant	RS Means 2011				
Annual Maintenance Cost ($)	Navigant / Distributors						

Data Sources » Commercial Electric Boilers

SOURCES	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical		
Typical Capacity (kW)	BSRIA			SAIC		
Efficiency (%)	DOE/SAIC					
Average Life (yrs)	ASHRAE 2007 HVAC Applications					
Retail Equipment Cost ($)	RS Means 2010/SAIC	RS Means 2013/SAIC				
Total Installed Cost ($)	RS Means 2010/SAIC	RS Means 2013/SAIC				
Annual Maintenance Cost ($)	RS Means 2010/SAIC	RS Means 2013/SAIC				

Data Sources » Commercial Gas-Fired Boilers

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical / High		
Typical Input Capacity (kBtu/h)	Navigant						Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Navigant		EERE	Navigant					
Average Life (yrs)	EERE								
Retail Equipment Cost ($)	CEC / RS Means 2010	RS Means 2011	RS Means 2011						
Total Installed Cost ($)	CEC / RS Means 2010	RS Means 2011	RS Means 2011						
Annual Maintenance Cost ($)	Navigant								

Data Sources » Commercial Oil-Fired Boilers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="3">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>Building Services Research and Information Association & Ducker Research Company, 1997, 1998</td><td>Navigant</td><td colspan="3">Navigant</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="2">ASHRAE Standard 90.1-2004</td><td>EERE</td><td colspan="2">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors / RS Means 2010 / Navigant</td><td>RS Means 2011 / Navigant</td><td colspan="3">RS Means 2011 / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">RS Means 2011 / Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="2">Navigant</td><td colspan="3">EERE</td></tr>
</table>

Data Sources » Commercial Gas-Fired Chillers

<table>
<tr><th rowspan="3">SOURCES</th><th colspan="2">2003</th><th colspan="2">2012</th><th colspan="2">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="4">Installed Base</th><th rowspan="2">Absorption</th><th rowspan="2">Engine-Driven</th><th colspan="3" rowspan="2">Absorption / Engine-Driven</th></tr>
<tr><th>Absorption</th><th>Engine-Driven</th><th>Absorption</th><th>Engine-Driven</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">BSRIA/Distributors</td><td colspan="3" rowspan="7">SAIC</td></tr>
<tr><td>Efficiency (kW/ton)</td><td colspan="6">Product Literature/SAIC</td></tr>
<tr><td>COP</td><td colspan="6">Product Literature/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">2007 ASHRAE Applications Handbook/Distributors</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="6">Manufacturer/Distributors/RS Means 2013/GIT/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td><td colspan="6">Manufacturer/Distributors/RS Means 2013/GIT/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="6">Manufacturer/Distributors/RS Means 2013/GIT/SAIC</td></tr>
</table>

Data Sources » Commercial Centrifugal Chillers

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Typical	Mid	High	Typical / High		
Typical Capacity (tons)	US Census	IPCC/TEAP/CARB/SAIC				SAIC		
Efficiency (kW/ton)	DEER/FEMP/ Product Literature	ASHRAE 90.1-2010/FEMP/ eSource/Product Literature						
COP	DEER/FEMP/ Product Literature	ASHRAE 90.1-2010/FEMP/ eSource/Product Literature						
Average Life (yrs)	2007 ASHRAE Applications Handbook							
Retail Equipment Cost ($/ton)	RS Means/Distributors/SAIC							
Total Installed Cost ($/ton)	RS Means/Distributors/SAIC							
Annual Maintenance Cost ($/ton)	SAIC							

Data Sources » Commercial Reciprocating Chillers

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Typical	Mid	High	Typical / High		
Typical Capacity (tons)	BSRIA/DEER					SAIC		
Efficiency (kW/ton)	ASHRAE 90.1-2010/DEER/FEMP/Product Literature							
COP	ASHRAE 90.1-2010/DEER/FEMP/Product Literature							
Average Life (yrs)	Manufacturers							
Retail Equipment Cost ($/ton)	RS Means 2013/Distributors/SAIC							
Total Installed Cost ($/ton)	RS Means 2013/Distributors/SAIC							
Annual Maintenance Cost ($/ton)	SAIC							

Data Sources » Commercial Screw Chillers

<table>
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<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>Mid</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">SAIC</td><td colspan="3" rowspan="7">SAIC</td></tr>
<tr><td>Efficiency (kW/ton)</td><td>DEER/FEMP/ Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>COP</td><td>DEER/FEMP/ Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">Manufacturers</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="6">RS Means 2013/Distributors/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td><td colspan="6">RS Means 2013/Distributors/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="6">SAIC</td></tr>
</table>

Data Sources » Commercial Scroll Chillers

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	Mid	High	Typical / High		
Typical Capacity (tons)	SAIC/Manufacturers						SAIC		
Efficiency [full-load/IPLV] (kW/ton)	Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC					
COP [full-load/IPLV]	Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC					
Average Life (yrs)	Manufacturers								
Retail Equipment Cost ($/ton)	Manufacturers/RS Means 2013/SAIC								
Total Installed Cost ($/ton)	Manufacturers/RS Means 2013/SAIC								
Annual Maintenance Cost ($/ton)	SAIC								

Data Sources » Commercial Rooftop Air Conditioners

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Output Capacity (kBtu/h)	AHRI / Navigant						Navigant		
Efficiency (EER)	ASHRAE Standard 90.1-2004	Distributors/ Navigant	EERE		ENERGY STAR	AHRI			
Average Life (yrs)	EERE								
Retail Equipment Cost $)	Navigant / LBNL, 2003	Distributors/ Navigant / DEER, 2008	EERE		Distributors				
Total Installed Cost ($)	Navigant / LBNL, 2003	Distributors/ Navigant / DEER, 2008	EERE		Distributors				
Annual Maintenance Cost ($)	EERE								

Data Sources » Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners/Heat Pumps

SOURCES	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical		
Typical Capacity (tons)	Manufacturer/Distributors/SAIC			SAIC		
Heating COP	NA	Product Literature				
Cooling COP	Product Literature/SAIC					
Average Life (yrs)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				
Retail Equipment Cost ($/ton)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				
Total Installed Cost ($/ton)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				
Annual Maintenance Cost ($)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC				

Data Sources » Commercial Rooftop Heat Pumps

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="6">AHRI / Navigant</td><td colspan="3" rowspan="7">Navigant</td></tr>
<tr><td>Efficiency (EER)</td><td colspan="2">ASHRAE Standard 90.1-2004 / Navigant</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>COP (Heating)</td><td colspan="2">EERE / Navigant</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="6">Distributors / RS Means 2010 / DEER / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="6">Distributors / RS Means 2010 / DEER / Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">Distributors / RS Means 2010 / DEER / Navigant</td></tr>
</table>

Data Sources » Commercial Ground Source Heat Pumps

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	Mid	High	Typical / High		
Typical Capacity (kBTU/h)	US DOE/EIA								
COP (Heating)	SAIC		ASHRAE 90.1-2010	Product Literature	Product Literature	Product Literature			
EER (Cooling)	SAIC		ASHRAE 90.1-2010	Product Literature	Product Literature	Product Literature			
Average Life (yrs)	System life 25 years, ground loop life 50 years (DOE); system life 25 years (ASHRAE RP 1237-TRP)						SAIC		
Retail Equipment Cost ($)	Distributors/SAIC								
Total Installed Cost ($)	US DOD/IGSHPA/MA DOER/CEFIA/ASHRAE								
Annual Maintenance Cost ($)	Geothermal Heat Pump Consortium, Inc. (US DOE Contract DE-FG07-95ID13347)								

Data Sources » Commercial Electric Resistance Heaters

SOURCES	2003		2012		2013		2020	2030	2040
	Small	Large	Small	Large	Small	Large	Small / Large		
Typical Capacity (kBTU/h)	Distributors/Navigant						SAIC		
Efficiency (%)	Navigant								
Average Life (yrs)	Technology Cost and Performance File for Commercial Model for AEO2010								
Retail Equipment Cost ($)	RS Means/Distributors/SAIC								
Total Installed Cost ($)	RS Means/Distributors/SAIC								
Annual Maintenance Cost ($)	Navigant								

Data Sources » Commercial Gas-Fired Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="3">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td colspan="2">Arthur D. Little / Distributors / AHRI</td><td colspan="3">AHRI</td><td colspan="3" rowspan="7">Navigant</td></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>Arthur D. Little / AHRI</td><td>AHRI</td><td colspan="3">AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="2">EERE / ASHRAE Standard 90.1-2004 / Navigant</td><td>EERE</td><td>AHRI</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors / CEC / Navigant</td><td colspan="3">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Distributors / CEC / Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">Navigant</td></tr>
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Data Sources » Commercial Electric Resistance Water Heaters

SOURCES	2003	2012	2013		2020	2030	2040
	Installed Base		Current Standard	Typical	Typical		
Typical Storage Capacity (gal)	Navigant / Product Literature		AHRI		Navigant		
Typical Input Capacity (kW)	Product Literature		AHRI				
Thermal Efficiency (%)	Product Literature	ASHRAE Standard 90.1-2004	AHRI				
Average Life (yrs)	EERE						
Retail Equipment Cost ($)	Distributors/ Navigant	Distributors	Distributors				
Total Installed Cost ($)	Distributors/ Navigant	Navigant	Navigant				
Annual Maintenance Cost ($)	Navigant						

Data Sources » Commercial Oil-Fired Water Heaters

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Storage Capacity (gal)	Navigant	AHRI / Navigant	AHRI / Navigant			Navigant		
Typical Input Capacity (kBtu/h)	Navigant	AHRI / Navigant	AHRI / Navigant					
Thermal Efficiency (%)	Navigant	Navigant	AHRI / Navigant					
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Navigant	Distributors / Navigant	Distributors					
Total Installed Cost ($)	Navigant	Distributors / Navigant	Navigant					
Annual Maintenance Cost ($)	Navigant	Distributors / Navigant	Navigant					

Data Sources » Commercial Gas-Fired Instantaneous Water Heaters

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / AHRI		AHRI			Navigant		
Thermal Efficiency (%)	AHRI	Navigant	EERE	AHRI				
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	CEC / Navigant / Distributors	Distributors / Navigant	Distributors					
Total Installed Cost ($)	CEC / Navigant / Distributors							
Annual Maintenance Cost ($)	CEC / Navigant / Distributors							

Data Sources » Commercial Electric Booster Water Heaters

SOURCES	2003	2012	2013	2020	2030	2040
	Installed Base		Typical	Typical		
Typical Capacity (gal)	Product Literature/SAIC			SAIC		
Thermal Efficiency (%)	Product Literature					
Average Life (yrs)	Product Literature					
Retail Equipment Cost ($)	Distributors/SAIC					
Total Installed Cost ($)	Distributors/SAIC					
Annual Maintenance Cost ($)	Distributors/SAIC					

Data Sources » Commercial Gas Booster Water Heaters

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Capacity (gal)	Distributors/SAIC					SAIC		
Thermal Efficiency (%)	Product Literature							
Average Life (yrs)	Product Literature/SAIC							
Retail Equipment Cost ($)	Distributors/SAIC							
Total Installed Cost ($)	Distributors/SAIC							
Annual Maintenance Cost ($)	Distributors/SAIC							

Data Sources » Commercial Gas Griddles

SOURCES	2003	2012	2013			2020	2030	2040
	Installed Base		Typical	ENERGY STAR	High	Typical / High		
Cooking Surface (ft^2)	FSTC, 2013					Navigant		
Cooking Energy Efficiency (%)	FSTC, 2002	Navigant		ENERGY STAR	ENERGY STAR QPL			
Normalized Idle Energy Rate (Btu/h/ft^2)	FSTC, 2002	Navigant		ENERGY STAR	ENERGY STAR QPL			
Average Life (yrs)	FSTC, 2013							
Retail Equipment Cost ($)	Distributors / ENERGY STAR Savings Calculator / Navigant							
Total Installed Cost ($)	FSTC, 2013							
Annual Maintenance Cost ($)	FSTC, 2013							

Data Sources » Commercial Electric Griddles

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="3">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
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<tr><td>Cooking Surface (ft²)</td><td colspan="5">FSTC, 2013</td><td colspan="3" rowspan="7">Navigant</td></tr>
<tr><td>Cooking Energy Efficiency (%)</td><td>FSTC, 2002</td><td colspan="2">Navigant</td><td>ENERGY STAR</td><td>ENERGY STAR QPL</td></tr>
<tr><td>Normalized Idle Energy Rate (W/ft²)</td><td>FSTC, 2002</td><td colspan="2">Navigant</td><td>ENERGY STAR</td><td>ENERGY STAR QPL</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">FSTC, 2013</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="5">Distributors / ENERGY STAR Savings Calculator / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">FSTC, 2013</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">FSTC, 2013</td></tr>
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Data Sources » Commercial Hot Food Holding Cabinets

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Interior Volume (ft³)</td><td colspan="6">FEMP</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Maximum Idle Energy Rate (W)</td><td colspan="2">CEE / Navigant</td><td colspan="3">ENERGY STAR Savings Calculator</td><td>FEMP</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">ENERGY STAR Savings Calculator</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="6">Distributors / ENERGY STAR Savings Calculator / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="6">Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">FSTC</td></tr>
</table>

Appendix B
References

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www.navigantconsulting.com

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APPENDIX C

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case

Presented to:

U.S. Energy Information Administration

Prepared by:

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December 19, 2012

DISCLAIMER

December 2012

Table of Contents

Objective

The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

- 2003/2007 (commercial) and 2005/2009 (residential) baselines, as well as today's (2011)
  - Review of literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
- Forecast of technology improvements that are projected to be available through 2040
  - Review of trends in standards, product enhancements, and Research and Development (R&D).
  - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- All cost forecasts are shown in 2011 dollars.

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2007 (for commercial products) and 2005 and 2009 (for residential) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- 2003/2007; 2005/2009 Installed Base: the installed and "in use" equipment for that year. Represents the installed stock of equipment, but does NOT represent sales.
- 2011 Current Standard: the minimum efficiency (or maximum energy use) required (allowed) by current DOE standards, when applicable.
- Typical: the average, or "typical," product being sold in the particular timeframe.
- ENERGY STAR: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable.
- Mid-Level: middle tier higher-efficiency product available in the particular timeframe.
- High: the product with the highest efficiency available in the particular timeframe.
- Lumens: All reported lumens are mean lumens, not initial lumens.
- CCT: The correlated color temperature (CCT) is a specification of the color appearance of the light emitted by a lamp.

Calculations

The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric.

- System Wattage = (Lamp Wattage * Ballast Factor) / Ballast Efficiency
- System Lumens = Lamp Lumens * Ballast Factor
- Lamp Efficacy = Lamp Lumens / Lamp Wattage
- System Efficacy = System Lumens / System Wattage
- Lamp Cost ($/klm) = Lamp Cost / (Lamp Lumens / 1000)
- Total Equipment Cost = Lamp Cost + Fixture (including ballast) Cost
- System Cost ($/klm) = Total Equipment Cost / (System Lumens / 1000)
- Total Installed Cost = Total Equipment Cost + Labor Installation Cost
- BLE = A/(1+B*Avg Total Lamp Arc Power^(-C))

The market for the reviewed products has changed since the analysis was performed in 2008. These changes are noted and reflected in the efficiency and cost characteristics.

- EPACT 2005 established standards for certain types of self-contained Commercial Refrigeration Equipment and batch Automatic Ice Makers which went into effect in 2010.
- EISA 2007 set several requirements for Walk-in Coolers and Freezers which went into effect in 2009.
- DOE issued Federal minimum efficiency standards that have or will soon go into effect for General Service Fluorescent Lamps (July 2012 effective date), Incandescent Reflector Lamps (July 2012), Fluorescent Lamp Ballasts (2014), Refrigerated Beverage Vending Machines (Aug. 2012), and certain Commercial Refrigeration Equipment (Jan. 2012) not covered by the EPACT 2005 standards.

Performance/Cost Characteristics » Residential General Service Incandescent Lamps (60 Watts)

DATA	2005	2009	2011			2014[1]		2020[2]	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	60W	60W	60W	60W	60W	60W	60W	60W	60W
Lamp Wattage	60	60	60	60	60	43	43	N/A	N/A
Lamp Lumens	850	850	830	860	870	750	750	N/A	N/A
Lamp Efficacy (lm/W)	14.2	14.2	13.8	14.3	14.5	17.4	17.4	N/A	N/A
Lamp Price	$0.25	$0.25	$0.31	$0.34	$0.37	$4.57	$4.57	N/A	N/A
Lamp Cost ($/klm)	$0.29	$0.29	$0.37	$0.40	$0.43	$6.09	$6.09	N/A	N/A
Average Lamp Life (1000 hrs)	1	1	2	1	1	3	3	N/A	N/A
CRI	100	100	100	100	100	100	100	N/A	N/A

[1] The Energy Independence and Security Act of 2007 prescribes standards for current 60 watt incandescent lamps as of January 1, 2014. Starting in 2014, we assume 60 watt incandescents will be replaced by halogen infrared incandescents.

[2] In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized incandescent lamp technologies and current trends in industry lead us to believe they will not be met.

Performance/Cost Characteristics » Residential General Service Incandescent Lamps (75 Watts)

DATA	2005	2009	2011			2013[1]		2020[2]	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	75W	75W	75W	75W	75W	75W	75W	75W	75W
Lamp Wattage	75	75	75	75	75	53	53	N/A	N/A
Lamp Lumens	1170	1170	1060	1170	1190	1050	1050	N/A	N/A
Lamp Efficacy (lm/W)	15.6	15.6	14.1	15.6	15.9	19.8	19.8	N/A	N/A
Lamp Price	$0.36	$0.37	$0.35	$0.40	$0.49	$4.69	$4.69	N/A	N/A
Lamp Cost ($/klm)	$0.32	$0.32	$0.33	$0.34	$0.41	$4.47	$4.47	N/A	N/A
Average Lamp Life (1000 hrs)	1	1	2	1	1	3	3	N/A	N/A
CRI	100	100	100	100	100	100	100	N/A	N/A

[1] The Energy Independence and Security Act of 2007 prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2014, we assume 75 watt incandescents will be replaced by halogen infrared incandescents.

[2] In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized incandescent lamp technologies and current trends in industry lead us to believe they will not be met.

Residential General Service Incandescent Lamps (60 and 75 Watts)

- The residential incandescent lighting characterized in this report is a 60 watt and a 75 watt medium screw based incandescent lamp.
- A standard 60 watt incandescent lamp produces approximately 860 lumens. A standard 75 watt incandescent lamp produces approximately 1170 lumens (GE, 2012; OSRAM, 2012; Philips, 2012; Sylvania, 2012). There is little variation in light output between products. Therefore, there is little variation in lamp efficacy.
- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60W lamps effective in 2014 and 75W lamps effective in 2013. These standards can be achieved if incandescent bulbs use halogen infrared technologies.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. These standards can not be achieved by any incandescent technology currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent technology.
- California's Appliance Efficiency Regulations include efficiency regulations for general service incandescent lamps with certain bases. California is currently undergoing a rulemaking to reduce indoor residential lighting by not less than 50% of 2007 levels over the next 10 years in accordance with Assembly Bill 1109. They are going to regulate general purpose lighting (incandescent lamps) and portable lighting fixtures.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Reflector Lighting

DATA	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	65	65	50	16	65	50	15
Lamp Lumens	620	620	660	750	630	630	720
Lamp Efficacy (lm/W)	9.5	9.5	13.2	46.9	9.7	12.6	48.0
Lamp Price	$1.36	$1.37	$4.19	$5.87	$3.38	$6.12	$6.36
Lamp Cost ($/klm)	$2.20	$2.21	$6.35	$7.82	$5.36	$9.72	$8.83
Average Lamp Life (1000 hrs)	2.0	2.0	3.0	8.0	1.8	3.0	8.0
CRI	100	100	100	82	100	100	82

Performance/Cost Characteristics » Residential Reflector Lighting

DATA	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	65	50	15	65	50	15	65	50	15
Lamp Lumens	636	662	756	643	695	794	649	729	833
Lamp Efficacy (lm/W)	9.8	13.2	50.4	9.9	13.9	52.9	10.0	14.6	55.6
Lamp Price	$3.30	$5.97	$6.20	$3.21	$5.82	$6.05	$3.13	$5.67	$5.89
Lamp Cost ($/klm)	$5.18	$9.02	$8.20	$5.00	$8.38	$7.62	$4.83	$7.78	$7.07
Average Lamp Life (1000 hrs)	1.8	3.1	8.2	1.9	3.2	8.4	1.9	3.2	8.6
CRI	100	100	82	100	100	82	100	100	82

Residential Reflector Lamps

- The residential reflector lamps characterized in this report is a 65W BR30 incandescent, a 50W PAR30 halogen, and a 16W BR30 Reflector compact fluorescent.
- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA 2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008. The 65W BR30, a large majority of the incandescent reflector lamp market is still exempted.
- The following future improvements for the system were assumed to occur over a 30 year period:
  - Incandescents: Efficacy +3%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - Halogen: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - CFL: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
- These improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Final

Performance/Cost Characteristics » Residential Compact Fluorescent Lighting

DATA	2005	2009	2011				2020		2030		2040	
	Installed Base		Energy Star	Low	Typical	High	Typical	High	Typical	High	Typical	High
	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W
Lamp Wattage	13	13	13	13	13	13	13	13	13	13	13	13
Lamp Lumens	825	825	715	825	875	900	919	945	965	992	1013	1042
Lamp Efficacy (lm/W)	63.5	63.5	55.0	63.5	67.2	69.2	70.7	72.7	74.2	76.3	77.9	80.1
Lamp Price	$3.14	$2.15	N/A	$1.57	$2.38	$3.33	$2.32	$3.25	$2.26	$3.17	$2.21	$3.09
Lamp Cost ($/klm)	$4.22	$2.61	N/A	$1.90	$2.72	$3.70	$2.53	$3.44	$2.35	$3.19	$2.18	$2.96
Average Lamp Life (1000 hrs)	10.0	10.0	6.0	8.0	10.0	10.0	10.3	10.3	10.5	10.5	10.8	10.8
CRI	82	82	80	82	82	82	82	82	82	82	82	82

Residential Compact Florescent Lamps

- The residential compact fluorescent lamp characterized in this report is a 13 watt compact fluorescent lamp.
- Compact Fluorescents contain mercury and therefore require appropriate disposal. In addition, because the color rendering index of compact fluorescents is lower than that incandescent lamps (82 compared to 100), the quality of the light of a compact fluorescent falls short of incandescent lamps.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts Energy Star performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. The Secretary may revise these requirements by rule or establish other requirements at a later date. *[Note: EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based)]*
- Energy Star® and the Consortium for Energy Efficiency (CEE) offer voluntary specifications for CFL lamps.
- The following future improvements were assumed to occur over a 30 year period: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the electrodes.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Linear Fluorescent Lamps (T12 and T8)

DATA	2005	2009		2011					
	Installed Base			Current Standard	Mid-Level T12	High T12	Baseline T8	Mid-Level T8	High T8
	32WT8	40WT12	32WT8	40WT12	40WT12	34WT12	32WT8	32WT8	28WT8
Lamp Wattage	64	80	64	80	80	68	64	64	56
Lamp Lumens	5040	5720	5040	5720	6500	5580	5040	5420	5120
System Wattage	65	70	65	70	70	60	65	65	57
System Lumens	4435	3890	4435	3890	4420	3794	4435	4770	4506
Lamp Efficacy (lm/W)	78.8	71.5	78.8	71.5	81.3	82.1	78.8	84.7	91.4
System Efficacy (lm/W)	68.7	55.6	68.7	55.6	63.1	63.8	68.7	73.8	79.7
Lamp Price ($)	$3.35	$1.85	$1.71	$1.85	$5.91	$5.79	$1.71	$2.67	$2.88
Ballast Price ($)	$15.71	$11.22	$9.94	$11.22	$11.22	$11.22	$9.94	$9.94	$9.94
Lamp Cost ($/klm)	$0.66	$0.32	$0.34	$0.32	$0.91	$1.04	$0.34	$0.49	$0.56
Average Lamp Life (1000 hrs)	20	15	20	15	24	24	20	20	18
CRI	75	70	75	70	85	85	75	82	82
Ballast Efficiency (BLE)	83%	78%	87%	78%	78%	78%	87%	87%	87%

Performance/Cost Characteristics » Residential Linear Fluorescent Lamps (T12 and T8)

DATA	2020		2030		2040	
	Typical T8	High T8	Typical T8	High T8	Typical T8	High T8
	32WT8	28WT8	32WT8	28WT8	32WT8	28WT8
Lamp Wattage	64	56	64	56	64	56
Lamp Lumens	5700	5197	5700	5282	5700	5367
System Wattage	65	57	65	57	65	57
System Lumens	5016	4573	5016	4648	5016	4723
Lamp Efficacy (lm/W)	89.1	92.8	89.1	94.3	89.1	95.8
System Efficacy (lm/W)	77.7	80.9	77.7	82.3	77.7	83.6
Lamp Price ($)	$2.76	$2.84	$2.71	$2.79	$2.67	$2.74
Ballast Price ($)	$9.79	$9.79	$9.62	$9.62	$9.46	$9.46
Lamp Cost ($/klm)	$0.48	$0.55	$0.48	$0.53	$0.47	$0.51
Average Lamp Life (1000 hrs)	25	19	26	19	26	20
CRI	85	82	85	82	85	82
Ballast Efficiency (BLE)	87%	87%	87%	87%	87%	87%

Residential Linear Fluorescent Lighting (T12/T8)

- This report assumes that T12 and T8 residential linear fluorescent lamps provide the same utility to consumers. Each characterized technology is a two-lamp, one-ballast system that emits approximately 4,500 system lumens.
- In a change from the 2008 EIA Reference Case, this report characterizes a range of efficacies for T12 and T8 lamps and does not use T5 lamps for direct comparison because T5 lamps are almost never used as residential replacement options.
- Assumptions for 2011:
  - Low efficiency and mid-range efficiency T12s: 2 F40T12 lamps with a residential low power factor electronic ballast (ballast factor =0.68, ballast luminous efficiency (BLE)= 77.7%)
  - High efficiency T12: 2 F34T12 lamps with a residential low power factor electronic ballast (ballast factor =0.68, BLE =77.7%)
  - Baseline and mid-range efficiency T8s: 2 F32T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=87.2%)
  - High efficiency T8: 2 F28T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=87.2%)
- Since 1995, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 75 lm/W and a minimum CRI of 69 for >35W lamps or 45 for <35W lamps.
- In 2005, DOE standards raised the minimum ballast efficacy factor (BEF) of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems. Residential ballasts were originally exempted from regulation.

Residential Linear Fluorescent Lighting (T12/T8)

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized residential ballasts have a minimum BLE = 0.993 / (1 + 0.41 * Avg Total Lamp Arc power ^ (- 0.25)). Residential ballasts also must have a minimum power factor of 0.5.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR residential fixtures require ≥ 65 lm/W per lamp-ballast platform before September 1, 2013 and ≥ 70 lm/W per lamp-ballast platform thereafter.
- The following future improvements were assumed to occur over a 30-year period in addition to the improvements necessitated by DOE standards: Efficacy +5%, Life +10%, and Price -5% (NCI, 2012). Improvements can be made by using more rare-earth phosphors. Improvements in life can be made by using better electrodes. Additional future energy savings are expected to come from increased use of dimming ballasts and occupancy sensors with linear fluorescent lighting.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Linear Fluorescent Lamps (T5)

DATA	2005	2009	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
Lamp Wattage	56	56	56	52	56	52	56	52	56	52
Lamp Lumens	5320	5320	5320	5320	5400	5400	5488	5488	5577	5577
System Wattage	63	63	63	59	61	57	61	57	61	57
System Lumens	5320	5320	5320	5320	5400	5400	5488	5488	5577	5577
Lamp Efficacy (lm/W)	95.0	95.0	95.0	102.3	96.4	103.8	98.0	105.5	99.6	107.3
System Efficacy (lm/W)	84.3	84.3	84.3	90.7	88.7	95.5	90.2	97.1	91.6	98.7
Lamp Price ($)	$3.56	$3.18	$3.18	$3.97	$3.13	$3.91	$3.08	$3.85	$3.03	$3.78
Ballast Price ($)	$20.94	$20.94	$20.94	$20.94	$26.72	$26.72	$26.26	$26.26	$25.81	$25.81
Lamp Cost ($/klm)	$0.67	$0.60	$0.60	$0.75	$0.58	$0.72	$0.56	$0.70	$0.54	$0.68
Average Lamp Life (1000 hrs)	20	20	20	25	21	26	21	27	22	27
CRI	85	85	85	85	85	85	85	85	85	85
Ballast Efficiency (BLE)	88.7%	88.7%	88.7%	88.7%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%

Residential Linear Fluorescent Lighting (T5)

- The residential T5 lamps characterized in this report are part of a two-lamp, one-ballast systems that emit approximately 5,300 system lumens.
- Compared to the 2008 EIA Reference Case, this report characterizes a range of efficacies within the T5 family and does not use T12 and T8 lamps for direct comparison because of a distinct utility for T5 lamps. Notably, T5 systems are very rarely used in the residential sector.
- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- Assumptions for 2011:
  - Typical: 2 F28T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)
  - Best available: 2 F26T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)

Residential Linear Fluorescent Lighting (T5)

- Currently no federal standards exist for the T5 lamps or their corresponding ballasts.
- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 86 lm/W.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- The following future improvements were assumed to occur over a 30-year period: Efficacy +5%, Life +10%, and Price -5% (NCI, 2012). Improvements can be made by using more rare-earth phosphors. Improvements in life can be made by using better electrodes. Additional future energy savings are expected to come from increased use of dimming ballasts and occupancy sensors with linear fluorescent lighting.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Torchieres

DATA	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	253	150	154	37	150	150	40
Lamp Lumens	4300	2670	2670	2670	2733	2650	2666
Lamp Efficacy (lm/W)	17.0	17.8	17.3	72.7	18.2	17.7	66.6
Lamp Price	$4.15	$2.27	$1.10	$12.71	$2.87	$3.88	$12.33
Lamp Cost ($/klm)	$0.97	$0.85	$0.42	$4.76	$1.05	$1.46	$4.63
Average Lamp Life (1000 hrs)	2.1	1.0	1.8	10.0	0.8	3.0	9.5
CRI	98	100	100	82	100	100	82

DATA	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	150	150	40	150	150	40	150	150	40
Lamp Lumens	2760	2783	2799	2788	2922	2939	2816	3068	3086
Lamp Efficacy (lm/W)	18.4	18.6	70.0	18.6	19.5	73.5	18.8	20.5	77.1
Lamp Price	$2.80	$3.78	$12.02	$2.73	$3.69	$11.72	$2.66	$3.60	$11.43
Lamp Cost ($/klm)	$1.01	$1.36	$4.30	$0.98	$1.26	$3.99	$0.94	$1.17	$3.70
Average Lamp Life (1000 hrs)	0.8	3.1	9.7	0.8	3.2	10.0	0.8	3.2	10.2
CRI	100	100	82	100	100	82	100	100	82

Residential Torchieres

- The residential torchiere characterized in this report emits approximately 2,683 lumens. The typical characteristics are a weighted average of a halogen, incandescent, and CFL torchieres based. The 2005 typical wattage is based on 2003 installed base data. The 2009 typical wattage is based on EPACT standards.
- Energy Star® and the Consortium for Energy Efficiency (CEE) offer voluntary specifications for torchieres.
- The following future improvements for the system were assumed to occur over a 30 year period:
  - Incandescents: Efficacy +3%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - Halogen: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - CFL: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Solid State Lighting (LED A19 Replacement)

DATA	2005	2009	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	A19 LED	A19 LED	A19 LED	A19 LED	A19 LED
Typical Wattage	36	18	13	5	4	4
Lumens	630	800	800	800	800	800
Efficacy (lm/W)	17.3	44.0	60.0	157.0	202.0	202.0
Lamp Price ($)	$189.82	$68.00	$26.40	$4.00	$2.40	$2.40
Cost ($/klm)	$301.00	$85.00	$33.00	$5.00	$3.00	$3.00
Average Life (1000 hrs)	50	20	25	50	50	50
CRI	92	80	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700

Performance/Cost Characteristics » Residential Solid State Lighting (LED PAR38 Replacement)

DATA	2005	2009	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	PAR38 LED	PAR38 LED	PAR38 LED	PAR38 LED	PAR38 LED
Typical Wattage	36	28	20	6	5	5
Lumens	630	1000	1000	1000	1000	1000
Efficacy (lm/W)	17.3	36.0	50.0	157.0	202.0	202.0
Lamp Price ($)	$189.82	$164.00	$51.00	$7.00	$5.00	$5.00
Cost ($/klm)	$301.00	$164.00	$51.00	$7.00	$5.00	$5.00
Average Life (1000 hrs)	50	20	25	50	50	50
CRI	92	80	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700

Residential Solid-State Lighting

- The residential solid-state lighting characterized in this report are replacements for a 60W A19 lamp and a 75W PAR38 lamp. These represent the most common uses of LED technology in the residential sector.
- This report characterizes two distinct applications for LEDs in the residential sector rather than one, as was done in the 2008 EIA Reference Case. Because of rapid LED technology development, the market is best characterized by the state of the technology at a given time rather than a range of performance at any one time.
- Assumptions for 2011:
  - 60W A19 equivalent: 13W LED emitting 800 lumens
  - 75W PAR38 equivalent: 20W LED emitting 1000 lumens
- No federal standards exist for solid-state lighting.
- The 2012 Solid State Lighting Multi-Year Program Plan and 2012 Energy Savings Forecast Model served as sources for many of the projections for LED technology.
- Installation costs and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Commercial General Service Incandescent Lighting

DATA	2003	2007	2011			2012[1]	2020[2]
	Installed Base		Low	Typical	High	Typical	Typical
	Typical	Typical	Low	Typical	High	72W Inc	72W Inc
System Wattage	100	100	100	100	100	72	N/A
System Lumens	997	997	903	965	1003	879	N/A
Lamp Efficacy (lm/W)	16.9	16.9	15.3	16.2	17.0	20.7	N/A
System Efficacy (lm/W)	10.0	10.0	9.0	9.6	10.0	12.2	N/A
Lamp Cost ($/klm)	$0.23	$0.19	$0.40	$0.35	$0.39	$3.09	N/A
System Cost ($/klm)	$17.07	$13.97	$20.46	$21.29	$22.59	$19.14	N/A
Average Lamp Life (1000 hrs)	1	1	2	1	1	3	N/A
CRI	100	100	100	100	100	100	N/A
Total Installed Cost ($)	$89.76	$73.45	$85.40	$85.35	$85.39	$71.00	N/A
Annual Maintenance Cost ($)	$3.58	$3.58	$3.58	$3.58	$3.58	$0.86	N/A

[1] The Energy Independence and Security Act of 2007 prescribes standards for current 100 watt incandescent lamps as of January 1, 2012. Starting in 2012, 100-watt incandescents will be replaced by halogen infrared incandescents.

[2] In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized incandescent lamp technologies and current trends in industry lead us to believe they will not be met.

Commercial General Service Incandescent Lighting

- The Commercial incandescent lighting characterized in this report is a 100 watt medium screw based incandescent lamp (NCI, 2002) in an open down light recessed can fixture (~$20) with a fixture efficiency of 59% (DOE, 2008).
- A The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards can be achieved if incandescent bulbs use halogen infrared technologies.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. These standards can not be achieved by any incandescent technology currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent technology.
- California's Appliance Efficiency Regulations include efficiency regulations for general service incandescent lamps with certain bases. California's Appliance Efficiency Regulations include efficiency regulations for general service incandescent lamps with certain bases. California is currently undergoing a rulemaking to reduce commercial lighting by not less than 25% of 2007 levels over the next 10 years in accordance with Assembly Bill 1109. They are going to regulate general purpose lighting (incandescent lamps).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the fluorescent and incandescent energy conservation standard advanced notice of proposed rulemaking (lamps ANOPR). Maintenance costs include labor only based on 3,376 operating hours per year. (lamps ANOPR)

Final

Performance/Cost Characteristics » Commercial Compact Fluorescent Lamps

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Low	Typical	High	Typical	High	Typical	High	Typical	High
	26W	26W	23W	23W	23W	23W	23W	23W	23W	23W	23W
System Wattage	26	26	23	23	23	23	23	23	23	23	23
System Lumens	1068	1068	976	976	1010	1025	1060	1076	1113	1130	1169
Lamp Efficacy (lm/W)	67.3	67.3	69.6	69.6	72.0	73.0	75.6	76.7	79.3	80.5	83.3
System Efficacy (lm/W)	41.1	41.1	42.4	42.4	43.9	44.6	46.1	46.8	48.4	49.1	50.8
Lamp Cost ($/klm)	$4.01	$3.28	$1.56	$1.56	$1.73	$1.52	$1.69	$1.49	$1.65	$1.45	$1.61
System Cost ($/klm)	$22.14	$18.12	$23.05	$23.05	$22.65	$22.48	$22.09	$21.92	$21.54	$21.37	$21.00
Average Lamp Life (1000 hrs)	10.0	10.0	10.0	12.0	12.0	12.3	12.3	12.6	12.6	12.9	12.9
CRI	82	82	82	82	82	82	82	82	82	82	82
Total Installed Cost ($)	$96.56	$79.02	$80.00	$80.00	$80.00	$78.00	$78.00	$76.05	$76.05	$74.15	$74.15
Annual Maintenance Cost ($)	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39

Commercial Compact Fluorescent Lamps

- The commercial compact fluorescent lamp characterized in this report is a 23 watt screw-base compact fluorescent lamp in an open down light recessed can fixture (~$20) with a fixture efficiency of 61%.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts Energy Star performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. The Secretary may revise these requirements by rule or establish other requirements at a later date. *[Note: EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based)]*
- Energy Star® and the Consortium for Energy Efficiency (CEE) offer voluntary specifications for CFL lamps.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005)
- The following future improvements were assumed to occur over a 30 year period: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012). Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the lamps ANOPR. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial Halogen Lighting (PAR 38)

DATA	2003		2007		2011		2020		2030		2040	
	Installed Base				Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR
System Wattage	90	70	90	70	90	70	90	70	90	70	90	70
System Lumens	1218	1172	1218	1172	1230	1306	1291	1372	1355	1441	1423	1513
Lamp Efficacy (lm/W)	14.6	18.0	14.6	18.0	14.7	20.1	15.4	21.1	16.2	22.1	17.0	23.2
System Efficacy (lm/W)	13.5	16.7	13.5	16.7	13.7	18.7	14.3	19.6	15.1	20.6	15.8	21.6
Lamp Cost ($/klm)	$4.98	$6.76	$4.07	$5.53	$2.87	$11.19	$2.80	$10.91	$2.73	$10.64	$2.66	$10.37
System Cost ($/klm)	$19.01	$21.46	$15.56	$17.56	$19.35	$27.34	$18.87	$26.65	$18.39	$25.99	$17.93	$25.34
Average Lamp Life (1000 hrs)	2.5	3.0	2.5	3.0	2.4	3.6	2.5	3.7	2.5	3.8	2.6	3.9
CRI	100	100	100	100	100	100	100	100	100	100	100	100
Total Installed Cost ($)	$96.56	$97.92	$79.02	$80.13	$81.00	$93.00	$80.19	$92.07	$79.39	$91.15	$78.59	$90.24
Annual Maintenance Cost ($)	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22

Final

Performance/Cost Characteristics » Commercial Halogen Lighting (Edison)

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	90W Edison	90W Edison	90W Edison	90W Edison	90W Edison	90W Edison
System Wattage	90	90	72	72	72	72
System Lumens	1218	1218	1395	1465	1538	1615
Lamp Efficacy (lm/W)	14.6	14.6	20.8	21.9	23.0	24.1
System Efficacy (lm/W)	13.5	13.5	19.4	20.3	21.4	22.4
Lamp Cost ($/klm)	$4.98	$4.07	$1.33	$1.30	$1.26	$1.23
System Cost ($/klm)	$19.01	$15.56	$15.76	$15.37	$14.99	$14.61
Average Lamp Life (1000 hrs)	2.5	2.5	1.0	1.0	1.1	1.1
CRI	100	100	100	100	100	100
Total Installed Cost ($)	$96.56	$79.02	$80.00	$78.00	$76.05	$74.15
Annual Maintenance Cost ($)	$1.92	$1.57	$1.41	$1.41	$1.41	$1.41

Commercial Halogen Lighting

- The commercial halogen lighting characterized in this report is a lamp that emits approximately 1200-1400 lumens in an open down light recessed can fixture (~$20) with a fixture efficiency of 93% (DOE, 2008).
- Multiple types of halogen lamps were analyzed, including:
  - Typical efficiency unit: 90W halogen PAR38
  - High efficiency unit: 70W halogen infrared reflector PAR38
  - Typical efficiency unit: 72 W halogen Edison A-line lamp
- Halogen infrared reflector (HIR) lamps contain a tungsten halogen capsule with a film coating on the inside of the capsule. The coating reflects infrared radiation back into the lamp filament, which forces the filament to burn at a higher temperature. This increases the efficacy of the lamp, without reducing operating life.
- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008.
- The following future improvements for the system were assumed to occur over a 30 year period: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012). These improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the lamps ANOPR. Maintenance costs include labor only based on 3,450 operating hours per year. (lamps ANOPR)

Performance/Cost Characteristics » Commercial Solid State Lighting (Edison Socket Substitute)

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	BR30 LED	BR30 LED	BR30 LED	BR30 LED	BR30 LED
Wattage	36.4	12.7	10.8	3.8	3.2	3.2
Lumens	548	650	650	650	650	650
Efficacy (lm/W)	15.1	51.0	60.0	170.0	202.0	202.0
Lamp Cost ($/klm)	$392.68	$205.00	$80.00	$20.00	$13.00	$13.00
Life (1000 hrs)	50	25	50	75	75	75
CRI	92	85	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700
Total Installed Cost ($)	$270.44	$186.77	$105.52	$66.52	$61.97	$61.97
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (Edison Socket Substitute)

- The commercial solid-state lighting characterized is a replacement for a 65W BR30 lamp. This represents the most common use of LED technology in Edison sockets in the commercial sector.
- Assumptions for 2011:
  - 65W BR30 equivalent: 11W LED emitting 650 lumens in a downlight fixture
- No federal standards exist for solid-state lighting.
- The 2012 Solid State Lighting Multi-Year Program Plan and 2012 Energy Savings Forecast Model served as sources for many of the projections for LED technology.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial 4-ft T8 Linear Fluorescent Lighting

DATA	2003	2007	2011				
	Installed Base		Baseline	High Efficiency	HE w/ Occ. Sensor	HE w/ Spec. Reflector	HE w/ OS & Spec. Ref.
	32WT8	32WT8	32WT8	28WT8	28WT8	28WT8	28WT8
System Wattage	65	65	65	57	57	57	57
System Lumens	3282	3282	3282	3334	3334	3942	3942
Lamp Efficacy (lm/W)	78.8	78.8	78.8	91.4	91.4	91.4	91.4
System Efficacy (lm/W)	50.1	50.1	50.1	58.2	58.2	68.8	68.8
Cost ($/klm)	$0.38	$0.38	$0.38	$0.63	$0.63	$0.63	$0.63
Cost ($/klm l/b/f)	$13.81	$13.81	$13.81	$14.38	$15.29	$17.64	$18.40
Average Lamp Life (1000 hrs)	20	20	20	18	9	18	9
CRI	75	75	75	82	82	82	82
Total Installed Cost ($)	$74.00	$74.00	$74.00	$76.63	$79.64	$98.20	$101.21
Annual Maintenance Cost ($)	$3.03	$3.03	$3.03	$3.16	$4.41	$3.16	$4.41
Ballast Efficiency (BLE)	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%

Performance/Cost Characteristics » Commercial 4-ft T8 Linear Fluorescent Lighting (Cont.'d)

DATA	2020					2030					2040				
	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max
	32WT8	28WT8	28WT8	28WT8	28WT8	32WT8	F28T8	F28T8	F28T8	F28T8	F32T8	F28T8	F28T8	F28T8	F28T8
System Wattage	62	54	54	54	54	62	54	54	54	54	62	54	54	54	54
System Lumens	3712	3384	3384	4002	4002	3712	3440	3440	4067	4067	3712	3495	3495	4133	4133
Lamp Efficacy (lm/W)	89.1	92.8	92.8	92.8	92.8	89.1	94.3	94.3	94.3	94.3	89.1	95.8	95.8	95.8	95.8
System Efficacy (lm/W)	60.0	62.6	62.6	74.0	74.0	60.0	63.6	63.6	75.2	75.2	60.0	64.6	64.6	76.4	76.4
Cost ($/klm)	$0.54	$0.61	$0.61	$0.61	$0.61	$0.53	$0.59	$0.59	$0.59	$0.59	$0.52	$0.57	$0.57	$0.57	$0.57
Cost ($/klm l/b/f)	$12.68	$13.96	$14.84	$17.11	$17.86	$12.46	$13.50	$14.35	$16.55	$17.27	$12.25	$13.06	$13.88	$16.01	$16.70
Average Lamp Life (1000 hrs)	25	19	9	19	9	26	19	10	19	10	26	20	10	20	10
CRI	85	82	82	82	82	85	82	82	82	82	85	82	82	82	82
Total Installed Cost ($)	$75.73	$75.91	$78.88	$97.15	$100.13	$74.93	$75.11	$78.03	$95.99	$98.92	$74.14	$74.31	$77.18	$94.84	$97.71
Annual Maintenance Cost ($)	$3.03	$3.16	$4.41	$3.16	$4.41	$3.03	$3.16	$4.41	$3.16	$4.41	$3.03	$3.16	$4.41	$3.16	$4.41
Ballast Efficiency (BLE)	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%

Commercial Linear Fluorescent Lighting – ≤ 4 ft. T8/T12

- The commercial linear fluorescent lighting (≤ 4 ft.) characterized in this report is a two-lamp system (one ballast and one fixture) that emits approximately 4,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report excludes F34T12 lamps and F32T8 HE magnetic systems. T12 lamps have largely disappeared from the market, and F32T8 HE magnetic systems are a niche product for sensitive applications that do not represent any significant portion of the market. This report also assumes that the high efficiency T8 lamp has a reduced wattage of 28W rather than 32W.
- Assumptions for 2011:
  - Baseline F32T8: 2 32W T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=86%), fixture efficiency = 74%
  - F32T8 HE unit: 2 28W T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=86%), fixture efficiency = 74%
  - F32T8 HE unit w/ occupancy sensor: 2 28W T8 lamps with a electronic ballast (ballast factor=0.88, BLE=86%) and occupancy sensor (designed for 1,000 sq. ft. or ~25 two lamp systems), fixture efficiency = 74%. Note that occupancy sensor is assumed to be associated with a 50% reduction in lamp lifetime.
  - F32T8 HE unit w/ specular reflector: 2 28W T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=86%), fixture efficiency = 88%
  - F32T8 HE unit w/ OS and SR: 2 28W T8 lamps with electronic ballast (ballast factor=0.88, BLE=86%) and occupancy sensor (designed for 1,000 sq. ft. or ~25 two lamp systems), fixture efficiency = 88%. Note that occupancy sensor is assumed to be associated with a 50% reduction in lamp lifetime.
- Since 1995, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 75 lm/W and a minimum CRI of 45 for <35W lamps.
- In 2005, DOE standards raised the minimum BEF of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems.

Commercial Linear Fluorescent Lighting – ≤ 4 ft. T8/T12

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.27 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Though system watts for the F32T8 HE with the occupancy sensor are the same as the F32T8 HE, occupancy sensors can result in 17% to 60% energy savings due to reduced operating hours. (LRC) Savings potential is highly dependent on the time-delay programmed into the sensor, which ranges from 5-30 minutes and room type. Shorter time delays save more energy, but possibly at expense of lamp life. Occupancy sensors can reduce fluorescent lamp lifetime by as much as 50%. (Lutron) This decrease in lifetime results in higher overall maintenance costs.
- The following future improvements were assumed to occur over a 30-year period: Efficacy +5%, Life +10%, and Price -5% (NCI, 2012). Improvements in efficacy and life can be made with better phosphors and electrodes. Additional future energy savings are expected to come from increased use of dimming ballasts and occupancy sensors with linear fluorescent lighting.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial 4-ft T5 Linear Fluorescent Lighting

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
System Wattage	66	63	63	59	61	57	61	57	61	57
System Lumens	4698	4698	4698	4698	4768	4768	4846	4846	4925	4925
Lamp Efficacy (lm/W)	95.0	95.0	95.0	102.3	96.4	103.8	98.0	105.5	99.6	107.3
System Efficacy (lm/W)	71.2	74.4	74.4	80.1	78.3	84.4	79.6	85.7	80.9	87.1
Cost ($/klm)	$1.53	$0.67	$0.67	$0.84	$0.65	$0.81	$0.63	$0.79	$0.61	$0.76
Cost ($/klm l/b/f)	$28.68	$28.46	$28.46	$28.84	$27.62	$27.99	$26.72	$27.07	$25.84	$26.18
Average Lamp Life (1000 hrs)	20	20	20	25	21	26	21	27	22	27
CRI	85	85	85	85	85	85	85	85	85	85
Total Installed Cost ($)	$164.95	$161.39	$161.39	$163.17	$159.38	$161.14	$157.15	$158.88	$154.92	$156.62
Annual Maintenance Cost ($)	$2.81	$2.93	$2.93	$2.71	$2.93	$2.71	$2.93	$2.71	$2.93	$2.71
Ballast Efficiency (BLE)	89%	89%	89%	89%	92%	92%	92%	92%	92%	92%

Commercial 4-ft T5 Linear Fluorescent Lighting

- The commercial T5 linear fluorescent lighting characterized in this report is a two-lamp system (one ballast and one 88.3% efficient fixture) that emits approximately 4,700 system lumens.
- Compared to the 2008 EIA Reference Case, this report assumes that the high efficiency T5 lamp has a reduced wattage of 26 W rather than 28 W.
- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- Assumptions for 2011:
  - Typical: 2 F28T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)
  - Best available: 2 F26T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)
- Currently no federal standards exist for the T5 lamps or corresponding ballasts characterized in this report.

Commercial 4-ft T5 Linear Fluorescent Lighting

- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 86 lm/W for standard output T5 lamps.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- The following future improvements were assumed to occur over a 30-year period: Efficacy +5%, Life +10%, and Price -5% (NCI, 2012). Efficiency and life improvements can be made by using improved phosphors and electrodes. Additional future energy savings are expected to come from increased use of dimming ballasts and occupancy sensors with linear fluorescent lighting.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial Solid State Lighting (4-ft Linear Fluorescent Lighting Substitute)

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		T8	T8	T8	T8
	LED	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8
Typical Wattage	36.4	80.0	55.4	29.6	25.0	25.0
Lumens	548	5040	5040	5040	5040	5040
Efficacy (lm/W)	15.1	63.0	91.0	170.0	202.0	202.0
Cost ($/klm)	$392.68	$301.00	$110.00	$20.00	$13.00	$13.00
Average Lamp Life (1000 hrs)	50	25	50	75	75	75
CRI	92	70	80	85	85	85
CCT	2700	3500	3500	3500	3500	3500
Total Installed Cost ($)	$270.44	$1,570.56	$607.92	$154.32	$119.04	$119.04
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (4-ft Linear Fluorescent Substitute)

- The commercial solid-state lighting characterized is a replacement for 2 4-ft 32W T8 lamps in a troffer fixture. This represents the most common use of LED technology in the 4-ft linear fluorescent lighting market.
- Assumptions for 2011:
  - 2 F32T8 lamps equivalent: 56W LED emitting 5040 lumens
- No federal standards exist for solid-state lighting.
- The 2012 Solid State Lighting Multi-Year Program Plan and 2012 Energy Savings Forecast Model served as sources for many of the projections for LED technology.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial 8-ft Linear Fluorescent Lighting

DATA	2003				2007			
	Installed Base							
	75WT12	60WT12	59WT8	59WT8 HE	75WT12	60WT12	59WT8	55WT8
System Wattage	158	126	113	100	148	119	113	106
System Lumens	10208	7546	8300	8311	9376	7404	8379	8844
Lamp Efficacy (lm/W)	78.7	77.7	86.9	98.2	78.7	77.7	86.9	98.5
System Efficacy (lm/W)	64.6	59.9	73.5	83.1	63.1	62.3	73.9	83.7
Cost ($/klm)	$0.99	$0.73	$0.80	$1.23	$0.52	$0.38	$0.42	$0.51
Cost ($/klm l/b/f)	$5.31	$6.54	$6.36	$7.09	$4.41	$4.41	$6.35	$9.26
Average Lamp Life (1000 hrs)	12	12	15	18	12	12	15	24
CRI	70	62	75	85	62	62	75	78
Total Installed Cost ($)	$106.42	$102.16	$105.35	$111.74	$83.44	$83.44	$103.93	$162.76
Annual Maintenance Cost ($)	$4.64	$4.64	$4.39	$4.22	$4.66	$4.66	$4.40	$4.55
Ballast Efficiency (BLE)	88.9%	88.9%	88.9%	88.9%	88.9%	88.9%	91.6%	91.7%

Performance/Cost Characteristics » Commercial 8-ft Linear Fluorescent Lighting (Cont.'d)

DATA	2011			2020		2030		2040	
	Electronic HE	Typical	High Efficiency	Typical	HE	Typical	HE	Typical	HE
	60WT12	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8
System Wattage	119	113	106	112	104	112	104	112	104
System Lumens	7404	8379	8844	8865	8977	8865	9124	8865	9272
Lamp Efficacy (lm/W)	77.7	86.9	98.5	92.0	99.9	92.0	101.6	92.0	103.2
System Efficacy (lm/W)	62.3	73.9	83.7	79.3	86.2	79.3	87.6	79.3	89.0
Cost ($/klm)	$0.38	$0.42	$0.59	$0.60	$0.57	$0.59	$0.55	$0.58	$0.53
Cost ($/klm l/b/f)	$4.41	$6.35	$6.48	$6.42	$6.29	$6.31	$6.08	$6.20	$5.88
Average Lamp Life (1000 hrs)	12	15	18	15	19	16	19	16	20
CRI	62	75	82	82	82	82	82	82	82
Total Installed Cost ($)	$83.44	$103.93	$108.05	$107.63	$107.19	$106.67	$106.24	$105.70	$105.28
Annual Maintenance Cost ($)	$4.66	$4.40	$4.23	$4.40	$4.23	$4.40	$4.23	$4.40	$4.23
Ballast Efficiency (BLE)	88.9%	91.6%	91.6%	92.9%	92.9%	92.9%	92.9%	92.9%	92.9%

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

- The commercial linear fluorescent lighting (> 4 ft.) characterized in this report is a two-lamp system (one ballast and one fixture) that emits approximately 8,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report:
  - Assumes that the high efficiency 8 ft. T8 lamp has a reduced wattage of 55 W rather than 59 W.
  - Continues to includes 75W T12 lamps only in the installed base
  - Characterizes the 60W T12 lamps with an electronic ballast rather than a magnetic ballast because of the inability to meet current ballast standards with magnetic ballasts
- Assumptions for 2011:
  - 2 F96T12 lamps (60W each) with electronic ballast (ballast factor =0.88, BLE=88.9%), fixture efficiency= 90.2%
  - 2 F96T8 lamps (59W each) with electronic ballast (ballast factor=0.88, BLE=91.6%), fixture efficiency= 92.8%
  - 2 high efficiency F96T8 lamps (55W each) with electronic ballast (ballast factor=0.88, BLE=91.6%), fixture efficiency= 92.8.%
- Since 1994, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 80 lm/W and a minimum CRI of 69 for >35W lamps.
- In 2005, DOE standards raised the minimum BEF of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems.

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 97 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.27 * Avg Total Lamp Arc power ^ (- 0.25)).
- The following future improvements were assumed to occur over a 30-year period: Efficacy +5%, Life +10%, and Price -5% (NCI, 2012). Improvements can be made through improved phosphors and electrodes. Additional future energy savings are expected to come from increased use of dimming ballasts and occupancy sensors with linear fluorescent lighting.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (NCI, 2009)

Performance/Cost Characteristics » Commercial 8-ft Linear Fluorescent Lighting (High Output)

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO
System Wattage	165	165	165	165	165	165	165	165	165	165
System Lumens	11488	11596	11596	12740	11770	12931	11964	13143	12157	13355
Lamp Efficacy (lm/W)	82.6	82.6	82.6	90.7	83.8	92.1	85.2	93.6	86.5	95.1
System Efficacy (lm/W)	69.6	70.3	70.3	77.2	71.3	78.3	72.5	79.6	73.7	80.9
Cost ($/klm)	$0.99	$0.51	$0.51	$0.58	$0.48	$0.54	$0.48	$0.54	$0.47	$0.52
Cost ($/klm l/b/f)	$9.29	$9.26	$9.26	$8.69	$8.69	$8.16	$8.69	$8.16	$8.41	$7.89
Average Lamp Life (1000 hrs)	24	24	24	18	26	19	26	19	26	20
CRI	78	78	78	86	78	86	78	86	78	86
Total Installed Cost ($)	$163.88	$162.76	$162.76	$166.10	$159.36	$162.59	$159.36	$162.59	$157.57	$160.75
Annual Maintenance Cost ($)	$4.64	$4.55	$4.55	$4.83	$4.55	$4.83	$4.55	$4.83	$4.55	$4.83
Ballast Efficiency (BLE)	88.9%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12 High Output

- The high output commercial linear fluorescent lighting (> 4 ft.) characterized in this report is a two-lamp system (one ballast and one 92.8% efficient fixture) that emits approximately 10,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report characterizes a best available unit in addition to the typical unit.
- Assumptions for 2011:
  - Typical: 2 F96T8HO lamps (86W each) with electronic ballast (ballast factor=0.78, BLE=91.7%)
  - Best available: 2 F96T8HO lamps (86W each) with electronic ballast (ballast factor=0.78, BLE=91.7%) and emitting additional lumens
- Since 1994, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 80 lm/W and a minimum CRI of 69 for >35W lamps.
- In 2005, DOE standards raised the minimum BEF of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems.

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12 High Output

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 92 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE of 0.993 / (1 + 0.38 * Avg Total Lamp Arc power ^ (- 0.25)).
- The following future improvements were assumed to occur over a 30 year period: Efficacy +5%, Life +10%, and Price -5% (NCI, 2012). Improvements can be made through improved phosphors and electrodes. Additional future energy savings are expected to come from increased use of dimming ballasts and occupancy sensors with linear fluorescent lighting.
- California's Title 24 mandates the use of electronic ballasts with high-efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial Low Bay HID Lighting (Metal Halide)

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH
System Wattage	208	210	211	199	170	199	170	199	170	199	170
System Lumens	5176	6669	7171	10186	11409	10492	11751	10832	12131	11171	12512
Lamp Efficacy (lm/W)	39.0	50.3	50.3	71.4	93.3	73.6	96.1	76.0	99.2	78.3	102.4
System Efficacy (lm/W)	24.9	31.8	34.0	51.2	67.2	52.8	69.3	54.5	71.5	56.2	73.7
Lamp Cost ($/klm)	$2.19	$2.75	$5.81	$5.67	$5.06	$5.42	$4.84	$5.17	$4.61	$4.92	$4.39
System Cost ($/klm)	$35.80	$26.17	$44.58	$39.92	$35.64	$38.18	$34.09	$36.35	$32.46	$34.64	$30.93
Average Lamp Life (1000 hrs)	24	10	10	15	15	15	15	16	16	16	16
CRI	15	65	67	69	69	69	69	69	69	69	69
Total Installed Cost ($)	$328.83	$318.18	$771.67	$858.59	$858.59	$852.49	$852.49	$845.72	$845.72	$838.94	$838.94
Annual Maintenance Cost ($)	$3.93	$4.81	$4.83	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32

Commercial HID Low Bay Lighting (Metal Halide)

- The commercial metal halide low bay lighting characterized in this report is a one-lamp and one-ballast system in a low bay fixture with 81.5% efficiency that emits approximately 10,000 system lumens.
- Low bay lighting is defined as “interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor.” (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency for the high efficiency unit rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Characterizes metal halide lamps separately from high pressure sodium lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.
- A 175W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.
- Assumptions for 2011:
  - Typical efficiency unit: 175W metal halide lamp with pulse start magnetic ballast (ballast efficiency=88%)
  - High efficiency unit: 175W metal halide lamp with pulse start magnetic ballast (ballast efficiency=88.4%)

Commercial HID Low Bay Lighting (Metal Halide)

- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- EISA 2007 established efficiency standards for probe start magnetic ballasts (94%) and pulse start magnetic or electronic ballasts (88%) for ballasts that operate metal halide lamps between 150 and 400 watts, effective January 1, 2009. The 94% efficiency requirement effectively banned probe start magnetic ballasts.
- A DOE rulemaking is ongoing to establish new and amended energy conservation standards for metal halide lamp fixtures as directed by EISA 2007. This rulemaking is expected to be completed by June 2014.
- The following future improvements were assumed to occur over a 30 year period: Efficacy +10%, Life +10%, and Price -5% (NCI, 2012). Improvements can be made by using ceramic arc tubes.
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Final

Performance/Cost Characteristics » Commercial Low Bay HID Lighting (High Pressure Sodium)

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	70W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS
System Wattage	208	93	130	130	122	130	122	130	122	130	122
System Lumens	5176	4130	7213	7213	7213	7213	7213	7213	7213	7213	7213
Lamp Efficacy (lm/W)	39.0	77.9	94.5	94.5	94.5	94.5	94.5	94.5	94.5	94.5	94.5
System Efficacy (lm/W)	24.9	44.4	55.5	55.5	59.1	55.5	59.1	55.5	59.1	55.5	59.1
Lamp Cost ($/klm)	$2.19	$3.11	$5.37	$5.37	$5.37	$5.29	$5.29	$5.20	$5.20	$5.11	$5.11
System Cost ($/klm)	$35.80	$41.15	$43.68	$43.68	$45.58	$43.03	$44.89	$42.30	$44.13	$41.57	$43.37
Average Lamp Life (1000 hrs)	24	24	24	24	24	24	24	24	24	24	24
CRI	15	22	22	22	22	22	22	22	22	22	22
Total Installed Cost ($)	$328.83	$312.86	$767.01	$767.01	$780.68	$762.29	$775.74	$757.04	$770.27	$751.78	$764.79
Annual Maintenance Cost ($)	$3.93	$3.93	$3.93	$3.93	$4.03	$3.93	$4.03	$3.93	$4.03	$3.93	$4.03

Commercial HID Low Bay Lighting (High Pressure Sodium)

- The commercial high pressure sodium low bay lighting characterized in this report is a one-lamp and one-ballast system in a low bay fixture with 76.3% efficiency that emits approximately 7,000 system lumens.
- Low bay lighting is defined as “interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor.” (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Analyzes a 100W unit rather than a 70W unit as the typical low bay unit.
  - Characterizes high pressure sodium lamps separately from metal halide lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.
- A 175W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.

Commercial HID Low Bay Lighting (High Pressure Sodium)

- Assumptions for 2011:
  - Typical efficiency unit: 100W high pressure sodium lamp with magnetic ballast (ballast efficiency=76.9%)
  - High efficiency unit: 100W high pressure sodium lamp with magnetic ballast (ballast efficiency=82%)
- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- Efficacy and lifetime are not expected to improve over a 30 year period for HPS lamps. Manufacturers do not plan to devote resources to HPS research and development. Price is expected to decrease 5% over 30 years. (NCI, 2012)
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial Solid State Lighting (Low Bay Applications)

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	100W HPS LED	100W HPS LED	100W HPS LED	100W HPS LED
Typical Wattage	36	11	100	42	36	36
Lumens	548	630	7200	7200	7200	7200
Efficacy (lm/W)	15.1	55.3	72.0	170.0	202.0	202.0
Cost ($/klm)	$392.68	$160.00	$112.00	$20.00	$13.00	$13.00
Average Lamp Life (1000 hrs)	50	50	50	75	75	75
CRI	92	92	80	80	80	80
CCT	2700	2700	5500	5500	5500	5500
Total Installed Cost ($)	$270.44	$154.32	$859.92	$197.52	$147.12	$147.12
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (Low Bay Applications)

- The commercial solid-state lighting technology characterized in this report is a replacement for a 100W high pressure sodium lamp. This represents the most common use of LED technology in the low bay market.
- Assumptions for 2011:
  - 100W HPS lamp equivalent: 100W LED emitting 7,200 lumens
- No federal standards exist for solid-state lighting.
- The 2012 Solid State Lighting Multi-Year Program Plan and 2012 Energy Savings Forecast Model served as sources for many of the projections for LED technology.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 Lamps Rule. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Final

Performance/Cost Characteristics » Commercial High Bay HID Lighting (Metal Halide)

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	250W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH
System Wattage	453	293	465	480	423	455	423	455	423	455	423
System Lumens	13061	12245	20607	21261	23551	21899	24257	22607	25042	23316	25827
Lamp Efficacy (lm/W)	36.0	54.0	63.0	65.0	72.0	67.0	74.2	69.1	76.6	71.3	79.0
System Efficacy (lm/W)	28.8	41.8	44.3	44.3	55.6	48.2	57.3	49.7	59.2	51.3	61.0
Lamp Cost ($/klm)	$1.16	$1.31	$2.38	$3.55	$3.21	$3.40	$3.07	$3.24	$2.92	$3.08	$2.78
System Cost ($/klm)	$11.06	$12.83	$21.54	$16.19	$22.14	$15.48	$21.17	$14.74	$20.16	$14.05	$19.21
Average Lamp Life (1000 hrs)	24.0	10.0	20.0	18.4	18.4	19.2	19.2	20.1	20.1	21.0	21.0
CRI	50	65	68	66	66	66	66	66	66	66	66
Total Installed Cost ($)	$287.32	$300.09	$926.65	$827.03	$1,004.28	$821.87	$996.45	$816.13	$987.77	$810.40	$979.08
Annual Maintenance Cost ($)	$3.93	$4.81	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13

Commercial HID High Bay Lighting (Metal Halide)

- The commercial metal halide high bay lighting characterized in this report is a one-lamp and one-ballast system in a high bay fixture with 81.8% efficiency that emits approximately 24,000 system lumens.
- High bay lighting is defined as “interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor.” (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Analyzes a 400W unit rather than a 250W unit as the typical high bay unit.
  - Characterizes metal halide lamps separately from high pressure sodium lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.
- A 400W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.
- Assumptions for 2011:
  - Typical efficiency unit: 400W metal halide lamp with pulse start magnetic ballast (ballast efficiency=88%)
  - High efficiency unit: 400W metal halide lamp with pulse start magnetic ballast (ballast efficiency=94.5%)

Commercial HID High Bay Lighting (Metal Halide)

- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- EISA 2007 established efficiency standards for probe start magnetic ballasts (94%) and pulse start magnetic or electronic ballasts (88%) for ballasts that operate metal halide lamps between 150 and 400 watts, effective January 1, 2009. The 94% efficiency requirement effectively banned probe start magnetic ballasts.
- A DOE rulemaking is ongoing to establish new and amended energy conservation standards for metal halide lamp fixtures as directed by EISA 2007. This rulemaking is expected to be completed by June 2014.
- The following future improvements were assumed to occur over a 30 year period: Efficacy +10%, Life +10%, and Price -5% (NCI, 2012). Improvements can be made by using ceramic arc tubes.
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial High Bay HID Lighting (High Pressure Sodium)

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS
System Wattage	453	190	190	190	171	190	171	190	171	190	171
System Lumens	13061	10754	10754	10754	10754	10754	10754	10754	10754	10754	10754
Lamp Efficacy (lm/W)	36.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
System Efficacy (lm/W)	28.8	56.6	56.6	56.6	62.9	56.6	62.9	56.6	62.9	56.6	62.9
Lamp Cost ($/klm)	$1.16	$4.65	$4.65	$4.65	$4.65	$4.58	$4.58	$4.50	$4.50	$4.43	$4.43
System Cost ($/klm)	$11.06	$30.96	$30.96	$30.96	$31.79	$30.50	$31.31	$29.98	$30.78	$29.47	$30.25
Average Lamp Life (1000 hrs)	24	24	24	24	24	24	24	24	24	24	24
CRI	50	22	22	22	22	22	22	22	22	22	22
Total Installed Cost ($)	$287.32	$815.84	$815.84	$815.84	$824.72	$810.84	$819.59	$805.29	$813.90	$799.74	$808.20
Annual Maintenance Cost ($)	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93

Commercial HID High Bay Lighting (High Pressure Sodium)

- The commercial high pressure sodium high bay lighting characterized in this report is a one-lamp and one-ballast system in a fixture with 79.7% efficiency that emits approximately 11,000 system lumens.
- High bay lighting is defined as “interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor.” (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Characterizes high pressure sodium lamps separately from metal halide lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.
- A 400W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.

Commercial HID High Bay Lighting (High Pressure Sodium)

- Assumptions for 2011:
  - Typical efficiency unit: 150W high pressure sodium lamp with magnetic ballast (ballast efficiency=78.9%)
  - High efficiency unit: 150W high pressure sodium lamp with magnetic ballast (ballast efficiency=87.7%)
- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- Efficacy and lifetime are not expected to improve over a 30 year period for HPS lamps. Manufacturers do not plan to devote resources to HPS research and development. Price is expected to decrease 5% over 30 years. (NCI, 2012)
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial T5 HO Lighting (High Bay Applications)

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	54WT5HO	54WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO
System Wattage	240	234	234	221	231	218	231	218	231	218
System Lumens	18060	17646	17646	17646	17910	17910	18204	18204	18498	18498
Lamp Efficacy (lm/W)	88.0	85.2	85.2	90.2	86.5	91.5	87.9	93.1	89.3	94.6
System Efficacy (lm/W)	75.2	75.5	75.5	79.9	77.5	82.1	78.8	83.4	80.0	84.8
Cost ($/klm)	$1.06	$0.26	$0.26	$0.38	$0.25	$0.37	$0.24	$0.36	$0.24	$0.35
Cost ($/klm l/b/f)	$8.50	$8.30	$8.30	$8.82	$8.05	$8.56	$7.79	$8.27	$7.53	$8.00
Average Lamp Life (1000 hrs)	20	20	20	20	21	21	21	21	22	22
CRI	85	85	85	85	85	85	85	85	85	85
Total Installed Cost ($)	$184.10	$174.12	$174.12	$183.24	$171.92	$180.91	$169.48	$178.32	$167.04	$175.72
Annual Maintenance Cost ($)	$2.81	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93
Ballast Efficiency (BLE)	92.4%	92.4%	92.4%	92.4%	93.5%	93.5%	93.5%	93.5%	93.5%	93.5%

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

- The commercial T5 HO linear fluorescent lighting characterized in this report is a four-lamp system (one ballast and one 95.9% efficient fixture) that emits approximately 17,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report characterizes a best available unit in addition to the typical unit and assumes that the high efficiency T5 HO lamp has a reduced wattage of 51 W rather than 54 W.
- Assumptions for 2011:
  - Typical: 4 54W T5 high output lamps with electronic ballast (ballast factor=1, BLE=92.4%)
  - Best available: 4 51W T5 lamps with electronic ballast (ballast factor =1, BLE=92.4%)
- Currently no federal standards exist for the T5 lamps or corresponding ballasts characterized in this report.

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 76 lm/W.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE of 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- Many utilities offer rebates for T5 high output fixtures, generally to replace HID high bay fixtures. The programs include new construction incentives, customized programs, retrofit and upgrade incentives.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher. (CEC, 2005)
- The following future improvements were assumed to occur over a 30 year period: Efficacy +5%, Life +10%, and Price -5% (NCI, 2012). Efficiency and life improvements can be made by using improved phosphors and electrodes. Additional future energy savings are expected to come from increased use of dimming ballasts and occupancy sensors with linear fluorescent lighting.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial Solid State Lighting (High Bay Applications)

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	150W HPS LED	150W HPS LED	150W HPS LED	150W HPS LED
Typical Wattage	36	11	125	63	53	53
Lumens	548	630	10700	10700	10700	10700
Efficacy (lm/W)	15.1	55.3	85.4	170.0	202.0	202.0
Cost ($/klm)	$392.68	$160.00	$63.00	$20.00	$13.00	$13.00
Average Lamp Life (1000 hrs)	50	50	50	75	75	75
CRI	92	92	80	80	80	80
CCT	2700	2700	5500	5500	5500	5500
Total Installed Cost ($)	$270.44	$154.32	$727.62	$267.52	$192.62	$192.62
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (High Bay Applications)

- The commercial solid-state lighting technology characterized is a replacement for a 150W high pressure sodium lamp. This represents the most common use of LED technology in the high bay market.
- Assumptions for 2011:
  - 150W HPS lamp equivalent: 125W LED emitting 10,700 lumens
- No federal standards exist for solid-state lighting.
- The 2012 Solid State Lighting Multi-Year Program Plan and 2012 Energy Savings Forecast Model served as sources for many of the projections for LED technology.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 Lamps Rule. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Commercial Supermarket Display Cases

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical[1]	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	20,000	20,730	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Median Store Size (ft^3)	44,000	47,500	46,000	46,000	46,000	46,000	46,000	46,000	46,000	46,000	46,000
Energy Use (kWh/yr)[2]	21,000	23,117	21,134	18,440	17,002	17,438	16,140	17,438	16,140	17,438	16,140
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$4,371	$10,094	$7,425	$7,600	$8,173	$8,763	$7,803	$8,763	$7,803	$8,763	$7,803
Total Installed Cost	$6,452	$12,176	$9,603	$9,777	$10,351	$10,937	$9,981	$10,937	$9,981	$10,937	$9,981
Annual Maintenance Cost[3]	$283	$337	$376	$376	$376	$376	$376	$376	$376	$376	$376

[1] DOE's Federal energy standards for Commercial Refrigeration Equipment (CRE) went into effect on January 1, 2012. The 2020 Typical values are based on this standard.

[2] The annual energy use for the display case includes the energy from the supermarket compressors and condensers necessary to cool the display case. This energy is also partially calculated in the commercial compressor rack and condenser annual energy consumption values.

[3] Maintenance cost includes preventative maintenance costs such as cleaning evaporator coils, drain pans, fans, and intake screens as well as lamp replacements and other lighting maintenance activities.

Commercial Supermarket Display Cases

- DOE set Federal energy efficiency standards for Commercial Refrigeration Equipment (CRE). These standards set maximum daily energy consumption levels, in kWh/day, for display cases manufactured and/or sold in the United States on or after January 1, 2012. The daily energy consumption is based on the total display area of the display case (TDA).
  - Vertical, open, medium temperature, remote condensing display case (VOP.RC.M) $\leq 0.82*TDA + 4.07$
- The Food Marketing Institute reported the median total supermarket size in 2003 was 44,000 sq. ft., in 2007 it was 47,500 sq. ft., and in 2010, the last year that was reported by the study, it was 46,000 sq. ft. (FMI, 2012)
- The unit used to estimate energy use and installed cost is a vertical, open, medium temperature, remote condensing display case 12 ft. in length with a total display area of 53 sq. ft.
- Commercial central refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks.
- A typical commercial supermarket display case contains T8 electronic lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- The efficiency of supermarket display cases can be increased through the use of improved evaporator coils, larger evaporators, higher efficiency evaporator fan blades, high efficiency doors, LED lighting, thicker insulation, improved insulation, etc.
- Approximately 20 percent of the total annual electricity consumption for a typical supermarket is directly attributable to display cases (this does not include the energy consumed by compressors and condensers necessary to cool the display cases). (NCI, 2009)
- As part of DOE's on-going CRE rulemaking, DOE estimates 177,000 display cases were shipped in 2005. Of those display cases 38,743 were vertical, open, medium temperature, remote condensing display cases (VOP.RC.M), which represented the most common type of remote condensing display case shipped in 2005.

Commercial Compressor Rack Systems

DATA	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)[1]	1,050	1,077	1,077	1,077	1,077	1,077	1,077	1,077	1,077	1,077
Power Input (kW)	180	184	162	146	162	146	162	146	162	146
Energy Use (MWh/yr)	1,000	1,023	900	810	900	810	900	810	900	810
Average Life (yrs)	20	15	15	15	15	15	15	15	15	15
Total Installed Cost ($1000)[2]	$630	$630	$630	$693	$630	$693	$630	$693	$630	$693
Annual Maintenance Cost ($1000)[3]	$33	$33	$33	$33	$33	$33	$33	$33	$33	$33

[1] The total capacity represents the capacity required for the entire refrigeration system of a typical supermarket. This usually includes two low temperature racks and two medium temperature racks. For 2007 and beyond a 1,077 MBtu/hr total cooling capacity is the sum of 769 MBtu/hr for the medium temperature racks and 308 MBtu/hr for the low temperature racks.

[2] The total installed cost is based on the entire supermarket compressor rack system (two medium temperature racks and two low temperature racks). The equipment purchase price for an entire supermarket compressor rack system is approximately $130,000, the installation cost (including piping, electrical, startup and commissioning) is approximately $400,000, and the rack defrost and lighting controls are approximately $100,000. Therefore the total installed cost for a typical supermarket compressor rack system is approximately $630,000.

[3] Maintenance cost includes oil changes, bearing lubrication, filter replacement, and system functionality checks.

Commercial Compressor Rack Systems

- Commercial compressor rack systems that serve commercial supermarket display cases and walk-ins consist of a number of parallel-connected compressors located in a separate machine room. By modulating compressor capacity, these integrated systems provide higher efficiency and mechanical longevity.
- Rack integrators generally supply a packaged compressor rack for which much of the necessary piping, insulation, components, and controls are pre-assembled.
- A typical supermarket will have 10 to 20 compressors mounted in racks in the 3-hp to 15-hp size range. Usually there are 3 to 5 compressors per rack serving a series of loads with nearly identical evaporator temperature.
- The duty cycle for compressors is usually in the range 60% to 70%.
- The typical supermarket uses a reciprocating compressor system that has two medium temperature compressor racks with an overall capacity of 769 MBtu/hr and two low temperature compressor racks with an overall capacity of 308 MBtu/hr. (NCI, 2009)
- Approximately 34 percent of the total annual electricity consumption for a typical supermarket is attributable to compressors. (NCI, 2009)
- There are an estimated 140,000 compressor rack systems installed in supermarkets across the U.S. as of 2008. (NCI, 2009)

Commercial Condensers

DATA	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)[1]	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520
Power Input (kW)	25	25	22	20	22	20	22	20	22	20
Energy Use (MWh/yr)	138	138	120	108	120	108	120	108	120	108
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10
Total Installed Cost ($1000)	$47	$54	$54	$60	$54	$60	$54	$60	$54	$60
Annual Maintenance Cost[2]	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090

[1] Total capacity is the total heat rejected (THR) of condensers comprised of two low temperature condensers (THR_L = 240 MBtu/hr each, suction temperature = -25°F, condensing temperature 110 F) and two medium temperature (THR_M = 520 MBtu/hr each, suction temperature = 15°F, condensing temperature = 115°F) condensers; ambient temperature = 95°F. (NCI, 2009)

[2] Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks.

Commercial Condensers

- Condensers are designed with multiple methods of cooling: air-cooled, water-cooled, and evaporative. These units can be single-circuit or a multiple circuit.
- Commercial condensers are remotely located, typically installed on the roof of a supermarket.
- For use with parallel compressors in supermarkets, air-cooled units are the most commonly used condensers. This analysis is based on multiple air-cooled condensers connected to a supermarket refrigeration system comprised of two low temperature condensers and two medium temperature condensers, using R-404A refrigerant.
- Each compressor rack has a dedicated condenser or a separate circuit of a single common condenser. Condenser temperatures of multiple racks are often different.
- The duty cycle for condensers is usually in the range 50 - 70%.
- Approximately 5 percent of the total annual electricity consumption for a typical supermarket is attributable to condensers. (NCI, 2009)
- There are an estimated 140,000 condensers installed in supermarkets across the U.S. as of 2008. (NCI, 2009)

Commercial Walk-In Refrigerators

DATA	2003	2007	2011[1]			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	44,970	44,970	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Size (ft^2)[2]	240	240	96	96	96	96	96	96	96	96	96
Energy Use (kWh/yr)	42,300	42,182	12,337	6,329	4,822	6,329	4,822	6,329	4,822	6,329	4,822
Insulated Box Average Life (yrs)	18	18	15	15	15	15	15	15	15	15	15
Compressor Average Life (yrs)	10	10	11	11	11	11	11	11	11	11	11
Retail Equipment Cost	$19,252	$33,821	$13,026	$15,087	$18,821	$15,087	$18,821	$15,087	$18,821	$15,087	$18,821
Total Installed Cost[3]	$23,415	$38,712	$14,080	$16,141	$19,875	$16,141	$19,875	$16,141	$19,875	$16,141	$19,875
Annual Maintenance Cost[4]	$817 - $1,090	$817 - $1,090	$2,755	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970

[1] EISA 2007 includes prescriptive standards for walk-in refrigerators that went into effect in 2009. All units for 2011 and beyond include these prescriptive standards.

[2] The size for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which states the typical footprint of a walk-in refrigerator is 240 sq. ft. The size for 2011 and beyond is based on the NOPR analysis shipment data from DOE's on-going Walk-In rulemaking which states the typical footprint of a walk-in refrigerator is 96 sq. ft.

[3] Installation cost for 2003 and 2007 are based on ADL, 1996 & NCI, 2009 reports which assume a cost of $4,163 and $4,891 respectively. Installation cost for 2011 and beyond is based on DOE's on-going Walk-In rulemaking which assumes installation cost scales based on the cooling capacity (which for a cooling capacity of 18,000 Btu/hr is $1,054).

[4] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

Commercial Walk-In Refrigerators

- The commercial walk-in refrigerator characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going Walk-In rulemaking, is a small non-display cooler with a footprint of 96 sq. ft. and includes a floor and a single door. The typical size of 240 sq. ft. was used for 2003 and 2007 because that was the typical size reported in the ADL, 1996 and NCI, 2009 reports respectively.
- A typical walk-in refrigerator includes:
  - insulated floor and wall panels
  - merchandising doors, shelving, and lighting (not included in cost estimate)
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- The high efficiency unit is based on the energy savings potential and cost premiums of several advanced refrigeration technologies identified in the preliminary analysis of DOE's ongoing Walk-In rulemaking. These include:
  - ECM (electronically commutated motor) evaporator and condenser fan motors
  - floating heat pressure
  - ambient sub-cooling
  - evaporator fan shutdown
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- DOE is currently working on a Federal energy consumption standard for commercial walk-in refrigerators. The estimated effective date is 2016.
- As part of DOE's on-going Walk-In rulemaking, DOE estimates 85,333 walk-in coolers will be shipped in 2015. Of those walk-in coolers, 41,403 will be small non-display coolers, which represents the most common type of walk-in cooler estimated to ship in 2015.

Commercial Walk-In Refrigerators

- The Energy Independence and Security Act (EISA) of 2007 included prescriptive standards for walk-in refrigerators (coolers) that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in refrigerators manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–25, except for glazed portions of doors and structural members
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in refrigerator is not occupied by people.

Commercial Walk-In Freezers

DATA	2003	2007	2011[1]			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,929	4,929	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
Size (ft^2)[2]	80	80	64	64	64	64	64	64	64	64	64
Energy Use (kWh/yr)	15,600	15,524	28,455	13,844	12,319	13,844	12,319	13,844	12,319	13,844	12,319
Insulated Box Average Life (yrs)	18	18	15	15	15	15	15	15	15	15	15
Compressor Average Life (yrs)	10	10	11	11	11	11	11	11	11	11	11
Retail Equipment Cost	$7,597	$13,008	$12,068	$14,070	$20,637	$14,070	$20,637	$14,070	$20,637	$14,070	$20,637
Total Installed Cost[3]	$8,637	$14,049	$12,920	$14,921	$21,489	$14,921	$21,489	$14,921	$21,489	$14,921	$21,489
Annual Maintenance Cost[4]	$545	$545	$2,755	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970

[1] EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2011 and beyond include these prescriptive standards.

[2] The size for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which states the typical footprint of a walk-in freezer is 80 sq. ft. The size for 2011 and beyond is based on the NOPR analysis shipment data from DOE's on-going Walk-In rulemaking which states the typical footprint of a walk-in freezer is 64 sq. ft.

[3] Installation cost for 2003 and 2007 are based on ADL, 1996 & NCI, 2009 reports which assume a cost of $1,040. Installation cost for 2011 and beyond is based on DOE's on-going Walk-In rulemaking which assumes installation cost scales based on the cooling capacity (which for a cooling capacity of 9,000 Btu/hr is $852).

[4] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

Commercial Walk-In Freezers

- The commercial walk-in freezer characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going Walk-In rulemaking, is a small non-display freezer with a footprint of 64 sq. ft. and includes a floor and a single door. The typical size of 80 sq. ft. was used for 2003 and 2007 because that was the typical size reported in the ADL, 1996 and NCI, 2009 reports respectively.
- A typical walk-in freezer includes:
  - insulated floor, door, and wall panels
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- The high efficiency unit is based on the energy savings potential and cost premiums of several advanced refrigeration technologies determined by the preliminary analysis from DOE's ongoing Walk-In standard rulemaking. These include:
  - ECM (electronically commutated motor) evaporator and condenser fan motors
  - external heat rejection
  - hot gas defrost
  - evaporator fan shutdown
- DOE is currently working on a Federal energy consumption standard for commercial walk-in freezers. The estimated effective date is 2016.
- As part of DOE's on-going Walk-In rulemaking, DOE estimates 34,985 walk-in freezers will be shipped in 2015. Of those walk-in freezers, 17,291 will be small non-display freezers, which represents the most common type of walk-in freezers estimated to ship in 2015.

Commercial Walk-In Freezers

- EISA 2007 included prescriptive standards for walk-in freezers that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in freezers manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–32, except for glazed portions of doors and structural members
  - contain floor insulation of at least R–28
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in freezer is not occupied by people.

Commercial Reach-In Refrigerators

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	3,000	2,700	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Size (ft^3)	48	48	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	3,800	2,477	2,533	1,598	993	1,598	993	1,598	993	1,598	993
Energy Use (kWh/yr/ft^3)	79	52	52	33	20	33	20	33	20	33	20
Average Life (yrs)	8	9	15	15	15	15	15	15	15	15	15
Retail Equipment Cost	$2,810	$2,988	$3,131	$3,146	$3,191	$3,146	$3,191	$3,146	$3,191	$3,146	$3,191
Total Installed Cost[3]	$2,966	$3,144	$3,948	$3,963	$4,008	$3,963	$4,008	$3,963	$4,008	$3,963	$4,008
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.

[2] ENERGY STAR® set energy consumption levels for solid door commercial refrigerators, including reach-in refrigerators, that went into effect in 2010. The 2011 Typical values are based on this energy consumption level.

[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2011 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $817.

[4] Maintenance is only performed if there is a problem with the equipment.

Commercial Reach-In Refrigerators

- The Energy Policy Act of 2005 (EPACT 2005) set maximum daily energy consumption levels, in kWh/day, for commercial reach-in refrigerators that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
  - Refrigerators with solid doors $\leq 0.10*V + 2.04$
  - Refrigerators with transparent doors $\leq 0.12*V + 3.34$
- Energy Star® also set maximum daily energy consumption levels, in KWh/day, for commercial reach-in refrigerators that went into effect on April 1, 2009 for glass and mixed door models and on January 1, 2010 for solid door models. These efficiency levels are also based on the volume of the unit (V).

Reach-In Refrigerator Size	$0 < V < 15$	$15 \leq V < 30$	$30 \leq V < 50$	$50 \leq V$
Solid Door	$\leq 0.089*V + 1.411$	$\leq 0.037*V + 2.200$	$\leq 0.056*V + 1.635$	$\leq 0.060*V + 1.416$
Glass Door	$\leq 0.118*V + 1.382$	$\leq 0.140*V + 1.050$	$\leq 0.088*V + 2.625$	$\leq 0.110*V + 1.500$

- The commercial reach-in refrigerator characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 49 cubic ft. solid two-door unit with a cooling capacity of 1,000 Btu/hr. The typical size of 48 cubic ft. solid two-door unit with a cooling capacity of 3,000 Btu/hr and 2,700 Btu/hr was used for 2003 and 2007 because that was the typical size and capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- The efficiency of commercial reach-in refrigerators can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- Annual shipments of reach-in refrigerators in the U.S. in 2008 are estimated to be 263,000 with an estimated installed base of 1,556,000. (NCI, 2009)

Commercial Reach-In Freezers

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	2,200	2,200	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Size (ft^3)	24	24	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	4,600	3,960	7,658	5,151	3,037	5,151	3,037	5,151	3,037	5,151	3,037
Energy Use (kWh/yr/ft^3)	192	165	156	105	62	105	62	105	62	105	62
Average Life (yrs)	8	9	15	15	15	15	15	15	15	15	15
Retail Equipment Cost	$2,498	$2,905	$3,277	$3,290	$3,353	$3,290	$3,353	$3,290	$3,353	$3,290	$3,353
Total Installed Cost[3]	$2,654	$3,061	$4,093	$4,107	$4,170	$4,107	$4,170	$4,107	$4,170	$4,107	$4,170
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.
[2] ENERGY STAR® set energy consumption levels for solid door commercial freezers, including reach-in freezers, that went into effect in 2010. The 2011 Typical values are based on this energy consumption level.
[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2011 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $816.
[4] Maintenance is only performed if there is a problem with the equipment.

Commercial Reach-In Freezers

- EPACT 2005 set maximum daily energy consumption levels, in kWh/day, for commercial reach-in freezers that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
  - Freezers with solid doors ≤ 0.40*V + 1.38
  - Freezers with transparent doors ≤ 0.75*V + 4.10
- Energy Star® also set maximum daily energy consumption levels, in KWh/day, for commercial reach-in freezers that went into effect on April 1, 2009 for glass and mixed door models and on January 1, 2010 for solid door models. These efficiency levels are also based on the volume of the unit (V).

Reach-In Freezer Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door	≤ 0.250*V + 1.250	≤ 0.400*V - 1.000	≤ 0.163*V + 6.125	≤ 0.158*V + 6.333
Glass Door	≤ 0.607*V + 0.893	≤ 0.733*V – 1.000	≤ 0.250*V + 13.500	≤ 0.450*V + 3.500

- The commercial reach-in freezer characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 49 cubic ft. solid two-door unit with a cooling capacity of 1,800 Btu/hr. The typical size of 24 cubit ft. solid one-door unit with a cooling capacity of 2,200 Btu/hr was used for 2003 and 2007 because that was the typical size and capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- The efficiency of commercial reach-in freezers can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- Annual shipments of reach-in freezers in the U.S. in 2008 are estimated to be 52,000 with an estimated installed base of 1,156,000. (NCI, 2009)

Commercial Ice Machines

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Output (lbs/day)[3]	500	500	300	300	300	300	300	300	300	300	300
Water Use (gal/100 lbs)	24	28	22	20	18	20	18	20	18	20	18
Energy Use (kWh/100 lbs)	7.0	5.5	7.7	6.9	6.1	6.9	6.1	6.9	6.1	6.9	6.1
Energy Use (kWh/yr)[4]	6,388	5,019	4,249	3,833	3,408	3,833	3,408	3,833	3,408	3,833	3,408
Average Life (yrs)	8.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Retail Equipment Cost	$2,289	$3,954	$4,059	$4,077	$4,152	$4,077	$4,152	$4,077	$4,152	$4,077	$4,152
Total Installed Cost (with Bin)[5]	$2,498	$4,475	$4,431	$4,449	$4,524	$4,449	$4,524	$4,449	$4,524	$4,449	$4,524
Annual Maintenance Cost[6]	$218 - $327	$218 - $327	$110	$110	$110	$110	$110	$110	$110	$110	$110

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.

[2] ENERGY STAR® set energy consumption levels for ice makers that went into effect in 2008. The 2011 Typical values are based on this energy consumption level.

[3] The output for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which states the typical ice output is 500 lbs/day. The output for 2011 and beyond is based on the preliminary analysis shipment data from DOE's on-going Automatic Ice Maker rulemaking which states the typical ice output is 300 lbs/day.

[4] The annual energy use is based on assuming 4,380 hours per year of use, which is a utilization rate of 50%.

[5] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $209 and $521 respectively. Installation cost for 2011 and beyond is based on DOE's on-going Automatic Ice Maker rulemaking which assumes a cost of $372.

[5] Maintenance cost includes cleaning and maintaining refrigerant levels, replacing filters, checking water distribution lines for leaks, cleaning, sanitizing, and descaling the bin and water system. Maintenance cost decreases as the size of the ice machine (i.e. output) decreases.

Commercial Ice Machines

- The commercial ice machine characterized in this report from 2011 and beyond is an air-cooled, ice maker head unit with an approximate output of 300 lbs/day. Commercial ice machines are typically integrated with an insulated ice storage bin or mounted on top of a separate storage bin. The retail equipment cost includes the ice making head and the integrated storage bin.
- Commercial ice machine condensers are either air-cooled or water-cooled. Approximately 90% of all units are the air-cooled type.
- ENERGY STAR® set maximum energy consumption levels, in KWh/100 lbs ice, for air cooled ice machines that went into effect on January 1, 2008. These efficiency levels are based on the harvest rate, in lbs/24 hrs. (H).

Equipment Type	Harvest Rate	Energy Use	Potable Water Use Limit
Ice Maker Head	< 450	9.23 – 0.0077*H	≤ 25
	≥ 450	6.20 – 0.0010*H	≤ 25

- Commercial ice machine maintenance includes periodic cleaning (every 2 to 6 weeks) to remove lime and scale, and sanitizing to kill bacteria. Some ice machines are self-cleaning/sanitizing.
- As part of DOE's on-going Automatic Ice Makers rulemaking, DOE estimates 263,552 ice machines will be shipped in 2016. Of those ice-machines 71,357 will be air cooled, ice making head units with a harvest capacity rate between 50 lbs/24 hr. and 450 lbs/24 hrs., which represents the most common type of ice maker estimated to ship in 2016.

Commercial Ice Machines: EPACT 2005

- EPACT 2005 issued standard levels for commercial ice machines with capacities between 50 and 2500 pounds per 24-hour period that are manufactured and/or sold in the United States on or after January 1, 2010. The energy consumption is based on the harvest rate in pounds per 24 hours (H).

Equipment Type	Type of Cooling	Harvest Rate (lbs ice/24 hrs)	Maximum Energy Use (kWh/100 lbs ice)	Maximum Condenser Water Use (gal/100 lbs ice)
Ice Making Head	Water	<500	7.80-0.0055 H	200-0.022 H
		≥500 and <1436	5.58-0.0011 H	200-0.022 H
		≥1436	4.0	200-0.022 H
	Air	<450	10.26-0.0086 H	Not Applicable
		≥450	6.89-0.0011 H	Not Applicable
Remote Condensing (but not remote compressor)	Air	<1000	8.85-0.0038 H	Not Applicable
		≥1000	5.10	Not Applicable
Remote Condensing and Remote Compressor	Air	<934	8.85-0.0038 H	Not Applicable
		≥934	5.3	Not Applicable
Self Contained	Water	<200	11.40-0.019 H	191-0.0315 H
		≥200	7.60	191-0.0315 H
	Air	<175	18.0-0.0469 H	Not Applicable
		≥175	9.80	Not Applicable

Water use is for the condenser only and does not include potable water used to make ice.

Commercial Beverage Merchandisers

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	1,200	2,500	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27
Energy Use (kWh/yr)	3,900	2,527	2,523	1,763	996	1,763	996	1,763	996	1,763	996
Average Life (yrs)	8.0	8.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Retail Equipment Cost	$1,457	$2,706	$2,662	$2,810	$2,935	$2,810	$2,935	$2,810	$2,935	$2,810	$2,935
Total Installed Cost[3]	$1,613	$2,862	$3,479	$3,626	$3,752	$3,626	$3,752	$3,626	$3,752	$3,626	$3,752
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.
[2] ENERGY STAR® set energy consumption levels for glass door beverage merchandisers that went into effect in 2009. The 2011 Typical values are based on this energy consumption level.
[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2011 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $817.
[4] Maintenance is only performed if there is a problem with the equipment.

Commercial Beverage Merchandisers

- EPACT 2005 sets maximum daily energy consumption levels, in kWh/day, for commercial refrigerators with a self-contained condensing unit designed for pull-down temperature applications and transparent doors (i.e., beverage merchandisers) that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
  - Beverage merchandisers with transparent doors $\leq 0.126^*V + 3.51$
- Energy Star® also set maximum daily energy consumption levels, in KWh/day, for beverage merchandisers that went into effect on April 1, 2009 for glass and mixed door models. These efficiency levels are also based on the volume of the unit (V).

Beverage Merchandiser Size	$0 < V < 15$	$15 \leq V < 30$	$30 \leq V < 50$	$50 \leq V$
Glass Door	$\leq 0.118^*V + 1.382$	$\leq 0.140^*V + 1.050$	$\leq 0.088^*V + 2.625$	$\leq 0.110^*V + 1.500$

- The beverage merchandiser characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a cooling capacity of 2,100 Btu/hr. A similar beverage merchandiser with a cooling capacity of 1,200 Btu/hr and 2,500 Btu/hr was used for 2003 and 2007 because that was the typical capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- The efficiency of beverage merchandisers can be increased through the use of more efficient compressors and fluorescent lighting with electronic ballasts.
- Beverage merchandisers have an estimated installed base of 920,000 units in 2008. Of those beverage merchandisers 460,000 are one-door units, which represents the most common type of beverage merchandiser.

Commercial Refrigerated Vending Machines

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical[1]	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	700	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Can Capacity	500	650	650	650	650	650	650	650	650	650	650
Energy Use (kWh/yr)[2]	3,000	2,913	2,383	2,029	1,821	1,740	1,566	1,740	1,566	1,740	1,566
Average Life (yrs)	14	14	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$1,769	$1,907	$1,742	$2,046	$2,096	$2,137	$2,632	$2,137	$2,632	$2,137	$2,632
Total Installed Cost[3]	$1,844	$2,011	$1,826	$2,130	$2,180	$2,221	$2,716	$2,221	$2,716	$2,221	$2,716
Annual Maintenance Cost[4]	$180	$177	$159	$159	$159	$159	$159	$159	$159	$159	$159

[1] DOE's Federal energy standards for Refrigerated Beverage Vending Machines will go into effect on August 31, 2012. The 2020 Typical values are based on this standard.
[2] Energy use is based on a zone-cooled machine tested in 75°F steady state ambient conditions.
[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $75 and $104 respectively. Installation cost for 2011 and beyond is based on DOE's Refrigerated Beverage Vending Machine rulemaking which assumes a cost of $84.
[4] Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils and also includes an annualized cost for refurbishments/remanufacturing.

Commercial Refrigerated Vending Machines

- DOE set Federal energy efficiency standards for refrigerated vending machines. These standards set maximum daily energy consumption levels, in kWh/day, for commercial refrigerated vending machines manufactured and/or sold in the United States on or after August 31, 2012. The daily energy consumption is based on the volume of the unit (V).
  - Refrigerated Vending Machines that are fully-cooled (Type A) $\leq 0.055^*V + 2.56$
  - Refrigerated Vending Machines that are zone-cooled (Type B) $\leq 0.073^*V + 3.16$

- Energy Star® also set maximum daily energy consumption efficiency levels, also in KWh/day, for refrigerated vending machines that went into effect on July 1, 2007. These efficiency levels are based on vendible capacity (C).
  - Refrigerated Vending Machines $\leq 0.45^*(8.66 + 0.009^*C)$

- The annual maintenance cost is consists of preventive maintenance including checking and maintaining refrigerant charge levels, cleaning heat exchanger coils, and replacement of lighting and the annualized value of a single refurbishment at approximately the mid-point of the machine's useful life. The preventative annual maintenance cost is approximately $98 and the annualize value of a one-time refurbishment cost of $599 over the lifetime of the machine is $61. Therefore, the annual maintenance cost is $159 for refrigerated vending machines.
- As part of DOE's Refrigerated Beverage Vending Machine rulemaking, DOE estimates 190,200 refrigerated vending machines will be shipped in 2012. Of those refrigerated vending machines 63,700 will be zone-cooled, medium size units, which represents the most common type of refrigerated vending machine estimated to ship in 2012.

Commercial Constant Air Volume Ventilation

DATA	2003	2007	2011			2020		2030		2040	
	Survey Base	Survey Base	Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	11.75	11.55	10.82	10.28	9.20	9.74	8.66	9.20	8.12	8.66	7.57
Specific Fan Power (W/CFM)	0.783	0.770	0.721	0.685	0.613	0.649	0.577	0.613	0.541	0.577	0.505
Annual Fan Energy Use (kWh/yr)[1]	44,631	43,890	41,120	39,064	34,952	37,008	32,896	34,952	30,840	32,896	28,784
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Total Installed Cost ($)[2]	$73,500	$73,500	$73,500	$73,500	$80,000	$73,500	$80,000	$73,500	$80,000	$73,500	$80,000
Annual Maintenance Cost ($)	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500

[1]Based on 3800 effective full load hours per year (operating 3800 hours per year at constant load) (ADL, 1999).
[2]Total installed cost of 15,000 CFM CAV AHU and hypothetical supply ductwork layout.
[3]Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

Commercial Constant Air Volume Ventilation

- Constant air volume (CAV) ventilation systems are common, inexpensive, and straightforward air-side HVAC systems. These systems provide a constant flow rate of air (typically a mix of recirculated and outside air) and adjust the supply temperature of that air in order to maintain space temperature setpoint. These systems are most applicable to single zone applications in order to ensure adequate temperature control. Many existing buildings utilize CAV systems that serve multiple zones where individual zone space temperatures are maintained by reheating air delivered to that zone after it is cooled by the central cooling coil; this is prohibited by most current energy codes. New building CAV systems are common for single zone applications. This analysis examines only the fan energy of the CAV system.
- The unit characterized in this report is a 15,000 CFM CAV system. The average commercial building is approximately 15,000 square feet (CBECS 2003 and BED 2007). Assuming 1 CFM is needed per square foot of floor area results in a 15,000 CFM air handling unit.
- A 15,000 CFM CAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $56,500 (RS Means 2012). Ductwork would cost approximately $17,000 additional ($73,500 total).
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP) for CAV systems. The 2007 version of Standard 90.1 was used to represent the 2011 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor efficiency.

Commercial Variable Air Volume Ventilation

DATA	2003	2007	2011			2020		2030		2040	
	Survey Base	Survey Base	Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	16.35	15.00	14.76	14.03	12.55	13.29	11.81	12.55	11.07	11.81	10.33
Specific Fan Power (W/CFM)	1.090	1.000	0.984	0.935	0.837	0.886	0.787	0.837	0.738	0.787	0.689
Annual Fan Energy Use (kWh/yr)[1]	14,502	13,305	13,096	12,441	11,131	11,786	10,477	11,131	9,822	10,477	9,167
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Total Installed Cost ($)[2]	$91,000	$91,000	$91,000	$91,000	$100,000	$91,000	$100,000	$91,000	$100,000	$91,000	$100,000
Annual Maintenance Cost ($)	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500

[1]Based on 887 effective full load hours (power-based) per year (operating 3800 hours per year at variable load).
[2]Total installed cost of 15,000 CFM VAV AHU, VFD, (10) VAV boxes, and hypothetical supply ductwork layout.
[3]Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

Commercial Variable Air Volume Ventilation

- Variable air volume (VAV) ventilation systems are the most common multi-zone system type specified today for conditioning commercial buildings. These systems provide conditioned air to multiple zone terminal units (VAV boxes) that use dampers to modulate the amount of cool air to each zone. An individual zone thermostat controls the VAV box damper to allow more or less cooling. If a zone requires heating then the VAV box provides the minimum flow rate and typically includes a reheat coil to meet space temperature setpoint. As VAV box dampers close in the system, a variable frequency drive reduces fan speed and flow continuously to meet current requirements.
- This analysis examines only the fan energy of the VAV system. VAV systems vary fan speeds between about 30-100% speed (and flow); most hours of operation being much lower than full speed. Since fan power varies with the cube of fan speed according to fan affinity laws, SAIC estimated the fan-power equivalent full load hours (EFLH) of 887 hours given an annual runtime of 3800 hours and a typical VAV operating profile. The unit characterized in this report is a 15,000 CFM VAV system.
- A 15,000 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $59,000 (RS Means 2012). Ductwork, (10) VAV boxes with reheat, and a VFD would cost approximately $32,000 additional ($91,000 total).
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power for VAV systems (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2011 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor VFD efficiency.

Commercial Fan Coil Unit

DATA	2003	2007	2011			2020		2030		2040	
	Survey Base	Survey Base	Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	800	800	800	800	800	800	800	800	800	800	800
System Fan Power (W)	315	304	875	241	148	232	143	223	136	215	130
Specific Fan Power (W/CFM)	0.394	0.380	1.094	0.302	0.185	0.290	0.178	0.279	0.171	0.268	0.163
Annual Fan Energy Use (kWh/yr)[1]	709	684	1,969	543	333	522	321	502	307	483	293
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Total Installed Cost ($)[2]	$2,400	$2,400	$2,400	$2,400	$2,600	$2,400	$2,600	$2,400	$2,600	$2,400	$2,600
Annual Maintenance Cost ($)	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100

[1] Based on 2250 effective full load hours per year (operating 2250 hours per year at constant load) (ADL, 1999).
[2] Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.
[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

Commercial Fan Coil Unit

- Commercial fan coil units (FCUs) are self-contained, mass-produced assemblies that provide cooling, heating, or cooling and heating, but do not include the source of cooling or heating. The unit characterized in this report is a cooling only (2-pipe), horizontal unit with housing and controls. Fan coil units are typically installed in or adjacent to the space being served and have no (or very limited) ductwork.
- Four-pipe units have separate circuits for heating and cooling. Two-pipe units with electric heat are a low-cost alternative to four-pipe units but may use more energy.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons.
- Fan coil unit fan motors can be shaded pole, a single phase AC motor with offset start winding and no capacitor; PSC, a single phase AC motor with offset start winding with capacitor; or ECM, an AC electronically commutated permanent magnet DC motor. PSC motors are currently the most common motor type in FCUs, but most manufacturers offer ECM as an option. This analysis examines only the fan energy of the CAV system.
- Fan coil units have higher maintenance costs than central air systems due to the distributed nature of the system. For each unit the filters must be changed and drain systems must be flushed periodically.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2011 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type configuration, filter and coil pressure drops, and motor efficiency.

Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

Data Sources » Residential General Service Incandescent Lamps (60 Watts)

DATA SOURCES	2005	2009	2011			2014*		2020**	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	60W	60W	60W	60W	60W	60W	60W	60W	60W
Lamp Wattage	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Lumens									
Lamp Efficacy (lm/W)			Calculated						
Lamp Price			Distributor Websites						
Lamp Cost ($/klm)			Calculated						
Average Lamp Life (1000 hrs)			Product Catalogs						
CRI									

Data Sources » Residential General Service Incandescent Lamps (75 Watts)

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th>2009</th><th colspan="3">2011</th><th colspan="2">2013*</th><th colspan="2">2020**</th></tr>
<tr><th colspan="2">Installed Base</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>75W</th><th>75W</th><th>75W</th><th>75W</th><th>75W</th><th>75W</th><th>75W</th><th>75W</th><th>75W</th></tr>
<tr><td>Lamp Wattage</td><td colspan="2" rowspan="7">2008 EIA Reference Case</td><td colspan="3" rowspan="2">Product Catalogs</td><td colspan="2" rowspan="7">EISA 2007;
NCI, 2012</td><td colspan="2" rowspan="7">EISA, 2007</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td></tr>
<tr><td>Lamp Price</td><td colspan="3">Distributor Websites</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">Product Catalogs</td></tr>
<tr><td>CRI</td></tr>
</table>

DATA SOURCES	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage					Product Catalogs		
Lamp Lumens							
Lamp Efficacy (lm/W)					Calculated		
Lamp Price	2008 EIA Reference Case				Distributor Websites		
Lamp Cost ($/klm)					Calculated		
Average Lamp Life (1000 hrs)					Product Catalogs		
CRI							

DATA SOURCES	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	NCI, 2012								
Lamp Lumens									
Lamp Efficacy (lm/W)									
Lamp Price									
Lamp Cost ($/klm)									
Average Lamp Life (1000 hrs)									
CRI									

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th>2009</th><th colspan="4">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Energy Star</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th></tr>
<tr><td>Lamp Wattage</td><td colspan="2" rowspan="7">2008 EIA Reference Case</td><td rowspan="2">Product Catalogs</td><td colspan="3" rowspan="2">Product Catalogs</td><td colspan="6" rowspan="7">NCI, 2012</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>Calculated</td><td colspan="3">Calculated</td></tr>
<tr><td>Lamp Price</td><td rowspan="2"></td><td colspan="3">Distributor Websites</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td rowspan="2">Product Catalogs</td><td colspan="3" rowspan="2">Product Catalogs</td></tr>
<tr><td>CRI</td></tr>
</table>

Data Sources » Residential Linear Fluorescent Lamps (T12 and T8)

DATA SOURCES	2005	2009		2011					
	Installed Base			Current Standard	Mid-Level T12	High T12	Baseline T8	Mid-Level T8	High T8
	32WT8	40WT12	32WT8	40WT12	40WT12	34WT12	32WT8	32WT8	28WT8
Lamp Wattage	2008 EIA Reference Case	DOE GSFL and IRL Energy Conservation Standard, 2009							
Lamp Lumens									
System Wattage		Calculated							
System Lumens									
Lamp Efficacy (lm/W)									
System Efficacy (lm/W)									
Lamp Price ($)		DOE GSFL and IRL Energy Conservation Standard, 2009							
Ballast Price ($)		DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011							
Lamp Cost ($/klm)		Calculated							
Average Lamp Life (1000 hrs)		DOE GSFL and IRL Energy Conservation Standard, 2009							
CRI									
Ballast Efficiency (BLE)		DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011							

Data Sources » Residential Linear Fluorescent Lamps (T12 and T8)

DATA SOURCES	2020		2030		2040	
	Typical T8	High T8	Typical T8	High T8	Typical T8	High T8
	32WT8	28WT8	32WT8	28WT8	32WT8	28WT8
Lamp Wattage	NCI, 2012					
Lamp Lumens						
System Wattage						
System Lumens						
Lamp Efficacy (lm/W)						
System Efficacy (lm/W)						
Lamp Price ($)						
Ballast Price ($)						
Lamp Cost ($/klm)						
Average Lamp Life (1000 hrs)						
CRI						
Ballast Efficiency (BLE)						

Data Sources » Residential Linear Fluorescent Lamps (T5)

DATA SOURCES	2005	2009	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
Lamp Wattage	DOE GSFL and IRL Energy Conservation Standard, 2009				NCI, 2012					
Lamp Lumens										
System Wattage	Calculated									
System Lumens										
Lamp Efficacy (lm/W)										
System Efficacy (lm/W)										
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009									
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011									
Lamp Cost ($/klm)	Calculated									
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009									
CRI										
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011									

Data Sources » Residential Torchieres

DATA SOURCES	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	2008 EIA Reference Case				Product Catalogs		
Lamp Lumens							
Lamp Efficacy (lm/W)					Calculated		
Lamp Price					Distributor Websites		
Lamp Cost ($/klm)					Calculated		
Average Lamp Life (1000 hrs)					Product Catalogs		
CRI							

Data Sources » Residential Torchieres

DATA SOURCES	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	NCI, 2012								
Lamp Lumens									
Lamp Efficacy (lm/W)									
Lamp Price									
Lamp Cost ($/klm)									
Average Lamp Life (1000 hrs)									
CRI									

Data Sources » Residential Solid State Lighting (LED A19 and PAR38 Replacements)

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th>2009</th><th>2011</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>LED</th><th>LED</th><th>LED</th><th>LED</th><th>LED</th><th>LED</th></tr>
<tr><td>Typical Wattage</td><td rowspan="8">2008 EIA Reference Case</td><td colspan="5">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="5">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td colspan="5">2012 SSL MYPP</td></tr>
<tr><td>Lamp Price ($)</td><td colspan="5">Calculated</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3">2012 SSL MYPP</td><td colspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Average Life (1000 hrs)</td><td colspan="2" rowspan="3">Product Catalogs</td><td colspan="3">2012 Energy Savings Forecast Model</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
</table>

Data Sources » Commercial General Service Incandescent Lighting

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th></tr>
<tr><th colspan="2">Installed Base</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>72W Inc</th><th>72W Inc</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">Distributor Websites; Calculated</td><td colspan="2" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">Distributor Websites; NCI 2012; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial Compact Fluorescent Lamps

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>26W</th><th>26W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">Distributor Websites; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">Distributor Websites; NCI 2012; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial Halogen Lighting (PAR 38)

<table>
<tr><th rowspan="3">DATA SOURCES</th><th colspan="2">2003</th><th colspan="2">2007</th><th colspan="2">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="4">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th></tr>
<tr><td>System Wattage</td><td colspan="4" rowspan="10">2008 EIA Reference Case</td><td colspan="2" rowspan="2">Distributor Websites; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="2" rowspan="4">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="2" rowspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="2" rowspan="2">NCI 2012; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial Halogen Lighting (Edison)

DATA SOURCES	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	90W Edison	90W Halogen	90W Halogen	90W Halogen	90W Halogen	90W Halogen
System Wattage	2008 EIA Reference Case		Distributor Websites; Calculated	NCI, 2012		
System Lumens						
Lamp Efficacy (lm/W)			Distributor Websites; Calculated			
System Efficacy (lm/W)						
Lamp Cost ($/klm)						
System Cost ($/klm)						
Average Lamp Life (1000 hrs)			Distributor Websites			
CRI						
Total Installed Cost ($)			NCI 2012; RSMeans 2007; Calculated			
Annual Maintenance Cost ($)						

Data Sources » Commercial Solid State Lighting (Edison Socket Substitute)

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th>2011</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>LED</th><th>BR30 LED</th><th>BR30 LED</th><th>BR30 LED</th><th>BR30 LED</th><th>BR30 LED</th></tr>
<tr><td>Wattage</td><td rowspan="9">2008 EIA Reference Case</td><td colspan="5">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="5">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td colspan="2" rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3" rowspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial 4-ft T8 Linear Fluorescent Lighting

DATA	2003	2007	2011				
	Installed Base		Baseline	High Efficiency	HE w/ Occ. Sensor	HE w/ Spec. Reflector	HE w/ OS & Spec. Ref.
	32WT8	32WT8	32WT8	28WT8	28WT8	28WT8	28WT8
System Wattage	2008 EIA Reference Case	DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated					
System Lumens							
Lamp Efficacy (lm/W)		Calculated					
System Efficacy (lm/W)							
Cost ($/klm)							
Cost ($/klm l/b/f)							
Average Lamp Life (1000 hrs)		DOE GSFL and IRL Energy Conservation Standard, 2009					
CRI							
Total Installed Cost ($)		DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated					
Annual Maintenance Cost ($)							
Ballast Efficiency (BLE)		DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011					

Data Sources » Commercial 4-ft T8 Linear Fluorescent Lighting (Cont.'d)

DATA	2020					2030					2040				
	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max
	32WT8	28WT8	28WT8	28WT8	28WT8	32WT8	F28T8	F28T8	F28T8	F28T8	F32T8	F28T8	F28T8	F28T8	F28T8
System Wattage	NCI, 2012														
System Lumens															
Lamp Efficacy (lm/W)															
System Efficacy (lm/W)															
Cost ($/klm)															
Cost ($/klm l/b/f)															
Average Lamp Life (1000 hrs)															
CRI															
Total Installed Cost ($)															
Annual Maintenance Cost ($)															
Ballast Efficiency (BLE)															

Data Sources » Commercial 4-ft T5 Linear Fluorescent Lighting

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="2">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>28WT5</th><th>28WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th></tr>
<tr><td>System Wattage</td><td rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td></td><td colspan="3">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td><td colspan="6"></td></tr>
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Data Sources » Commercial Solid State Lighting (4-ft Linear Fluorescent Lighting Substitute)

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>LED</th><th>LED 32W T8</th><th>LED 32W T8</th><th>LED 32W T8</th><th>LED 32W T8</th><th>LED 32W T8</th></tr>
<tr><td>Wattage</td><td rowspan="9">2008 EIA Reference Case</td><td colspan="5">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="5">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td colspan="2" rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3" rowspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial 8-ft Linear Fluorescent Lighting

<table>
<tr><th rowspan="3">DATA SOURCES</th><th colspan="4">2003</th><th colspan="4">2007</th></tr>
<tr><th colspan="8">Installed Base</th></tr>
<tr><th>75WT12</th><th>60WT12</th><th>59WT8</th><th>59WT8 HE</th><th>75WT12</th><th>60WT12</th><th>59WT8</th><th>55WT8</th></tr>
<tr><td>System Wattage</td><td colspan="4" rowspan="11">2008 EIA Reference Case</td><td colspan="4" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="4" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="4" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="4" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="4">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
</table>

Data Sources » Commercial 8-ft Linear Fluorescent Lighting (Cont.'d)

DATA SOURCES	2011			2020		2030		2040	
	Magnetic HE	Typical	High Efficiency	Typical	HE	Typical	HE	Typical	HE
	60WT12	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8
System Wattage	DOE Energy Conservation Standards, 2009 and 2011; Product Catalogs; Calculated			NCI, 2012					
System Lumens									
Lamp Efficacy (lm/W)	Calculated								
System Efficacy (lm/W)									
Cost ($/klm)									
Cost ($/klm l/b/f)									
Average Lamp Life (1000 hrs)	DOE Energy Conservation Standards, 2009								
CRI									
Total Installed Cost ($)	DOE Energy Conservation Standards, 2009; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)									

<table>
<tr><th rowspan="3">DATA SOURCES</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Magnetic HE</th><th>Typical</th><th>High Efficiency</th><th>Typical</th><th>HE</th><th>Typical</th><th>HE</th><th>Typical</th><th>HE</th></tr>
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<tr><td>System Wattage</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td><td colspan="6" rowspan="11">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="3">DOE Ballast Energy Conservation Standard, 2011</td></tr>
</table>

Data Sources » Commercial Low Bay HID Lighting (Metal Halide)

DATA SOURCES	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH
System Wattage	2008 EIA Reference Case		DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Efficacy (lm/W)											
Cost ($/klm)											
Cost ($/klm l/b/f)											
Average Lamp Life (1000 hrs)			DOE Energy Conservation Standards, 2010								
CRI			Product Catalogs								
Total Installed Cost ($)			DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

Data Sources » Commercial Low Bay HID Lighting (High Pressure Sodium)

DATA SOURCES	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	70W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS
System Wattage	2008 EIA Reference Case		DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Efficacy (lm/W)											
Cost ($/klm)											
Cost ($/klm l/b/f)											
Average Lamp Life (1000 hrs)			DOE Energy Conservation Standards, 2010								
CRI			Product Catalogs								
Total Installed Cost ($)			DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

Data Sources » Commercial Solid State Lighting (Low Bay Applications)

DATA SOURCES	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	100W HPS LED	100W HPS LED	100W HPS LED	100W HPS LED
Typical Wattage	2008 EIA Reference Case		Calculated			
Lumens			Product Catalogs			
Efficacy (lm/W)			Product Catalogs	2012 SSL MYPP		
Cost ($/klm)				2012 Energy Savings Forecast Model		
Average Lamp Life (1000 hrs)						
CRI				NCI, 2012		
CCT						
Total Installed Cost ($)				RSMeans 2007; Calculated		
Annual Maintenance Cost ($)						

Data Sources » Commercial High Bay HID Lighting (Metal Halide)

DATA SOURCES	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	250W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH
System Wattage	2008 EIA Reference Case		DOE Energy Conservation Standards, 2010 and 2011; Product Catalogs; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Efficacy (lm/W)											
Cost ($/klm)											
Cost ($/klm l/b/f)											
Average Lamp Life (1000 hrs)			DOE Energy Conservation Standards, 2010 and 2011								
CRI			Product Catalogs								
Total Installed Cost ($)			DOE Energy Conservation Standards, 2010 and 2011; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

<table>
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<tr><th colspan="3">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>400W MV</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
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<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3">DOE Energy Conservation Standards, 2010</td></tr>
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<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="3">DOE Ballast Energy Conservation Standard, 2011</td></tr>
</table>

Data Sources » Commercial Solid State Lighting (High Bay Applications)

<table>
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<tr><th colspan="2">Installed Base</th><th>HPS</th><th>HPS</th><th>HPS</th><th>HPS</th></tr>
<tr><th>LED</th><th>LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th></tr>
<tr><td>Typical Wattage</td><td colspan="2" rowspan="9">2008 EIA Reference Case</td><td colspan="4">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="4">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3" rowspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2009 / DOE, 2011 / FMI, 2012 / NCI Analysis 2012</td></tr>
<tr><td>Median Store Size (ft^3)</td><td colspan="5">Food Marketing Institute (FMI), 2012</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td rowspan="5">DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009 / NCI Analysis, 2012</td><td colspan="3" rowspan="5">DOE, 2011</td></tr>
<tr><td>Average Life (yrs)</td><td rowspan="4">NCI, 2009</td></tr>
<tr><td>Retail Equipment Cost</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td></tr>
</table>

Data Sources » Commercial Compressor Rack Systems

DATA SOURCES	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	ADL, 1996	NCI, 2009 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012 / ADL, 1996							
Power Input (kW)	Copeland, 2008									
Energy Use (MWh/yr)	ADL, 1996 / NCI Analysis, 2008									
Average Life (yrs)	Kysor-Warren, 2008									
Total Installed Cost ($1000)	NCI, 2009 / NCI Analysis, 2012									
Annual Maintenance Cost ($1000)	ADL, 1996 / NCI Analysis, 2008	ADL, 1996 / NCI Analysis, 2012								

Data Sources » Commercial Condensers

DATA SOURCES	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	NCI, 2009	NCI, 2009 / NCI Analysis, 2012							
Power Input (kW)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996									
Energy Use (MWh/yr)	NCI Analysis, 2008 / ADL, 1996									
Average Life (yrs)	ADL, 1996 / NCI Analysis, 2008									
Total Installed Cost ($1000)	NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007									
Annual Maintenance Cost	NCI Analysis, 2008	NCI Analysis, 2012								

Data Sources » Commercial Walk-In Refrigerators

<table>
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<tr><td>Cooling Capacity (Btu/hr)</td><td rowspan="2">ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009</td><td colspan="3" rowspan="8">DOE, 2011</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft²)</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008</td></tr>
<tr><td>Insulated Box Average Life (yrs)</td><td rowspan="2">ADL, 1996 / PG&E, 2004</td></tr>
<tr><td>Compressor Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost</td><td rowspan="2">ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / FMI, 2005 / NCI Analysis, 2008</td><td>DOE, 2011 / NCI Analysis, 2012</td></tr>
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Data Sources » Commercial Walk-In Freezers

<table>
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<tr><td>Cooling Capacity (Btu/hr)</td><td rowspan="2">ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009</td><td rowspan="8" colspan="3">DOE, 2011</td><td rowspan="8" colspan="6">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft²)</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008</td></tr>
<tr><td>Insulated Box Average Life (yrs)</td><td rowspan="2">ADL, 1996 / PG&E, 2004</td></tr>
<tr><td>Compressor Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost</td><td rowspan="2">ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / FMI, 2005 / NCI Analysis, 2008</td><td>DOE, 2011 / NCI Analysis, 2012</td></tr>
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Data Sources » Commercial Reach-In Refrigerators

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<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft³)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr/ft³)</td><td>NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr/ft^3)</td><td>NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
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<tr><td>Output (lbs/day)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="6">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Water Use (gal/100 lbs)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/100 lbs)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ACEEE, 2002 / NCI Analysis, 2012</td><td colspan="3" rowspan="4">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Retail Equipment Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost (with Bin)</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / NCI Analysis, 2008</td><td>NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6">DOE, 2011 / NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Beverage Merchandisers

<table>
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<tr><td>**Cooling Capacity (Btu/hr)**</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="6">NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>**Size (ft^3)**</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>**Energy Use (kWh/yr)**</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>**Average Life (yrs)**</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>**Retail Equipment Cost**</td><td>ADL, 1996 / Distributor Web Sites</td></tr>
<tr><td>**Total Installed Cost**</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>**Annual Maintenance Cost**</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>DOE, 2008 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3" rowspan="2">DOE, 2009</td><td colspan="6" rowspan="7">DOE, 2009 / NCI Analysis, 2012</td></tr>
<tr><td>Can Capacity</td><td>CEC, 2005 / NREL, 2003 / FEMP, 2004</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / CEC, 2008 / NREL, 2003</td><td colspan="3">DOE, 2009 / ENERGY STAR, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>DOE, 2008</td><td colspan="3" rowspan="4">DOE, 2009</td></tr>
<tr><td>Retail Equipment Cost</td><td>Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>DOE, 2008</td></tr>
</table>

Final

Data Sources » Commercial Constant Air Volume Ventilation

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	Assumed based on average 15,000 square foot commercial building (CBECS 2003 and BED 2007)										
System Fan Power (kW)	eQUEST/DOE-2		ASHRAE 90.1-2007	SAIC & Mfrs							
Specific Fan Power (W/CFM)											
Annual Fan Energy Use (kWh/yr)[1]	Calculated – see note 1										
Average Life (yrs)	2011 ASHRAE Handbook: HVAC Applications										
Total Installed Cost ($)[2]	RS Means 2012										
Annual Maintenance Cost ($)	Jones Lang LaSalle										

[1]Based on 3800 effective full load hours per year (operating 3800 hours per year at constant load) (ADL, 1999).
[2]Total installed cost of 15,000 CFM CAV AHU and hypothetical supply ductwork layout.
[3]Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

Data Sources » Commercial Variable Air Volume Ventilation

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	Assumed based on average 15,000 square foot commercial building (CBECS 2003 and BED 2007)										
System Fan Power (kW)	eQUEST/DOE-2		ASHRAE 90.1-2007	SAIC & Mfrs							
Specific Fan Power (W/CFM)											
Annual Fan Energy Use (kWh/yr)[1]	Calculated – see note 1										
Average Life (yrs)	2011 ASHRAE Handbook: HVAC Applications										
Total Installed Cost ($)[2]	RS Means 2012										
Annual Maintenance Cost ($)	Jones Lang LaSalle										

[1]Based on 887 effective full load hours (power-based) per year (operating 3800 hours per year at variable load).
[2]Total installed cost of 15,000 CFM VAV AHU, VFD, (10) VAV boxes, and hypothetical supply ductwork layout.
[3]Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

Data Sources » Commercial Fan Coil Unit

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	800 CFM is typical for a 2-ton fan coil unit										
System Fan Power (kW)	ADL 1999, NCI 2008		ASHRAE 90.1-2007	SAIC & Mfrs							
Specific Fan Power (W/CFM)											
Annual Fan Energy Use (kWh/yr)[1]	Calculated – see note 1										
Average Life (yrs)	2011 ASHRAE Handbook: HVAC Applications										
Total Installed Cost ($)[2]	RS Means 2012										
Annual Maintenance Cost ($)	ASHRAE 2000, NCI 2008										

[1]Based on 2250 effective full load hours per year (operating 2250 hours per year at constant load) (ADL, 1999).
[2]Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.
[3]Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

Appendix B
References

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APPENDIX D

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case

Presented to:

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Table of Contents

Objective

The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment, assuming an accelerated adoption of technology.

- 2003/2007 (commercial) and 2005/2009 (residential) baselines, as well as today's (2011)
  - Review of literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
- Forecast of technology improvements that are projected to be available through 2040
  - Review of trends in standards, product enhancements, and Research and Development (R&D).
  - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Methodology

Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- All cost forecasts are shown in 2011 dollars.

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2007 (for commercial products) and 2005 and 2009 (for residential) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming advanced adoption. Below are definitions for the terms used in characterizing the status of each technology.

- Advanced Adoption Case: the projected end-use characteristics if an outside force (i.e., fuel price increase, deregulation) or industry adoption of energy-efficient technology takes place.
- 2003/2007; 2005/2009 Installed Base: the installed and "in use" equipment for that year. Represents the installed stock of equipment, but does NOT represent sales.
- 2011 Current Standard: the minimum efficiency (or maximum energy use) required (allowed) by current DOE standards, when applicable.
- Typical: the average, or "typical," product being sold in the particular timeframe.
- ENERGY STAR: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable.
- Mid-Level: middle tier higher-efficiency product available in the particular timeframe.
- High: the product with the highest efficiency available in the particular timeframe.
- Lumens: All reported lumens are mean lumens, not initial lumens.
- CCT: The correlated color temperature (CCT) is a specification of the color appearance of the light emitted by a lamp.

The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric.

- System Wattage = (Lamp Wattage * Ballast Factor) / Ballast Efficiency
- System Lumens = Lamp Lumens * Ballast Factor
- Lamp Efficacy = Lamp Lumens / Lamp Wattage
- System Efficacy = System Lumens / System Wattage
- Lamp Cost ($/klm) = Lamp Cost / (Lamp Lumens / 1000)
- Total Equipment Cost = Lamp Cost + Fixture (including ballast) Cost
- System Cost ($/klm) = Total Equipment Cost / (System Lumens / 1000)
- Total Installed Cost = Total Equipment Cost + Labor Installation Cost
- BLE = A/(1+B*Avg Total Lamp Arc Power^(-C))

The market for the reviewed products has changed since the analysis was performed in 2008. These changes are noted and reflected in the efficiency and cost characteristics.

- EPACT 2005 established standards for certain types of self-contained Commercial Refrigeration Equipment and batch Automatic Ice Makers which went into effect in 2010.
- EISA 2007 set several requirements for Walk-in Coolers and Freezers which went into effect in 2009.
- DOE issued Federal minimum efficiency standards that have or will soon go into effect for General Service Fluorescent Lamps (July 2012 effective date), Incandescent Reflector Lamps (July 2012), Fluorescent Lamp Ballasts (2014), Refrigerated Beverage Vending Machines (Aug. 2012), and certain Commercial Refrigeration Equipment (Jan. 2012) not covered by the EPACT 2005 standards.

Performance/Cost Characteristics » Residential General Service Incandescent Lamps (60 Watts)

DATA	2005	2009	2011			2014[1]		2020[2]	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	60W	60W	60W	60W	60W	60W	60W	60W	60W
Lamp Wattage	60	60	60	60	60	43	43	N/A	N/A
Lamp Lumens	850	850	830	860	870	750	750	N/A	N/A
Lamp Efficacy (lm/W)	14.2	14.2	13.8	14.3	14.5	17.4	17.4	N/A	N/A
Lamp Price	$0.25	$0.25	$0.31	$0.34	$0.37	$4.57	$4.57	N/A	N/A
Lamp Cost ($/klm)	$0.29	$0.29	$0.37	$0.40	$0.43	$6.09	$6.09	N/A	N/A
Average Lamp Life (1000 hrs)	1	1	2	1	1	3	3	N/A	N/A
CRI	100	100	100	100	100	100	100	N/A	N/A

[1] The Energy Independence and Security Act of 2007 prescribes standards for current 60 watt incandescent lamps as of January 1, 2014. Starting in 2014, we assume 60 watt incandescents will be replaced by halogen infrared incandescents.

[2] In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized incandescent lamp technologies and current trends in industry lead us to believe they will not be met.

Performance/Cost Characteristics » Residential General Service Incandescent Lamps (75 Watts)

DATA	2005	2009	2011			2013[1]		2020[2]	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	75W	75W	75W	75W	75W	75W	75W	75W	75W
Lamp Wattage	75	75	75	75	75	53	53	N/A	N/A
Lamp Lumens	1170	1170	1060	1170	1190	1050	1050	N/A	N/A
Lamp Efficacy (lm/W)	15.6	15.6	14.1	15.6	15.9	19.8	19.8	N/A	N/A
Lamp Price	$0.36	$0.37	$0.35	$0.40	$0.49	$4.69	$4.69	N/A	N/A
Lamp Cost ($/klm)	$0.32	$0.32	$0.33	$0.34	$0.41	$4.47	$4.47	N/A	N/A
Average Lamp Life (1000 hrs)	1	1	2	1	1	3	3	N/A	N/A
CRI	100	100	100	100	100	100	100	N/A	N/A

[1] The Energy Independence and Security Act of 2007 prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2014, we assume 75 watt incandescents will be replaced by halogen infrared incandescents.

[2] In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized incandescent lamp technologies and current trends in industry lead us to believe they will not be met.

Residential General Service Incandescent Lamps (60 and 75 Watts)

- The residential incandescent lighting characterized in this report is a 60 watt and a 75 watt medium screw based incandescent lamp.
- A standard 60 watt incandescent lamp produces approximately 860 lumens. A standard 75 watt incandescent lamp produces approximately 1170 lumens (GE, 2012; OSRAM, 2012; Philips, 2012; Sylvania, 2012). There is little variation in light output between products. Therefore, there is little variation in lamp efficacy.
- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60W lamps effective in 2014 and 75W lamps effective in 2013. These standards can be achieved if incandescent bulbs use halogen infrared technologies.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. These standards can not be achieved by any incandescent technology currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent technology.
- California's Appliance Efficiency Regulations include efficiency regulations for general service incandescent lamps with certain bases. California is currently undergoing a rulemaking to reduce indoor residential lighting by not less than 50% of 2007 levels over the next 10 years in accordance with Assembly Bill 1109. They are going to regulate general purpose lighting (incandescent lamps) and portable lighting fixtures.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Reflector Lighting

DATA	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	65	65	50	16	65	50	15
Lamp Lumens	620	620	660	750	630	630	720
Lamp Efficacy (lm/W)	9.5	9.5	13.2	46.9	9.7	12.6	48.0
Lamp Price	$1.36	$1.37	$4.19	$5.87	$3.38	$6.12	$6.36
Lamp Cost ($/klm)	$2.20	$2.21	$6.35	$7.82	$5.36	$9.72	$8.83
Average Lamp Life (1000 hrs)	2.0	2.0	3.0	8.0	1.8	3.0	8.0
CRI	100	100	100	82	100	100	82

Performance/Cost Characteristics » Residential Reflector Lighting

DATA	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	65	50	15	65	50	15	65	50	15
Lamp Lumens	636	662	756	643	695	794	649	729	833
Lamp Efficacy (lm/W)	9.8	13.2	50.4	9.9	13.9	52.9	10.0	14.6	55.6
Lamp Price	$3.30	$5.97	$6.20	$3.21	$5.82	$6.05	$3.13	$5.67	$5.89
Lamp Cost ($/klm)	$5.18	$9.02	$8.20	$5.00	$8.38	$7.62	$4.83	$7.78	$7.07
Average Lamp Life (1000 hrs)	1.9	3.2	8.3	2.1	3.5	8.5	2.2	3.7	8.8
CRI	100	100	82	100	100	82	100	100	82

Residential Reflector Lamps

- The residential reflector lamps characterized in this report is a 65W BR30 incandescent, a 50W PAR30 halogen, and a 16W BR30 Reflector compact fluorescent.
- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA 2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008. The 65W BR30, a large majority of the incandescent reflector lamp market is still exempted.
- The following future improvements for the system were assumed to occur over a 30 year period:
  - Incandescents: Efficacy +3%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - Halogen: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - CFL: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
- These improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Compact Fluorescent Lighting

DATA	2005	2009	2011				2020		2030		2040	
	Installed Base		Energy Star	Low	Typical	High	Typical	High	Typical	High	Typical	High
	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W
Lamp Wattage	13	13	13	13	13	13	13	13	13	13	13	13
Lamp Lumens	825	825	715	825	875	900	919	945	965	992	1013	1042
Lamp Efficacy (lm/W)	63.5	63.5	55.0	63.5	67.2	69.2	70.7	72.7	74.2	76.3	77.9	80.1
Lamp Price	$3.14	$2.15	N/A	$1.57	$2.38	$3.33	$2.32	$3.25	$2.26	$3.17	$2.21	$3.09
Lamp Cost ($/klm)	$4.22	$2.61	N/A	$1.90	$2.72	$3.70	$2.53	$3.44	$2.35	$3.19	$2.18	$2.96
Average Lamp Life (1000 hrs)	10.0	10.0	6.0	8.0	10.0	10.0	10.3	10.3	10.7	10.7	11.0	11.0
CRI	82	82	80	82	82	82	82	82	82	82	82	82

Residential Compact Florescent Lamps

- The residential compact fluorescent lamp characterized in this report is a 13 watt compact fluorescent lamp.
- Compact Fluorescents contain mercury and therefore require appropriate disposal. In addition, because the color rendering index of compact fluorescents is lower than that incandescent lamps (82 compared to 100), the quality of the light of a compact fluorescent falls short of incandescent lamps.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts Energy Star performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. The Secretary may revise these requirements by rule or establish other requirements at a later date. *[Note: EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based)]*
- Energy Star® and the Consortium for Energy Efficiency (CEE) offer voluntary specifications for CFL lamps.
- The following future improvements were assumed to occur over a 30 year period: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the electrodes.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Linear Fluorescent Lamps (T12 and T8)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2005	2009		2011						
	Installed Base			Current Standard	Mid-Level T12	High T12	Baseline T8	Mid-Level T8	High T8
	32WT8	40WT12	32WT8	40WT12	40WT12	34WT12	32WT8	32WT8	28WT8
Lamp Wattage	64	80	64	80	80	68	64	64	56
Lamp Lumens	5040	5720	5040	5720	6500	5580	5040	5420	5120
System Wattage	65	70	65	70	70	60	65	65	57
System Lumens	4435	3890	4435	3890	4420	3794	4435	4770	4506
Lamp Efficacy (lm/W)	78.8	71.5	78.8	71.5	81.3	82.1	78.8	84.7	91.4
System Efficacy (lm/W)	68.7	55.6	68.7	55.6	63.1	63.8	68.7	73.8	79.7
Lamp Price ($)	$3.35	$1.85	$1.71	$1.85	$5.91	$5.79	$1.71	$2.67	$2.88
Ballast Price ($)	$15.71	$11.22	$9.94	$11.22	$11.22	$11.22	$9.94	$9.94	$9.94
Lamp Cost ($/klm)	$0.66	$0.32	$0.34	$0.32	$0.91	$1.04	$0.34	$0.49	$0.56
Average Lamp Life (1000 hrs)	20	15	20	15	24	24	20	20	18
CRI	75	70	75	70	85	85	75	82	82
Ballast Efficiency (BLE)	83.0%	77.7%	87.2%	77.7%	77.7%	77.7%	87.2%	87.2%	87.2%

Performance/Cost Characteristics » Residential Linear Fluorescent Lamps (T12 and T8)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2020		2030		2040	
	Typical T8	High T8	Typical T8	High T8	Typical T8	High T8
	32WT8	28WT8	32WT8	28WT8	32WT8	28WT8
Lamp Wattage	64	56	64	56	64	56
Lamp Lumens	5740	5274	5785	5444	5830	5615
System Wattage	65	57	65	57	65	57
System Lumens	5052	4641	5091	4791	5130	4941
Lamp Efficacy (lm/W)	89.7	94.2	90.4	97.2	91.1	100.3
System Efficacy (lm/W)	78.2	82.1	78.8	84.8	79.4	87.4
Lamp Price ($)	$2.72	$2.79	$2.62	$2.70	$2.53	$2.60
Ballast Price ($)	$9.64	$9.64	$9.31	$9.31	$8.98	$8.98
Lamp Cost ($/klm)	$0.47	$0.53	$0.45	$0.50	$0.43	$0.46
Average Lamp Life (1000 hrs)	25	19	26	19	26	20
CRI	85	82	85	82	85	82
Ballast Efficiency (BLE)	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%

Residential Linear Fluorescent Lighting (T12/T8)

- This report assumes that T12 and T8 residential linear fluorescent lamps provide the same utility to consumers. Each characterized technology is a two-lamp, one-ballast system that emits approximately 4,500 system lumens.
- In a change from the 2008 EIA Reference Case, this report characterizes a range of efficacies for T12 and T8 lamps and does not use T5 lamps for direct comparison because T5 lamps are almost never used as residential replacement options.
- Assumptions for 2011:
  - Low efficiency and mid-range efficiency T12s: 2 F40T12 lamps with a residential low power factor electronic ballast (ballast factor =0.68, ballast luminous efficiency (BLE)= 77.7%)
  - High efficiency T12: 2 F34T12 lamps with a residential low power factor electronic ballast (ballast factor =0.68, BLE =77.7%)
  - Baseline and mid-range efficiency T8s: 2 F32T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=87.2%)
  - High efficiency T8: 2 F28T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=87.2%)
- Since 1995, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 75 lm/W and a minimum CRI of 69 for >35W lamps or 45 for <35W lamps.
- In 2005, DOE standards raised the minimum ballast efficacy factor (BEF) of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems. Residential ballasts were originally exempted from regulation.

Residential Linear Fluorescent Lighting (T12/T8)

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized residential ballasts have a minimum BLE = 0.993 / (1 + 0.41 * Avg Total Lamp Arc power ^ (- 0.25)). Residential ballasts also must have a minimum power factor of 0.5.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR residential fixtures require ≥ 65 lm/W per lamp-ballast platform before September 1, 2013 and ≥ 70 lm/W per lamp-ballast platform thereafter.
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Linear Fluorescent Lamps (T5)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2005	2009	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
Lamp Wattage	56	56	56	52	56	52	56	52	56	52
Lamp Lumens	5320	5320	5320	5320	5468	5480	5632	5657	5796	5834
System Wattage	63	63	63	59	61	57	61	57	61	57
System Lumens	5320	5320	5320	5320	5468	5480	5632	5657	5796	5834
Lamp Efficacy (lm/W)	95.0	95.0	95.0	102.3	97.6	105.4	100.6	108.8	103.5	112.2
System Efficacy (lm/W)	84.3	84.3	84.3	90.7	89.8	96.9	92.5	100.1	95.2	103.2
Lamp Price ($)	$3.56	$3.18	$3.18	$3.97	$3.08	$3.85	$2.98	$3.72	$2.87	$3.59
Ballast Price ($)	$20.94	$20.94	$20.94	$20.94	$26.31	$26.31	$25.41	$25.41	$24.50	$24.50
Lamp Cost ($/klm)	$0.67	$0.60	$0.60	$0.75	$0.56	$0.70	$0.53	$0.66	$0.50	$0.62
Average Lamp Life (1000 hrs)	20	20	20	25	21	26	21	27	22	27
CRI	85	85	85	85	85	85	85	85	85	85
Ballast Efficiency (BLE)	88.7%	88.7%	88.7%	88.7%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%

Residential Linear Fluorescent Lighting (T5)

- The residential T5 lamps characterized in this report are part of a two-lamp, one-ballast systems that emit approximately 5,300 system lumens.
- Compared to the 2008 EIA Reference Case, this report characterizes a range of efficacies within the T5 family and does not use T12 and T8 lamps for direct comparison because of a distinct utility for T5 lamps. Notably, T5 systems are very rarely used in the residential sector.
- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- Assumptions for 2011:
  - Typical: 2 F28T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)
  - Best available: 2 F26T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)

Residential Linear Fluorescent Lighting (T5)

- Currently no federal standards exist for the T5 lamps or their corresponding ballasts.
- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 86 lm/W.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Torchieres

DATA	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	253	150	154	37	150	150	40
Lamp Lumens	4300	2670	2670	2670	2733	2650	2666
Lamp Efficacy (lm/W)	17.0	17.8	17.3	72.7	18.2	17.7	66.6
Lamp Price	$4.15	$2.27	$1.10	$12.71	$2.87	$3.88	$12.33
Lamp Cost ($/klm)	$0.97	$0.85	$0.42	$4.76	$1.05	$1.46	$4.63
Average Lamp Life (1000 hrs)	2.1	1.0	1.8	10.0	0.8	3.0	9.5
CRI	98	100	100	82	100	100	82

Performance/Cost Characteristics » Residential Torchieres

DATA	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	150	150	40	150	150	40	150	150	40
Lamp Lumens	2760	2783	2799	2788	2922	2939	2816	3068	3086
Lamp Efficacy (lm/W)	18.4	18.6	70.0	18.6	19.5	73.5	18.8	20.5	77.1
Lamp Price	$2.80	$3.78	$12.02	$2.73	$3.69	$11.72	$2.66	$3.60	$11.43
Lamp Cost ($/klm)	$1.01	$1.36	$4.30	$0.98	$1.26	$3.99	$0.94	$1.17	$3.70
Average Lamp Life (1000 hrs)	0.8	3.2	9.8	0.9	3.5	10.1	0.9	3.7	10.5
CRI	100	100	82	100	100	82	100	100	82

Residential Torchieres

- The residential torchiere characterized in this report emits approximately 2,683 lumens. The typical characteristics are a weighted average of a halogen, incandescent, and CFL torchieres based. The 2005 typical wattage is based on 2003 installed base data. The 2009 typical wattage is based on EPACT standards.
- Energy Star® and the Consortium for Energy Efficiency (CEE) offer voluntary specifications for torchieres.
- The following future improvements for the system were assumed to occur over a 30 year period:
  - Incandescents: Efficacy +3%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - Halogen: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
  - CFL: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012).
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Solid State Lighting (LED A19 Replacement)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2005	2009	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	A19 LED	A19 LED	A19 LED	A19 LED	A19 LED
Typical Wattage	36	18	13	3.8	3.6	3.5
Lumens	630	800	800	800	800	800
Efficacy (lm/W)	17.3	44.0	60.0	210.0	224.0	230.0
Lamp Price ($)	$189.82	$68.00	$26.40	$2.16	$1.12	$0.80
Cost ($/klm)	$301.00	$85.00	$33.00	$2.70	$1.40	$1.40
Average Life (1000 hrs)	50	20	25	90	100	100
CRI	92	80	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700

Advanced Case Final

Performance/Cost Characteristics » Residential Solid State Lighting (LED PAR38 Replacement)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2005	2009	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	PAR38 LED	PAR38 LED	PAR38 LED	PAR38 LED	PAR38 LED
Typical Wattage	36	28	20	4.8	4.5	4.3
Lumens	630	1000	1000	1000	1000	1000
Efficacy (lm/W)	17.3	36.0	50.0	210.0	224.0	230.0
Lamp Price ($)	$189.82	$164.00	$51.00	$2.70	$1.40	$1.00
Cost ($/klm)	$301.00	$164.00	$51.00	$2.70	$1.40	$1.00
Average Life (1000 hrs)	50	20	25	90	100	100
CRI	92	80	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700

Residential Solid-State Lighting

- The residential solid-state lighting characterized in this report are replacements for a 60W A19 lamp and a 75W PAR38 lamp. These represent the most common uses of LED technology in the residential sector.
- This report characterizes two distinct applications for LEDs in the residential sector rather than one, as was done in the 2008 EIA Reference Case. Because of rapid LED technology development, the market is best characterized by the state of the technology at a given time rather than a range of performance at any one time.
- Assumptions for 2011:
  - 60W A19 equivalent: 13W LED emitting 800 lumens
  - 75W PAR38 equivalent: 20W LED emitting 1000 lumens
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.

Performance/Cost Characteristics » Commercial General Service Incandescent Lighting

DATA	2003	2007	2011			2012[1]	2020[2]
	Installed Base		Low	Typical	High	Typical	Typical
	Typical	Typical	Low	Typical	High	72W Inc	72W Inc
System Wattage	100	100	100	100	100	72	N/A
System Lumens	997	997	903	965	1003	879	N/A
Lamp Efficacy (lm/W)	16.9	16.9	15.3	16.2	17.0	20.7	N/A
System Efficacy (lm/W)	10.0	10.0	9.0	9.6	10.0	12.2	N/A
Lamp Cost ($/klm)	$0.23	$0.19	$0.40	$0.35	$0.39	$3.09	N/A
System Cost ($/klm)	$17.07	$13.97	$20.46	$21.29	$22.59	$19.14	N/A
Average Lamp Life (1000 hrs)	1	1	2	1	1	3	N/A
CRI	100	100	100	100	100	100	N/A
Total Installed Cost ($)	$89.76	$73.45	$85.40	$85.35	$85.39	$71.00	N/A
Annual Maintenance Cost ($)	$3.58	$3.58	$3.58	$3.58	$3.58	$0.86	N/A

[1] The Energy Independence and Security Act of 2007 prescribes standards for current 100 watt incandescent lamps as of January 1, 2012. Starting in 2012, 100-watt incandescents will be replaced by halogen infrared incandescents.

[2] In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized incandescent lamp technologies and current trends in industry lead us to believe they will not be met.

Commercial General Service Incandescent Lighting

- The Commercial incandescent lighting characterized in this report is a 100 watt medium screw based incandescent lamp (NCI, 2002) in an open down light recessed can fixture (~$20) with a fixture efficiency of 59% (DOE, 2008).
- A The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards can be achieved if incandescent bulbs use halogen infrared technologies.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. These standards can not be achieved by any incandescent technology currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent technology.
- California's Appliance Efficiency Regulations include efficiency regulations for general service incandescent lamps with certain bases. California's Appliance Efficiency Regulations include efficiency regulations for general service incandescent lamps with certain bases. California is currently undergoing a rulemaking to reduce commercial lighting by not less than 25% of 2007 levels over the next 10 years in accordance with Assembly Bill 1109. They are going to regulate general purpose lighting (incandescent lamps).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the fluorescent and incandescent energy conservation standard advanced notice of proposed rulemaking (lamps ANOPR). Maintenance costs include labor only based on 3,376 operating hours per year. (lamps ANOPR)

Advanced Case Final

Performance/Cost Characteristics » Commercial Compact Fluorescent Lamps

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Low	Typical	High	Typical	High	Typical	High	Typical	High
	26W	26W	23W	23W	23W	23W	23W	23W	23W	23W	23W
System Wattage	26	26	23	23	23	23	23	23	23	23	23
System Lumens	1068	1068	976	976	1010	1025	1060	1076	1113	1130	1169
Lamp Efficacy (lm/W)	67.3	67.3	69.6	69.6	72.0	73.0	75.6	76.7	79.3	80.5	83.3
System Efficacy (lm/W)	41.1	41.1	42.4	42.4	43.9	44.6	46.1	46.8	48.4	49.1	50.8
Lamp Cost ($/klm)	$4.01	$3.28	$1.56	$1.56	$1.73	$1.52	$1.69	$1.49	$1.65	$1.45	$1.61
System Cost ($/klm)	$22.14	$18.12	$23.05	$23.05	$22.65	$22.48	$22.09	$21.92	$21.54	$21.37	$21.00
Average Lamp Life (1000 hrs)	10.0	10.0	10.0	12.0	12.0	12.4	12.4	12.8	12.8	13.2	13.2
CRI	82	82	82	82	82	82	82	82	82	82	82
Total Installed Cost ($)	$96.56	$79.02	$80.00	$80.00	$80.00	$78.00	$78.00	$76.05	$76.05	$74.15	$74.15
Annual Maintenance Cost ($)	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39

Commercial Compact Fluorescent Lamps

- The commercial compact fluorescent lamp characterized in this report is a 23 watt screw-base compact fluorescent lamp in an open down light recessed can fixture (~$20) with a fixture efficiency of 61%.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts Energy Star performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. The Secretary may revise these requirements by rule or establish other requirements at a later date. *[Note: EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based)]*
- Energy Star® and the Consortium for Energy Efficiency (CEE) offer voluntary specifications for CFL lamps.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005)
- The following future improvements were assumed to occur over a 30 year period: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012). Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the lamps ANOPR. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial Halogen Lighting (PAR 38)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003		2007		2011		2020		2030		2040	
	Installed Base				Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR
System Wattage	90	70	90	70	90	70	90	70	90	70	90	70
System Lumens	1218	1172	1218	1172	1230	1306	1291	1372	1355	1441	1423	1513
Lamp Efficacy (lm/W)	14.6	18.0	14.6	18.0	14.7	20.1	15.4	21.1	16.2	22.1	17.0	23.2
System Efficacy (lm/W)	13.5	16.7	13.5	16.7	13.7	18.7	14.3	19.6	15.1	20.6	15.8	21.6
Lamp Cost ($/klm)	$4.98	$6.76	$4.07	$5.53	$2.87	$11.19	$2.80	$10.91	$2.73	$10.64	$2.66	$10.37
System Cost ($/klm)	$19.01	$21.46	$15.56	$17.56	$19.35	$27.34	$18.87	$26.65	$18.39	$25.99	$17.93	$25.34
Average Lamp Life (1000 hrs)	2.5	3.0	2.5	3.0	2.4	3.6	2.6	3.9	2.8	4.2	3.0	4.5
CRI	100	100	100	100	100	100	100	100	100	100	100	100
Total Installed Cost ($)	$96.56	$97.92	$79.02	$80.13	$81.00	$93.00	$80.19	$92.07	$79.39	$91.15	$78.59	$90.24
Annual Maintenance Cost ($)	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22

Performance/Cost Characteristics » Commercial Halogen Lighting (Edison)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	90W Edison	90W Edison	90W Edison	90W Edison	90W Edison	90W Edison
System Wattage	90	90	72	72	72	72
System Lumens	1218	1218	1395	1465	1538	1615
Lamp Efficacy (lm/W)	14.6	14.6	20.8	21.9	23.0	24.1
System Efficacy (lm/W)	13.5	13.5	19.4	20.3	21.4	22.4
Lamp Cost ($/klm)	$4.98	$4.07	$1.33	$1.30	$1.26	$1.23
System Cost ($/klm)	$19.01	$15.56	$15.76	$15.37	$14.99	$14.61
Average Lamp Life (1000 hrs)	2.5	2.5	1.0	1.1	1.2	1.2
CRI	100	100	100	100	100	100
Total Installed Cost ($)	$96.56	$79.02	$80.00	$78.00	$76.05	$74.15
Annual Maintenance Cost ($)	$1.92	$1.57	$1.41	$1.41	$1.41	$1.41

Commercial Halogen Lighting

- The commercial halogen lighting characterized in this report is a lamp that emits approximately 1200-1400 lumens in an open down light recessed can fixture (~$20) with a fixture efficiency of 93% (DOE, 2008).
- Multiple types of halogen lamps were analyzed, including:
  - Typical efficiency unit: 90W halogen PAR38
  - High efficiency unit: 70W halogen infrared reflector PAR38
  - Typical efficiency unit: 72 W halogen Edison A-line lamp
- Halogen infrared reflector (HIR) lamps contain a tungsten halogen capsule with a film coating on the inside of the capsule. The coating reflects infrared radiation back into the lamp filament, which forces the filament to burn at a higher temperature. This increases the efficacy of the lamp, without reducing operating life.
- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008.
- The following future improvements for the system were assumed to occur over a 30 year period: Efficacy +15%, Life +7.5%, and Price -7.5% (NCI, 2012). These improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the lamps ANOPR. Maintenance costs include labor only based on 3,450 operating hours per year. (lamps ANOPR)

Performance/Cost Characteristics » Commercial Solid State Lighting (Edison Socket Substitute)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	BR30 LED	BR30 LED	BR30 LED	BR30 LED	BR30 LED
Wattage	36	13	11	3.1	2.9	2.8
Lumens	548	650	650	650	650	650
Efficacy (lm/W)	15.1	51.0	60.0	210.0	224.0	230.0
Lamp Cost ($/klm)	$392.68	$205.00	$80.00	$10.00	$5.30	$3.60
Life (1000 hrs)	50	25	50	100	100	100
CRI	92	85	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700
Total Installed Cost ($)	$270.44	$186.77	$105.52	$60.02	$56.96	$55.86
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (Edison Socket Substitute)

- The commercial solid-state lighting characterized is a replacement for a 65W BR30 lamp. This represents the most common use of LED technology in Edison sockets in the commercial sector.
- Assumptions for 2011:
  - 65W BR30 equivalent: 11W LED emitting 650 lumens in a downlight fixture
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial 4-ft T8 Linear Fluorescent Lighting

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011				
	Installed Base		Baseline	High Efficiency	HE w/ Occ. Sensor	HE w/ Spec. Reflector	HE w/ OS & Spec. Ref.
	32WT8	32WT8	32WT8	28WT8	28WT8	28WT8	28WT8
System Wattage	65	65	65	57	57	57	57
System Lumens	3282	3282	3282	3334	3334	3942	3942
Lamp Efficacy (lm/W)	78.8	78.8	78.8	91.4	91.4	91.4	91.4
System Efficacy (lm/W)	50.1	50.1	50.1	58.2	58.2	68.8	68.8
Cost ($/klm)	$0.38	$0.38	$0.38	$0.63	$0.63	$0.63	$0.63
Cost ($/klm l/b/f)	$13.81	$13.81	$13.81	$14.38	$15.29	$17.64	$18.40
Average Lamp Life (1000 hrs)	20	20	20	18	9	18	9
CRI	75	75	75	82	82	82	82
Total Installed Cost ($)	$74.00	$74.00	$74.00	$76.63	$79.64	$98.20	$101.21
Annual Maintenance Cost ($)	$3.03	$3.03	$3.03	$3.16	$4.41	$3.16	$4.41
Ballast Efficiency (BLE)	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%

Performance/Cost Characteristics » Commercial 4-ft T8 Linear Fluorescent Lighting (Cont.'d)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2020					2030					2040				
	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max
	32WT8	28WT8	28WT8	28WT8	28WT8	32WT8	F28T8	F28T8	F28T8	F28T8	F32T8	F28T8	F28T8	F28T8	F28T8
System Wattage	62	54	54	54	54	62	54	54	54	54	62	54	54	54	54
System Lumens	3738	3434	3434	4061	4061	3767	3545	3545	4192	4192	3796	3656	3656	4323	4323
Lamp Efficacy (lm/W)	89.7	94.2	94.2	94.2	94.2	90.4	97.2	97.2	97.2	97.2	91.1	100.3	100.3	100.3	100.3
System Efficacy (lm/W)	60.5	63.5	63.5	75.1	75.1	60.9	65.5	65.5	77.5	77.5	61.4	67.6	67.6	79.9	79.9
Cost ($/klm)	$0.53	$0.59	$0.59	$0.59	$0.59	$0.51	$0.56	$0.56	$0.56	$0.56	$0.49	$0.52	$0.52	$0.52	$0.52
Cost ($/klm l/b/f)	$12.40	$13.55	$14.40	$16.61	$17.33	$11.88	$12.67	$13.47	$15.53	$16.21	$11.37	$11.85	$12.59	$14.53	$15.16
Average Lamp Life (1000 hrs)	25	19	9	19	9	26	19	10	19	10	26	20	10	20	10
CRI	85	82	82	82	82	85	82	82	82	82	85	82	82	82	82
Total Installed Cost ($)	$75.01	$75.19	$78.11	$96.11	$99.04	$73.42	$73.59	$76.42	$93.79	$96.62	$71.83	$71.99	$74.72	$91.47	$94.20
Annual Maintenance Cost ($)	$3.03	$3.16	$4.41	$3.16	$4.41	$3.03	$3.16	$4.41	$3.16	$4.41	$3.03	$3.16	$4.41	$3.16	$4.41
Ballast Efficiency (BLE)	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%

Commercial Linear Fluorescent Lighting – ≤ 4 ft. T8/T12

- The commercial linear fluorescent lighting (≤ 4 ft.) characterized in this report is a two-lamp system (one ballast and one fixture) that emits approximately 4,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report excludes F34T12 lamps and F32T8 HE magnetic systems. T12 lamps have largely disappeared from the market, and F32T8 HE magnetic systems are a niche product for sensitive applications that do not represent any significant portion of the market. This report also assumes that the high efficiency T8 lamp has a reduced wattage of 28W rather than 32W.
- Assumptions for 2011:
  - Baseline F32T8: 2 32W T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=86%), fixture efficiency = 74%
  - F32T8 HE unit: 2 28W T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=86%), fixture efficiency = 74%
  - F32T8 HE unit w/ occupancy sensor: 2 28W T8 lamps with a electronic ballast (ballast factor=0.88, BLE=86%) and occupancy sensor (designed for 1,000 sq. ft. or ~25 two lamp systems), fixture efficiency = 74%. Note that occupancy sensor is assumed to be associated with a 50% reduction in lamp lifetime.
  - F32T8 HE unit w/ specular reflector: 2 28W T8 lamps with instant start electronic ballast (ballast factor=0.88, BLE=86%), fixture efficiency = 88%
  - F32T8 HE unit w/ OS and SR: 2 28W T8 lamps with electronic ballast (ballast factor=0.88, BLE=86%) and occupancy sensor (designed for 1,000 sq. ft. or ~25 two lamp systems), fixture efficiency = 88%. Note that occupancy sensor is assumed to be associated with a 50% reduction in lamp lifetime.
- Since 1995, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 75 lm/W and a minimum CRI of 45 for <35W lamps.
- In 2005, DOE standards raised the minimum BEF of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems.

Commercial Linear Fluorescent Lighting – ≤ 4 ft. T8/T12

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.27 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Though system watts for the F32T8 HE with the occupancy sensor are the same as the F32T8 HE, occupancy sensors can result in 17% to 60% energy savings due to reduced operating hours. (LRC) Savings potential is highly dependent on the time-delay programmed into the sensor, which ranges from 5-30 minutes and room type. Shorter time delays save more energy, but possibly at expense of lamp life. Occupancy sensors can reduce fluorescent lamp lifetime by as much as 50%. (Lutron) This decrease in lifetime results in higher overall maintenance costs.
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Advanced Case Final

Performance/Cost Characteristics » Commercial 4-ft T5 Linear Fluorescent Lighting

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
System Wattage	66	63	63	59	61	57	61	57	61	57
System Lumens	4698	4698	4698	4698	4783	4838	4973	4995	5118	5152
Lamp Efficacy (lm/W)	95.0	95.0	95.0	102.3	96.7	105.4	100.6	108.8	103.5	112.2
System Efficacy (lm/W)	71.2	74.4	74.4	80.1	78.6	85.6	81.7	88.4	84.1	91.1
Cost ($/klm)	$1.53	$0.67	$0.67	$0.84	$0.64	$0.79	$0.59	$0.74	$0.56	$0.69
Cost ($/klm l/b/f)	$28.68	$28.46	$28.46	$28.84	$27.12	$27.16	$25.18	$25.41	$23.60	$23.76
Average Lamp Life (1000 hrs)	20	20	20	25	21	26	21	27	22	27
CRI	85	85	85	85	85	85	85	85	85	85
Total Installed Cost ($)	$164.95	$161.39	$161.39	$163.17	$157.38	$159.10	$152.92	$154.59	$148.46	$150.07
Annual Maintenance Cost ($)	$2.81	$2.93	$2.93	$2.71	$2.93	$2.71	$2.93	$2.71	$2.93	$2.71
Ballast Efficiency (BLE)	88.7%	88.7%	88.7%	88.7%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%

Commercial 4-ft T5 Linear Fluorescent Lighting

- The commercial T5 linear fluorescent lighting characterized in this report is a two-lamp system (one ballast and one 88.3% efficient fixture) that emits approximately 4,700 system lumens.
- Compared to the 2008 EIA Reference Case, this report assumes that the high efficiency T5 lamp has a reduced wattage of 26 W rather than 28 W.
- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- Assumptions for 2011:
  - Typical: 2 F28T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)
  - Best available: 2 F26T5 lamps with a programmed start electronic ballast (ballast factor =1, BLE=88.7%)
- Currently no federal standards exist for the T5 lamps or corresponding ballasts characterized in this report.

Commercial 4-ft T5 Linear Fluorescent Lighting

- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 86 lm/W for standard output T5 lamps.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial Solid State Lighting (4-ft Linear Fluorescent Lighting Substitute)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		T8	T8	T8	T8
	LED	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8
Typical Wattage	36.4	80.0	55.4	24.0	22.5	21.9
Lumens	548	5040	5040	5040	5040	5040
Efficacy (lm/W)	15.1	63.0	91.0	210.0	224.0	230.0
Cost ($/klm)	$392.68	$301.00	$110.00	$10.00	$5.30	$3.60
Average Lamp Life (1000 hrs)	50	25	50	100	100	100
CRI	92	70	80	85	85	85
CCT	2700	3500	3500	3500	3500	3500
Total Installed Cost ($)	$270.44	$1,570.56	$607.92	$103.92	$80.23	$71.66
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (4-ft Linear Fluorescent Substitute)

- The commercial solid-state lighting characterized is a replacement for 2 4-ft 32W T8 lamps in a troffer fixture. This represents the most common use of LED technology in the 4-ft linear fluorescent lighting market.
- Assumptions for 2011:
  - 2 F32T8 lamps equivalent: 56W LED emitting 5040 lumens
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial 8-ft Linear Fluorescent Lighting

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003				2007			
	Installed Base							
	75WT12	60WT12	59WT8	59WT8 HE	75WT12	60WT12	59WT8	55WT8
System Wattage	158	126	113	100	148	119	113	106
System Lumens	10208	7546	8300	8311	9376	7404	8379	8844
Lamp Efficacy (lm/W)	78.7	77.7	86.9	98.2	78.7	77.7	86.9	98.5
System Efficacy (lm/W)	64.6	59.9	73.5	83.1	63.1	62.3	73.9	83.7
Cost ($/klm)	$0.99	$0.73	$0.80	$1.23	$0.52	$0.38	$0.42	$0.51
Cost ($/klm l/b/f)	$5.31	$6.54	$6.36	$7.09	$4.41	$4.41	$6.35	$9.26
Average Lamp Life (1000 hrs)	12	12	15	18	12	12	15	24
CRI	70	62	75	85	62	62	75	78
Total Installed Cost ($)	$106.42	$102.16	$105.35	$111.74	$83.44	$83.44	$103.93	$162.76
Annual Maintenance Cost ($)	$4.64	$4.64	$4.39	$4.22	$4.66	$4.66	$4.40	$4.55
Ballast Efficiency (BLE)	88.9%	88.9%	88.9%	88.9%	88.9%	88.9%	91.6%	91.7%

Performance/Cost Characteristics » Commercial 8-ft Linear Fluorescent Lighting (Cont.'d)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2011			2020		2030		2040	
	Electronic HE	Typical	High Efficiency	Typical	HE	Typical	HE	Typical	HE
	60WT12	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8
System Wattage	119	113	106	112	104	112	104	112	104
System Lumens	7404	8379	8844	9051	9110	9258	9404	9465	9699
Lamp Efficacy (lm/W)	77.7	86.9	98.5	93.9	101.4	96.1	104.7	98.2	108.0
System Efficacy (lm/W)	62.3	73.9	83.7	81.0	87.4	82.8	90.3	84.7	93.1
Cost ($/klm)	$0.38	$0.42	$0.59	$0.58	$0.55	$0.54	$0.52	$0.51	$0.48
Cost ($/klm l/b/f)	$4.41	$6.35	$6.48	$6.19	$6.10	$5.84	$5.71	$5.51	$5.34
Average Lamp Life (1000 hrs)	12	15	18	15	19	16	19	16	20
CRI	62	75	82	82	82	82	82	82	82
Total Installed Cost ($)	$83.44	$103.93	$108.05	$106.76	$106.33	$104.84	$104.42	$102.91	$102.51
Annual Maintenance Cost ($)	$4.66	$4.40	$4.23	$4.40	$4.23	$4.40	$4.23	$4.40	$4.23
Ballast Efficiency (BLE)	88.9%	91.6%	91.6%	92.9%	92.9%	92.9%	92.9%	92.9%	92.9%

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

- The commercial linear fluorescent lighting (> 4 ft.) characterized in this report is a two-lamp system (one ballast and one fixture) that emits approximately 8,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report:
  - Assumes that the high efficiency 8 ft. T8 lamp has a reduced wattage of 55 W rather than 59 W.
  - Continues to includes 75W T12 lamps only in the installed base
  - Characterizes the 60W T12 lamps with an electronic ballast rather than a magnetic ballast because of the inability to meet current ballast standards with magnetic ballasts
- Assumptions for 2011:
  - 2 F96T12 lamps (60W each) with electronic ballast (ballast factor =0.88, BLE=88.9%), fixture efficiency= 90.2%
  - 2 F96T8 lamps (59W each) with electronic ballast (ballast factor=0.88, BLE=91.6%), fixture efficiency= 92.8%
  - 2 high efficiency F96T8 lamps (55W each) with electronic ballast (ballast factor=0.88, BLE=91.6%), fixture efficiency= 92.8.%
- Since 1994, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 80 lm/W and a minimum CRI of 69 for >35W lamps.
- In 2005, DOE standards raised the minimum BEF of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems.

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 97 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.27 * Avg Total Lamp Arc power ^ (- 0.25)).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- California’s Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (NCI, 2009)

Performance/Cost Characteristics » Commercial 8-ft Linear Fluorescent Lighting (High Output)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO
System Wattage	165	165	165	165	165	165	165	165	165	165
System Lumens	11488	11596	11596	12740	11951	13122	12345	13546	12740	13971
Lamp Efficacy (lm/W)	82.6	82.6	82.6	90.7	85.1	93.4	87.9	96.4	90.7	99.5
System Efficacy (lm/W)	69.6	70.3	70.3	77.2	72.4	79.5	74.8	82.1	77.2	84.6
Cost ($/klm)	$0.99	$0.51	$0.51	$0.58	$0.45	$0.51	$0.45	$0.51	$0.42	$0.47
Cost ($/klm l/b/f)	$9.29	$9.26	$9.26	$8.69	$8.15	$7.66	$8.15	$7.66	$7.62	$7.16
Average Lamp Life (1000 hrs)	24	24	24	18	26	19	26	19	26	20
CRI	78	78	78	86	78	86	78	86	78	86
Total Installed Cost ($)	$163.88	$162.76	$162.76	$166.10	$155.96	$159.09	$155.96	$159.09	$152.38	$155.40
Annual Maintenance Cost ($)	$4.64	$4.55	$4.55	$4.83	$4.55	$4.83	$4.55	$4.83	$4.55	$4.83
Ballast Efficiency (BLE)	88.9%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12 High Output

- The high output commercial linear fluorescent lighting (> 4 ft.) characterized in this report is a two-lamp system (one ballast and one 92.8% efficient fixture) that emits approximately 10,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report characterizes a best available unit in addition to the typical unit.
- Assumptions for 2011:
  - Typical: 2 F96T8HO lamps (86W each) with electronic ballast (ballast factor=0.78, BLE=91.7%)
  - Best available: 2 F96T8HO lamps (86W each) with electronic ballast (ballast factor=0.78, BLE=91.7%) and emitting additional lumens
- Since 1994, DOE standards have required that the lamps characterized by this report have a minimum efficacy of 80 lm/W and a minimum CRI of 69 for >35W lamps.
- In 2005, DOE standards raised the minimum BEF of the ballasts paired with the characterized lamps, effectively promoting the use of T8 lamp and ballast systems.

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12 High Output

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 92 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE of 0.993 / (1 + 0.38 * Avg Total Lamp Arc power ^ (- 0.25)).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- California's Title 24 mandates the use of electronic ballasts with high-efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial Low Bay HID Lighting (Metal Halide)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH
System Wattage	208	210	211	199	170	199	170	199	170	199	170
System Lumens	5176	6669	7171	10186	11409	10645	11922	11154	12493	11663	13063
Lamp Efficacy (lm/W)	39.0	50.3	50.3	71.4	93.3	74.6	97.5	78.2	102.2	81.8	106.9
System Efficacy (lm/W)	24.9	31.8	34.0	51.2	67.2	53.5	70.3	56.1	73.6	58.7	77.0
Lamp Cost ($/klm)	$2.19	$2.75	$5.81	$5.67	$5.06	$5.26	$4.70	$4.85	$4.33	$4.47	$4.00
System Cost ($/klm)	$35.80	$26.17	$44.58	$39.92	$35.64	$37.06	$33.09	$34.15	$30.49	$31.49	$28.12
Average Lamp Life (1000 hrs)	24.0	10.0	10.0	15.0	15.0	15.7	15.7	16.4	16.4	17.2	17.2
CRI	15	65	67	69	69	69	69	69	69	69	69
Total Installed Cost ($)	$328.83	$318.18	$771.67	$858.59	$858.59	$846.39	$846.39	$832.84	$832.84	$819.28	$819.28
Annual Maintenance Cost ($)	$3.93	$4.81	$4.83	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32

Commercial HID Low Bay Lighting (Metal Halide)

- The commercial metal halide low bay lighting characterized in this report is a one-lamp and one-ballast system in a low bay fixture with 81.5% efficiency that emits approximately 10,000 system lumens.
- Low bay lighting is defined as "interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor." (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency for the high efficiency unit rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Characterizes metal halide lamps separately from high pressure sodium lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.
- A 175W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.
- Assumptions for 2011:
  - Typical efficiency unit: 175W metal halide lamp with pulse start magnetic ballast (ballast efficiency=88%)
  - High efficiency unit: 175W metal halide lamp with pulse start magnetic ballast (ballast efficiency=88.4%)

Commercial HID Low Bay Lighting (Metal Halide)

- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- EISA 2007 established efficiency standards for probe start magnetic ballasts (94%) and pulse start magnetic or electronic ballasts (88%) for ballasts that operate metal halide lamps between 150 and 400 watts, effective January 1, 2009. The 94% efficiency requirement effectively banned probe start magnetic ballasts.
- A DOE rulemaking is ongoing to establish new and amended energy conservation standards for metal halide lamp fixtures as directed by EISA 2007. This rulemaking is expected to be completed by June 2014.
- In the advanced case, assumed improvements could be made using improved ceramic arc tubes and better electrodes (and double arc tubes for lifetime improvement).
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial Low Bay HID Lighting (High Pressure Sodium)

No change from reference case.

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	70W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS
System Wattage	208	93	130	130	122	130	122	130	122	130	122
System Lumens	5176	4130	7213	7213	7213	7213	7213	7213	7213	7213	7213
Lamp Efficacy (lm/W)	39.0	77.9	94.5	94.5	94.5	94.5	94.5	94.5	94.5	94.5	94.5
System Efficacy (lm/W)	24.9	44.4	55.5	55.5	59.1	55.5	59.1	55.5	59.1	55.5	59.1
Lamp Cost ($/klm)	$2.19	$3.11	$5.37	$5.37	$5.37	$5.29	$5.29	$5.20	$5.20	$5.11	$5.11
System Cost ($/klm)	$35.80	$41.15	$43.68	$43.68	$45.58	$43.03	$44.89	$42.30	$44.13	$41.57	$43.37
Average Lamp Life (1000 hrs)	24	24	24	24	24	24	24	24	24	24	24
CRI	15	22	22	22	22	22	22	22	22	22	22
Total Installed Cost ($)	$328.83	$312.86	$767.01	$767.01	$780.68	$762.29	$775.74	$757.04	$770.27	$751.78	$764.79
Annual Maintenance Cost ($)	$3.93	$3.93	$3.93	$3.93	$4.04	$3.93	$4.04	$3.93	$4.04	$3.93	$4.04

Commercial HID Low Bay Lighting (High Pressure Sodium)

- The commercial high pressure sodium low bay lighting characterized in this report is a one-lamp and one-ballast system in a low bay fixture with 76.3% efficiency that emits approximately 7,000 system lumens.
- Low bay lighting is defined as "interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor." (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Analyzes a 100W unit rather than a 70W unit as the typical low bay unit.
  - Characterizes high pressure sodium lamps separately from metal halide lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.

- A 175W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.

Commercial HID Low Bay Lighting (High Pressure Sodium)

- Assumptions for 2011:
  - Typical efficiency unit: 100W high pressure sodium lamp with magnetic ballast (ballast efficiency=76.9%)
  - High efficiency unit: 100W high pressure sodium lamp with magnetic ballast (ballast efficiency=82%)
- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- The market is moving away from HPS technology with relatively little investment going into its development. Therefore, even in an advanced case, efficacy, price and lifetime are not expected to improve faster than the reference case.
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial Solid State Lighting (Low Bay Applications)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	100W HPS LED	100W HPS LED	100W HPS LED	100W HPS LED
Typical Wattage	36	11	100	34	32	31
Lumens	548	630	7200	7200	7200	7200
Efficacy (lm/W)	15.1	55.3	72.0	210.0	224.0	230.0
Cost ($/klm)	$392.68	$160.00	$112.00	$10.00	$5.30	$3.60
Average Lamp Life (1000 hrs)	50	50	50	100	100	100
CRI	92	92	80	80	80	80
CCT	2700	2700	5500	5500	5500	5500
Total Installed Cost ($)	$270.44	$154.32	$859.92	$125.52	$91.68	$79.44
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (Low Bay Applications)

- The commercial solid-state lighting technology characterized in this report is a replacement for a 100W high pressure sodium lamp. This represents the most common use of LED technology in the low bay market.
- Assumptions for 2011:
  - 100W HPS lamp equivalent: 100W LED emitting 7,200 lumens
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 Lamps Rule. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial High Bay HID Lighting (Metal Halide)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	250W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH
System Wattage	453	293	465	480	423	455	423	455	423	455	423
System Lumens	13061	12245	20607	21261	23551	22218	24610	23281	25788	24344	26965
Lamp Efficacy (lm/W)	36.0	54.0	63.0	65.0	72.0	67.9	75.2	71.2	78.8	74.4	82.4
System Efficacy (lm/W)	28.8	41.8	44.3	44.3	55.6	48.9	58.1	51.2	60.9	53.6	63.7
Lamp Cost ($/klm)	$1.16	$1.31	$2.38	$3.55	$3.21	$3.30	$2.98	$3.04	$2.74	$2.80	$2.53
System Cost ($/klm)	$11.06	$12.83	$21.54	$16.19	$22.14	$15.03	$20.55	$13.85	$18.94	$12.77	$17.47
Average Lamp Life (1000 hrs)	24.0	10.0	20.0	18.4	18.4	19.2	19.2	20.1	20.1	21.0	21.0
CRI	50	65	68	66	66	66	66	66	66	66	66
Total Installed Cost ($)	$287.32	$300.09	$926.65	$827.03	$1,004.28	$816.71	$988.63	$805.24	$971.25	$793.76	$953.87
Annual Maintenance Cost ($)	$3.93	$4.81	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13

Commercial HID High Bay Lighting (Metal Halide)

- The commercial metal halide high bay lighting characterized in this report is a one-lamp and one-ballast system in a high bay fixture with 81.8% efficiency that emits approximately 24,000 system lumens.
- High bay lighting is defined as "interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor." (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Analyzes a 400W unit rather than a 250W unit as the typical high bay unit.
  - Characterizes metal halide lamps separately from high pressure sodium lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.
- A 400W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.
- Assumptions for 2011:
  - Typical efficiency unit: 400W metal halide lamp with pulse start magnetic ballast (ballast efficiency=88%)
  - High efficiency unit: 400W metal halide lamp with pulse start magnetic ballast (ballast efficiency=94.5%)

Commercial HID High Bay Lighting (Metal Halide)

- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- EISA 2007 established efficiency standards for probe start magnetic ballasts (94%) and pulse start magnetic or electronic ballasts (88%) for ballasts that operate metal halide lamps between 150 and 400 watts, effective January 1, 2009. The 94% efficiency requirement effectively banned probe start magnetic ballasts.
- A DOE rulemaking is ongoing to establish new and amended energy conservation standards for metal halide lamp fixtures as directed by EISA 2007. This rulemaking is expected to be completed by June 2014.
- In the advanced case , assumed improvements could be made using improved ceramic arc tubes and better electrodes (and double arc tubes for lifetime improvement).
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Performance/Cost Characteristics » Commercial High Bay HID Lighting (High Pressure Sodium)

No change from reference case.

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS
System Wattage	453	190	190	190	171	190	171	190	171	190	171
System Lumens	13061	10754	10754	10754	10754	10754	10754	10754	10754	10754	10754
Lamp Efficacy (lm/W)	36.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
System Efficacy (lm/W)	28.8	56.6	56.6	56.6	62.9	56.6	62.9	56.6	62.9	56.6	62.9
Lamp Cost ($/klm)	$1.16	$4.65	$4.65	$4.65	$4.65	$4.51	$4.51	$4.36	$4.36	$4.20	$4.20
System Cost ($/klm)	$11.06	$30.96	$30.96	$30.96	$31.79	$30.03	$30.83	$29.00	$29.77	$27.97	$28.72
Average Lamp Life (1000 hrs)	24	24	24	24	24	24	24	24	24	24	24
CRI	50	22	22	22	22	22	22	22	22	22	22
Total Installed Cost ($)	$287.32	$815.84	$815.84	$815.84	$824.72	$805.85	$814.47	$794.75	$803.07	$783.65	$791.68
Annual Maintenance Cost ($)	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93

Commercial HID High Bay Lighting (High Pressure Sodium)

- The commercial high pressure sodium high bay lighting characterized in this report is a one-lamp and one-ballast system in a fixture with 79.7% efficiency that emits approximately 11,000 system lumens.
- High bay lighting is defined as “interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor.” (IESNA, 2000)
- Compared to the 2008 EIA Reference Case, this report:
  - Characterizes a best available unit in addition to the typical unit.
  - Increases the ballast efficiency to increase system efficiency rather than increase the lamp efficacy due to the existence of more data on ballast efficiency than lamp efficacy at this time.
  - Characterizes high pressure sodium lamps separately from metal halide lamps because of their separate utilities. Metal halide lamps provide an intense white light and are typically used in retail applications; high pressure sodium lamps provide a yellow light and are typically used in warehouses and distribution centers.
- A 400W mercury vapor lamp with a magnetic ballast is included in the 2003 reference case for comparison, but EPACT 2005 prohibited the manufacture and import of mercury vapor lamp ballasts after January 1, 2008, causing mercury vapor lamp sales to decline until ultimately disappearing after the failure of all existing mercury vapor lamp ballasts.

Commercial HID High Bay Lighting (High Pressure Sodium)

- Assumptions for 2011:
  - Typical efficiency unit: 150W high pressure sodium lamp with magnetic ballast (ballast efficiency=78.9%)
  - High efficiency unit: 150W high pressure sodium lamp with magnetic ballast (ballast efficiency=87.7%)
- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- The market is moving away from HPS technology with relatively little investment going into its development. Therefore, even in an advanced case, efficacy, price and lifetime are not expected to improve faster than the reference case.
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

Advanced Case Final

Performance/Cost Characteristics » Commercial T5 HO Lighting (High Bay Applications)

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	54WT5HO	54WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO
System Wattage	240	234	234	221	231	218	231	218	231	218
System Lumens	18060	17646	17646	17646	18175	18175	18763	18763	19351	19351
Lamp Efficacy (lm/W)	88.0	85.2	85.2	90.2	87.7	92.9	90.6	95.9	93.4	98.9
System Efficacy (lm/W)	75.2	75.5	75.5	79.9	78.6	83.3	81.2	86.0	83.7	88.7
Cost ($/klm)	$1.06	$0.26	$0.26	$0.38	$0.24	$0.36	$0.23	$0.34	$0.21	$0.32
Cost ($/klm l/b/f)	$8.50	$8.30	$8.30	$8.82	$7.82	$8.30	$7.31	$7.77	$6.84	$7.26
Average Lamp Life (1000 hrs)	20	20	20	20	21	21	21	21	22	22
CRI	85	85	85	85	85	85	85	85	85	85
Total Installed Cost ($)	$184.10	$174.12	$174.12	$183.24	$169.72	$178.58	$164.84	$173.39	$159.96	$168.20
Annual Maintenance Cost ($)	$2.81	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93
Ballast Efficiency (BLE)	92.4%	92.4%	92.4%	92.4%	93.5%	93.5%	93.5%	93.5%	93.5%	93.5%

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

- The commercial T5 HO linear fluorescent lighting characterized in this report is a four-lamp system (one ballast and one 95.9% efficient fixture) that emits approximately 17,000 system lumens.
- Compared to the 2008 EIA Reference Case, this report characterizes a best available unit in addition to the typical unit and assumes that the high efficiency T5 HO lamp has a reduced wattage of 51 W rather than 54 W.
- Assumptions for 2011:
  - Typical: 4 54W T5 high output lamps with electronic ballast (ballast factor=1, BLE=92.4%)
  - Best available: 4 51W T5 lamps with electronic ballast (ballast factor =1, BLE=92.4%)
- Currently no federal standards exist for the T5 lamps or corresponding ballasts characterized in this report.

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 76 lm/W.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE of 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- Many utilities offer rebates for T5 high output fixtures, generally to replace HID high bay fixtures. The programs include new construction incentives, customized programs, retrofit and upgrade incentives.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher. (CEC, 2005)
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

Performance/Cost Characteristics » Commercial Solid State Lighting (High Bay Applications)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	150W HPS LED	150W HPS LED	150W HPS LED	150W HPS LED
Typical Wattage	36	11	125	51	48	47
Lumens	548	630	10700	10700	10700	10700
Efficacy (lm/W)	15.1	55.3	85.4	210.0	224.0	230.0
Cost ($/klm)	$392.68	$160.00	$63.00	$10.00	$5.30	$3.60
Average Lamp Life (1000 hrs)	50	50	50	100	100	100
CRI	92	92	80	80	80	80
CCT	2700	2700	5500	5500	5500	5500
Total Installed Cost ($)	$270.44	$154.32	$727.62	$160.52	$110.23	$92.04
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (High Bay Applications)

- The commercial solid-state lighting technology characterized is a replacement for a 150W high pressure sodium lamp. This represents the most common use of LED technology in the high bay market.
- Assumptions for 2011:
  - 150W HPS lamp equivalent: 125W LED emitting 10,700 lumens
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 Lamps Rule. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Commercial Supermarket Display Cases

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical[1]	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	20,000	20,730	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Median Store Size (ft^3)	44,000	47,500	46,000	46,000	46,000	46,000	46,000	46,000	46,000	46,000	46,000
Energy Use (kWh/yr)[2]	21,000	23,117	21,134	18,440	17,002	16,566	15,333	15,694	14,526	14,823	13,719
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$4,371	$10,094	$7,425	$7,600	$8,173	$8,763	$7,803	$8,763	$7,803	$8,763	$7,803
Total Installed Cost	$6,452	$12,176	$9,603	$9,777	$10,351	$10,937	$9,981	$10,937	$9,981	$10,937	$9,981
Annual Maintenance Cost[3]	$283	$337	$376	$376	$376	$376	$376	$376	$376	$376	$376

[1] DOE's Federal energy standards for Commercial Refrigeration Equipment (CRE) went into effect on January 1, 2012. The 2020 Typical values are based on this standard.

[2] The annual energy use for the display case includes the energy from the supermarket compressors and condensers necessary to cool the display case. This energy is also partially calculated in the commercial compressor rack and condenser annual energy consumption values.

[3] Maintenance cost includes preventative maintenance costs such as cleaning evaporator coils, drain pans, fans, and intake screens as well as lamp replacements and other lighting maintenance activities.

Commercial Supermarket Display Cases

- DOE set Federal energy efficiency standards for Commercial Refrigeration Equipment (CRE). These standards set maximum daily energy consumption levels, in kWh/day, for display cases manufactured and/or sold in the United States on or after January 1, 2012. The daily energy consumption is based on the total display area of the display case (TDA).
  - Vertical, open, medium temperature, remote condensing display case (VOP.RC.M) $\leq 0.82*TDA + 4.07$
- The Food Marketing Institute reported the median total supermarket size in 2003 was 44,000 sq. ft., in 2007 it was 47,500 sq. ft., and in 2010, the last year that was reported by the study, it was 46,000 sq. ft. (FMI, 2012)
- The unit used to estimate energy use and installed cost is a vertical, open, medium temperature, remote condensing display case 12 ft. in length with a total display area of 53 sq. ft.
- Commercial central refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks.
- Approximately 20 percent of the total annual electricity consumption for a typical supermarket is directly attributable to display cases (this does not include the energy consumed by compressors and condensers necessary to cool the display cases). (NCI, 2009)
- As part of DOE's on-going CRE rulemaking, DOE estimates 177,000 display cases were shipped in 2005. Of those display cases 38,743 were vertical, open, medium temperature, remote condensing display cases (VOP.RC.M), which represented the most common type of remote condensing display case shipped in 2005.
- A typical commercial supermarket display case contains T8 electronic lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- The energy use decreases in the advanced case due to the use of more efficient technologies including improved evaporator coils, larger evaporators, higher efficiency evaporator fan blades, high efficiency doors, LED lighting, thicker insulation, and improved insulation.
- Assuming the use of more efficient technologies, the energy use will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Compressor Rack Systems

Assumes increased rate of technology advancement (lower energy use and power input)

DATA	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)[1]	1,050	1,077	1,077	1,077	1,077	1,077	1,077	1,077	1,077	1,077
Power Input (kW)	180	184	162	146	159	143	156	140	152	137
Energy Use (MWh/yr)	1,000	1,023	900	810	882	794	864	778	846	761
Average Life (yrs)	20	15	15	15	15	15	15	15	15	15
Total Installed Cost ($1000)[2]	$630	$630	$630	$693	$630	$693	$630	$693	$630	$693
Annual Maintenance Cost ($1000)[3]	$33	$33	$33	$33	$33	$33	$33	$33	$33	$33

[1] The total capacity represents the capacity required for the entire refrigeration system of a typical supermarket. This usually includes two low temperature racks and two medium temperature racks. For 2007 and beyond a 1,077 MBtu/hr total cooling capacity is the sum of 769 MBtu/hr for the medium temperature racks and 308 MBtu/hr for the low temperature racks.

[2] The total installed cost is based on the entire supermarket compressor rack system (two medium temperature racks and two low temperature racks). The equipment purchase price and the installation cost of a typical rack is approximately $208,130 and $20,813 per rack respectively. Therefore the total installed cost for a typical supermarket compressor rack system is approximately $913,691.

[3] Maintenance cost includes oil changes, bearing lubrication, filter replacement, and system functionality checks.

Commercial Compressor Rack Systems

- Commercial compressor rack systems that serve commercial supermarket display cases and walk-ins consist of a number of parallel-connected compressors located in a separate machine room. By modulating compressor capacity, these integrated systems provide higher efficiency and mechanical longevity.
- Rack integrators generally supply a packaged compressor rack for which much of the necessary piping, insulation, components, and controls are pre-assembled.
- A typical supermarket will have 10 to 20 compressors mounted in racks in the 3-hp to 15-hp size range. Usually there are 3 to 5 compressors per rack serving a series of loads with nearly identical evaporator temperature.
- The duty cycle for compressors is usually in the range 60% to 70%.
- The typical supermarket uses a reciprocating compressor system that has two medium temperature compressor racks with an overall capacity of 769 MBtu/hr and two low temperature compressor racks with an overall capacity of 308 MBtu/hr. (NCI, 2009)
- Approximately 34 percent of the total annual electricity consumption for a typical supermarket is attributable to compressors. (NCI, 2009)
- There are an estimated 140,000 compressor rack systems installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- The energy use and power input decreases in the advanced case due to the use of more efficient technologies including higher efficiency compressors, improved compressor configurations, and improved controls.
- Assuming the use of more efficient technologies, the energy use and power input will decrease by 2% in 2020, 4% in 2030, and 6% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Condensers

Assumes increased rate of technology advancement (lower energy use and power input)

DATA	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)[1]	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520
Power Input (kW)	25	25	22	20	21	19	20	18	19	17
Energy Use (MWh/yr)	138	138	120	108	114	103	108	97	102	92
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10
Total Installed Cost ($1000)	$47	$54	$54	$60	$54	$60	$54	$60	$54	$60
Annual Maintenance Cost[2]	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090

[1] Total capacity is the total heat rejected (THR) of condensers comprised of two low temperature condensers (THR_L = 240 MBtu/hr each, suction temperature = -25°F, condensing temperature 110 F) and two medium temperature (THR_M = 520 MBtu/hr each, suction temperature = 15°F, condensing temperature = 115°F) condensers; ambient temperature = 95°F. (NCI, 2009)

[2] Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks.

Commercial Condensers

- Condensers are designed with multiple methods of cooling: air-cooled, water-cooled, and evaporative. These units can be single-circuit or a multiple circuit.
- Commercial condensers are remotely located, typically installed on the roof of a supermarket.
- For use with parallel compressors in supermarkets, air-cooled units are the most commonly used condensers. This analysis is based on multiple air-cooled condensers connected to a supermarket refrigeration system comprised of two low temperature condensers and two medium temperature condensers, using R-404A refrigerant.
- Each compressor rack has a dedicated condenser or a separate circuit of a single common condenser. Condenser temperatures of multiple racks are often different.
- The duty cycle for condensers is usually in the range 50 - 70%.
- Approximately 5 percent of the total annual electricity consumption for a typical supermarket is attributable to condensers. (NCI, 2009)
- There are an estimated 140,000 condensers installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- The energy use and power input decreases in the advanced case due to the use of more efficient fan motors.
- Assuming the use of more efficient technologies, the energy use and power input will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Walk-In Refrigerators

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011[1]			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	44,970	44,970	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Size (ft^2)[2]	240	240	96	96	96	96	96	96	96	96	96
Energy Use (kWh/yr)	42,300	42,182	12,337	6,329	4,822	6,013	4,581	5,696	4,339	5,380	4,098
Insulated Box Average Life (yrs)	18	18	15	15	15	15	15	15	15	15	15
Compressor Average Life (yrs)	10	10	11	11	11	11	11	11	11	11	11
Retail Equipment Cost	$19,252	$33,821	$13,026	$15,087	$18,821	$15,087	$18,821	$15,087	$18,821	$15,087	$18,821
Total Installed Cost[3]	$23,415	$38,712	$14,080	$16,141	$19,875	$16,141	$19,875	$16,141	$19,875	$16,141	$19,875
Annual Maintenance Cost[4]	$817 - $1,090	$817 - $1,090	$2,755	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970

[1] EISA 2007 includes prescriptive standards for walk-in refrigerators that went into effect in 2009. All units for 2011 and beyond include these prescriptive standards.

[2] The size for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which states the typical footprint of a walk-in refrigerator is 240 sq. ft. The size for 2011 and beyond is based on the NOPR analysis shipment data from DOE's on-going Walk-In rulemaking which states the typical footprint of a walk-in refrigerator is 96 sq. ft.

[3] Installation cost for 2003 and 2007 are based on ADL, 1996 & NCI, 2009 reports which assume a cost of $4,163 and $4,891 respectively. Installation cost for 2011 and beyond is based on DOE's on-going Walk-In rulemaking which assumes installation cost scales based on the cooling capacity (which for a cooling capacity of 18,000 Btu/hr is $1,054).

[4] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

Commercial Walk-In Refrigerators

- The commercial walk-in refrigerator characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going Walk-In rulemaking, is a small non-display cooler with a footprint of 96 sq. ft. and includes a floor and a single door. The typical size of 240 sq. ft. was used for 2003 and 2007 because that was the typical size reported in the ADL, 1996 and NCI, 2009 reports respectively.
- A typical walk-in refrigerator includes: insulated floor and wall panels, merchandising doors, shelving, lighting (not included in cost estimate), semi-hermetic reciprocating compressor, refrigerant (R404A), condenser, and evaporator.
- The high efficiency unit is based on the energy savings potential and cost premiums of several advanced refrigeration technologies identified in the preliminary analysis of DOE's ongoing Walk-In rulemaking. These include:
  - ECM (electronically commutated motor) evaporator and condenser fan motors
  - floating heat pressure
  - ambient sub-cooling
  - evaporator fan shutdown
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- DOE is currently working on a Federal energy consumption standard for commercial walk-in refrigerators. The estimated effective date is 2016.
- As part of DOE's on-going Walk-In rulemaking, DOE estimates 85,333 walk-in coolers will be shipped in 2015. Of those walk-in coolers, 41,403 will be small non-display coolers, which represents the most common type of walk-in cooler estimated to ship in 2015.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Walk-In Refrigerators

- The Energy Independence and Security Act (EISA) of 2007 included prescriptive standards for walk-in refrigerators (coolers) that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in refrigerators manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–25, except for glazed portions of doors and structural members
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in refrigerator is not occupied by people.

Commercial Walk-In Freezers

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011[1]			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,929	4,929	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
Size (ft^2)[2]	80	80	64	64	64	64	64	64	64	64	64
Energy Use (kWh/yr)	15,600	15,524	28,455	13,844	12,319	13,637	12,134	13,429	11,949	13,152	11,703
Insulated Box Average Life (yrs)	18	18	15	15	15	15	15	15	15	15	15
Compressor Average Life (yrs)	10	10	11	11	11	11	11	11	11	11	11
Retail Equipment Cost	$7,597	$13,008	$12,068	$14,070	$20,637	$14,070	$20,637	$14,070	$20,637	$14,070	$20,637
Total Installed Cost[3]	$8,637	$14,049	$12,920	$14,921	$21,489	$14,921	$21,489	$14,921	$21,489	$14,921	$21,489
Annual Maintenance Cost[4]	$545	$545	$2,755	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970

[1] EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2011 and beyond include these prescriptive standards.

[2] The size for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which states the typical footprint of a walk-in freezer is 80 sq. ft. The size for 2011 and beyond is based on the NOPR analysis shipment data from DOE's on-going Walk-In rulemaking which states the typical footprint of a walk-in freezer is 64 sq. ft.

[3] Installation cost for 2003 and 2007 are based on ADL, 1996 & NCI, 2009 reports which assume a cost of $1,040. Installation cost for 2011 and beyond is based on DOE's on-going Walk-In rulemaking which assumes installation cost scales based on the cooling capacity (which for a cooling capacity of 9,000 Btu/hr is $852).

[4] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

Commercial Walk-In Freezers

- The commercial walk-in freezer characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going Walk-In rulemaking, is a small non-display freezer with a footprint of 64 sq. ft. and includes a floor and a single door. The typical size of 80 sq. ft. was used for 2003 and 2007 because that was the typical size reported in the ADL, 1996 and NCI, 2009 reports respectively.
- A typical walk-in freezer includes: insulated floor, door, and wall panels, semi-hermetic reciprocating compressor, refrigerant (R404A), condenser, and evaporator.
- The high efficiency unit is based on the energy savings potential and cost premiums of several advanced refrigeration technologies determined by the preliminary analysis from DOE's ongoing Walk-In standard rulemaking. These include:
  - ECM (electronically commutated motor) evaporator and condenser fan motors
  - external heat rejection
  - hot gas defrost
  - evaporator fan shutdown
- DOE is currently working on a Federal energy consumption standard for commercial walk-in freezers. The estimated effective date is 2016.
- As part of DOE's on-going Walk-In rulemaking, DOE estimates 34,985 walk-in freezers will be shipped in 2015. Of those walk-in freezers, 17,291 will be small non-display freezers, which represents the most common type of walk-in freezers estimated to ship in 2015.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, defrost, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 1.5% in 2020, 3% in 2030, and 5% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Walk-In Freezers

- EISA 2007 included prescriptive standards for walk-in freezers that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in freezers manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–32, except for glazed portions of doors and structural members
  - contain floor insulation of at least R–28
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in freezer is not occupied by people.

Commercial Reach-In Refrigerators

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	3,000	2,700	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Size (ft^3)	48	48	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	3,800	2,477	2,533	1,598	993	1,439	894	1,359	844	1,279	794
Energy Use (kWh/yr/ft^3)	79	52	52	33	20	29	18	28	17	26	16
Average Life (yrs)	8	9	15	15	15	15	15	15	15	15	15
Retail Equipment Cost	$2,810	$2,988	$3,131	$3,146	$3,191	$3,146	$3,191	$3,146	$3,191	$3,146	$3,191
Total Installed Cost[3]	$2,966	$3,144	$3,948	$3,963	$4,008	$3,963	$4,008	$3,963	$4,008	$3,963	$4,008
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.

[2] ENERGY STAR® set energy consumption levels for solid door commercial refrigerators, including reach-in refrigerators, that went into effect in 2010. The 2011 Typical values are based on this energy consumption level.

[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2011 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $817.

[4] Maintenance is only performed if there is a problem with the equipment.

Commercial Reach-In Refrigerators

- The Energy Policy Act of 2005 (EPACT 2005) set maximum daily energy consumption levels, in kWh/day, for commercial reach-in refrigerators that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
  - Refrigerators with solid doors ≤ 0.10*V + 2.04
  - Refrigerators with transparent doors ≤ 0.12*V + 3.34
- Energy Star® also set maximum daily energy consumption levels, in KWh/day, for commercial reach-in refrigerators that went into effect on April 1, 2009 for glass and mixed door models and on January 1, 2010 for solid door models. These efficiency levels are also based on the volume of the unit (V).

Reach-In Refrigerator Size	**0 < V < 15**	**15 ≤ V < 30**	**30 ≤ V < 50**	**50 ≤ V**
Solid Door	≤ 0.089*V + 1.411	≤ 0.037*V + 2.200	≤ 0.056*V + 1.635	≤ 0.060*V + 1.416
Glass Door	≤ 0.118*V + 1.382	≤ 0.140*V + 1.050	≤ 0.088*V + 2.625	≤ 0.110*V + 1.500

- The commercial reach-in refrigerator characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 49 cubic ft. solid two-door unit with a cooling capacity of 1,000 Btu/hr. The typical size of 48 cubic ft. solid two-door unit with a cooling capacity of 3,000 Btu/hr and 2,700 Btu/hr was used for 2003 and 2007 because that was the typical size and capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- Annual shipments of reach-in refrigerators in the U.S. in 2008 are estimated to be 263,000 with an estimated installed base of 1,556,000. (NCI, 2009)
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls..
- Assuming the use of more efficient technologies, the energy use will decrease by 10% in 2020, 15% in 2030, and 20% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Reach-In Freezers

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	2,200	2,200	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Size (ft^3)	24	24	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	4,600	3,960	7,658	5,151	3,037	4,636	2,733	4,378	2,581	4,121	2,429
Energy Use (kWh/yr/ft^3)	192	165	156	105	62	95	56	89	53	84	50
Average Life (yrs)	8	9	15	15	15	15	15	15	15	15	15
Retail Equipment Cost	$2,498	$2,905	$3,277	$3,290	$3,353	$3,290	$3,353	$3,290	$3,353	$3,290	$3,353
Total Installed Cost[3]	$2,654	$3,061	$4,093	$4,107	$4,170	$4,107	$4,170	$4,107	$4,170	$4,107	$4,170
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.
[2] ENERGY STAR® set energy consumption levels for solid door commercial freezers, including reach-in freezers, that went into effect in 2010. The 2011 Typical values are based on this energy consumption level.
[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2011 and beyond is based on DOE’s on-going CRE rulemaking which assumes a cost of $816.
[4] Maintenance is only performed if there is a problem with the equipment.

Commercial Reach-In Freezers

- EPACT 2005 set maximum daily energy consumption levels, in kWh/day, for commercial reach-in freezers that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
  - Freezers with solid doors ≤ 0.40*V + 1.38
  - Freezers with transparent doors ≤ 0.75*V + 4.10
- Energy Star® also set maximum daily energy consumption levels, in KWh/day, for commercial reach-in freezers that went into effect on April 1, 2009 for glass and mixed door models and on January 1, 2010 for solid door models. These efficiency levels are also based on the volume of the unit (V).

Reach-In Freezer Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door	≤ 0.250*V + 1.250	≤ 0.400*V - 1.000	≤ 0.163*V + 6.125	≤ 0.158*V + 6.333
Glass Door	≤ 0.607*V + 0.893	≤ 0.733*V – 1.000	≤ 0.250*V + 13.500	≤ 0.450*V + 3.500

- The commercial reach-in freezer characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 49 cubic ft. solid two-door unit with a cooling capacity of 1,800 Btu/hr. The typical size of 24 cubit ft. solid one-door unit with a cooling capacity of 2,200 Btu/hr was used for 2003 and 2007 because that was the typical size and capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- Annual shipments of reach-in freezers in the U.S. in 2008 are estimated to be 52,000 with an estimated installed base of 1,156,000. (NCI, 2009)
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, defrost, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 10% in 2020, 15% in 2030, and 20% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Ice Machines

Assumes increased rate of technology advancement (lower energy use and water use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Output (lbs/day)[3]	500	500	300	300	300	300	300	300	300	300	300
Water Use (gal/100 lbs)	24.0	27.5	22.0	19.8	17.6	19.6	17.4	19.4	17.3	19.2	17.2
Energy Use (kWh/100 lbs)	7.0	5.5	7.7	6.9	6.1	6.7	6.0	6.6	5.8	6.4	5.7
Energy Use (kWh/yr)[4]	6,388	5,019	4,249	3,833	3,408	3,719	3,307	3,643	3,239	3,529	3,139
Average Life (yrs)	8.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Retail Equipment Cost	$2,289	$3,954	$4,059	$4,077	$4,152	$4,077	$4,152	$4,077	$4,152	$4,077	$4,152
Total Installed Cost (with Bin)[5]	$2,498	$4,475	$4,431	$4,449	$4,524	$4,449	$4,524	$4,449	$4,524	$4,449	$4,524
Annual Maintenance Cost[6]	$218 - $327	$218 - $327	$110	$110	$110	$110	$110	$110	$110	$110	$110

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.

[2] ENERGY STAR® set energy consumption levels for ice makers that went into effect in 2008. The 2011 Typical values are based on this energy consumption level.

[3] The output for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which states the typical ice output is 500 lbs/day. The output for 2011 and beyond is based on the preliminary analysis shipment data from DOE's on-going Automatic Ice Maker rulemaking which states the typical ice output is 300 lbs/day.

[4] The annual energy use is based on assuming 4,380 hours per year of use, which is a utilization rate of 50%.

[5] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $209 and $521 respectively. Installation cost for 2011 and beyond is based on DOE's on-going Automatic Ice Maker rulemaking which assumes a cost of $372.

[5] Maintenance cost includes cleaning and maintaining refrigerant levels, replacing filters, checking water distribution lines for leaks, cleaning, sanitizing, and descaling the bin and water system. Maintenance cost decreases as the size of the ice machine (i.e. output) decreases.

Commercial Ice Machines

- The commercial ice machine characterized in this report from 2011 and beyond is an air-cooled, ice maker head unit with an approximate output of 300 lbs/day. Commercial ice machines are typically integrated with an insulated ice storage bin or mounted on top of a separate storage bin. The retail equipment cost includes the ice making head and the integrated storage bin.
- Commercial ice machine condensers are either air-cooled or water-cooled. Approximately 90% of all units are the air-cooled type.
- ENERGY STAR® set maximum energy consumption levels, in KWh/100 lbs ice, for air cooled ice machines that went into effect on January 1, 2008. These efficiency levels are based on the harvest rate, in lbs/24 hrs. (H).

Equipment Type	Harvest Rate	Energy Use	Potable Water Use Limit
Ice Maker Head	< 450	9.23 – 0.0077*H	≤ 25
	≥ 450	6.20 – 0.0010*H	≤ 25

- Commercial ice machine maintenance includes periodic cleaning (every 2 to 6 weeks) to remove lime and scale, and sanitizing to kill bacteria. Some ice machines are self-cleaning/sanitizing.
- As part of DOE's on-going Automatic Ice Makers rulemaking, DOE estimates 263,552 ice machines will be shipped in 2016. Of those ice-machines 71,357 will be air cooled, ice making head units with a harvest capacity rate between 50 lbs/24 hr. and 450 lbs/24 hrs., which represents the most common type of ice maker estimated to ship in 2016.
- The energy use and water use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, evaporators, condensers, compressors, insulation, water circulation pumps, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 3% in 2020, 5% in 2030, and 8% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Ice Machines: EPACT 2005

- EPACT 2005 issued standard levels for commercial ice machines with capacities between 50 and 2500 pounds per 24-hour period that are manufactured and/or sold in the United States on or after January 1, 2010. The energy consumption is based on the harvest rate in pounds per 24 hours (H).

Equipment Type	Type of Cooling	Harvest Rate (lbs ice/24 hrs)	Maximum Energy Use (kWh/100 lbs ice)	Maximum Condenser Water Use (gal/100 lbs ice)
Ice Making Head	Water	<500	7.80-0.0055 H	200-0.022 H
		≥500 and <1436	5.58-0.0011 H	200-0.022 H
		≥1436	4.0	200-0.022 H
	Air	<450	10.26-0.0086 H	Not Applicable
		≥450	6.89-0.0011 H	Not Applicable
Remote Condensing (but not remote compressor)	Air	<1000	8.85-0.0038 H	Not Applicable
		≥1000	5.10	Not Applicable
Remote Condensing and Remote Compressor	Air	<934	8.85-0.0038 H	Not Applicable
		≥934	5.3	Not Applicable
Self Contained	Water	<200	11.40-0.019 H	191-0.0315 H
		≥200	7.60	191-0.0315 H
	Air	<175	18.0-0.0469 H	Not Applicable
		≥175	9.80	Not Applicable

Water use is for the condenser only and does not include potable water used to make ice.

Commercial Beverage Merchandisers

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	1,200	2,500	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27
Energy Use (kWh/yr)	3,900	2,527	2,523	1,763	996	1,587	897	1,499	847	1,410	797
Average Life (yrs)	8.0	8.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Retail Equipment Cost	$1,457	$2,706	$2,662	$2,810	$2,935	$2,810	$2,935	$2,810	$2,935	$2,810	$2,935
Total Installed Cost[3]	$1,613	$2,862	$3,479	$3,626	$3,752	$3,626	$3,752	$3,626	$3,752	$3,626	$3,752
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

[1] EPACT 2005 energy standards went into effect in 2010. The 2011 Low values are based on this standard.
[2] ENERGY STAR® set energy consumption levels for glass door beverage merchandisers that went into effect in 2009. The 2011 Typical values are based on this energy consumption level.
[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2011 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $817.
[4] Maintenance is only performed if there is a problem with the equipment.

Commercial Beverage Merchandisers

- EPACT 2005 sets maximum daily energy consumption levels, in kWh/day, for commercial refrigerators with a self-contained condensing unit designed for pull-down temperature applications and transparent doors (i.e., beverage merchandisers) that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
  - Beverage merchandisers with transparent doors $\leq 0.126*V + 3.51$
- Energy Star® also set maximum daily energy consumption levels, in KWh/day, for beverage merchandisers that went into effect on April 1, 2009 for glass and mixed door models. These efficiency levels are also based on the volume of the unit (V).

Beverage Merchandiser Size	$0 < V < 15$	$15 \leq V < 30$	$30 \leq V < 50$	$50 \leq V$
Glass Door	$\leq 0.118*V + 1.382$	$\leq 0.140*V + 1.050$	$\leq 0.088*V + 2.625$	$\leq 0.110*V + 1.500$

- The beverage merchandiser characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a cooling capacity of 2,100 Btu/hr. A similar beverage merchandiser with a cooling capacity of 1,200 Btu/hr and 2,500 Btu/hr was used for 2003 and 2007 because that was the typical capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- Beverage merchandisers have an estimated installed base of 920,000 units in 2008. Of those beverage merchandisers 460,000 are one-door units, which represents the most common type of beverage merchandiser.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 10% in 2020, 15% in 2030, and 20% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Refrigerated Vending Machines

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical[1]	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	700	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Can Capacity	500	650	650	650	650	650	650	650	650	650	650
Energy Use (kWh/yr)[2]	3,000	2,913	2,383	2,029	1,821	1,653	1,487	1,566	1,409	1,479	1,331
Average Life (yrs)	14	14	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$1,769	$1,907	$1,742	$2,046	$2,096	$2,137	$2,632	$2,137	$2,632	$2,137	$2,632
Total Installed Cost[3]	$1,844	$2,011	$1,826	$2,130	$2,180	$2,221	$2,716	$2,221	$2,716	$2,221	$2,716
Annual Maintenance Cost[4]	$180	$177	$159	$159	$159	$159	$159	$159	$159	$159	$159

[1] DOE's Federal energy standards for Refrigerated Beverage Vending Machines will go into effect on August 31, 2012. The 2020 Typical values are based on this standard.
[2] Energy use is based on a zone-cooled machine tested in 75°F steady state ambient conditions.
[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $75 and $104 respectively. Installation cost for 2011 and beyond is based on DOE's Refrigerated Beverage Vending Machine rulemaking which assumes a cost of $84.
[4] Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils and also includes an annualized cost for refurbishments/remanufacturing.

Commercial Refrigerated Vending Machines

- DOE set Federal energy efficiency standards for refrigerated vending machines. These standards set maximum daily energy consumption levels, in kWh/day, for commercial refrigerated vending machines manufactured and/or sold in the United States on or after August 31, 2012. The daily energy consumption is based on the volume of the unit (V).
  - Refrigerated Vending Machines that are fully-cooled (Type A) $\leq 0.055*V + 2.56$
  - Refrigerated Vending Machines that are zone-cooled (Type B) $\leq 0.073*V + 3.16$

- Energy Star® also set maximum daily energy consumption efficiency levels, also in KWh/day, for refrigerated vending machines that went into effect on July 1, 2007. These efficiency levels are based on vendible capacity (C).
  - Refrigerated Vending Machines $\leq 0.45*(8.66 + 0.009*C)$

- The annual maintenance cost is consists of preventive maintenance including checking and maintaining refrigerant charge levels, cleaning heat exchanger coils, and replacement of lighting and the annualized value of a single refurbishment at approximately the mid-point of the machine's useful life. The preventative annual maintenance cost is approximately $98 and the annualize value of a one-time refurbishment cost of $599 over the lifetime of the machine is $61. Therefore, the annual maintenance cost is $159 for refrigerated vending machines.
- As part of DOE's Refrigerated Beverage Vending Machine rulemaking, DOE estimates 190,200 refrigerated vending machines will be shipped in 2012. Of those refrigerated vending machines 63,700 will be zone-cooled, medium size units, which represents the most common type of refrigerated vending machine estimated to ship in 2012.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Constant Air Volume Ventilation

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Survey Base	Survey Base	Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	11.75	11.55	10.82	10.28	9.20	9.74	8.66	9.20	8.12	8.66	7.57
Specific Fan Power (W/CFM)	0.783	0.770	0.721	0.685	0.613	0.649	0.577	0.613	0.541	0.577	0.505
Annual Fan Energy Use (kWh/yr)[1]	44,631	43,890	41,120	39,064	34,952	37,008	32,896	34,952	30,840	32,896	28,784
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Total Installed Cost ($)[2]	$73,500	$73,500	$73,500	$73,500	$80,000	$73,500	$80,000	$73,500	$80,000	$73,500	$80,000
Annual Maintenance Cost ($)	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500

[1] Based on 3800 effective full load hours per year (operating 3800 hours per year at constant load) (ADL, 1999).
[2] Total installed cost of 15,000 CFM CAV AHU and hypothetical supply ductwork layout.
[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

Commercial Constant Air Volume Ventilation

- Constant air volume (CAV) ventilation systems are common, inexpensive, and straightforward air-side HVAC systems. These systems provide a constant flow rate of air (typically a mix of recirculated and outside air) and adjust the supply temperature of that air in order to maintain space temperature setpoint. These systems are most applicable to single zone applications in order to ensure adequate temperature control. Many existing buildings utilize CAV systems that serve multiple zones where individual zone space temperatures are maintained by reheating air delivered to that zone after it is cooled by the central cooling coil; this is prohibited by most current energy codes. New building CAV systems are common for single zone applications. This analysis examines only the fan energy of the CAV system.
- The unit characterized in this report is a 15,000 CFM CAV system. The average commercial building is approximately 15,000 square feet (CBECS 2003 and BED 2007). Assuming 1 CFM is needed per square foot of floor area results in a 15,000 CFM air handling unit.
- A 15,000 CFM CAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $56,500 (RS Means 2012). Ductwork would cost approximately $17,000 additional ($73,500 total).
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP) for CAV systems. The 2007 version of Standard 90.1 was used to represent the 2011 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor efficiency.

Commercial Variable Air Volume Ventilation

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Survey Base	Survey Base	Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	16.35	15.00	14.76	14.03	12.55	13.29	11.81	12.55	11.07	11.81	10.33
Specific Fan Power (W/CFM)	1.090	1.000	0.984	0.935	0.837	0.886	0.787	0.837	0.738	0.787	0.689
Annual Fan Energy Use (kWh/yr)[1]	14,502	13,305	13,096	12,441	11,131	11,786	10,477	11,131	9,822	10,477	9,167
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Total Installed Cost ($)[2]	$91,000	$91,000	$91,000	$91,000	$100,000	$91,000	$100,000	$91,000	$100,000	$91,000	$100,000
Annual Maintenance Cost ($)	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500

[1]Based on 887 effective full load hours (power-based) per year (operating 3800 hours per year at variable load).
[2]Total installed cost of 15,000 CFM VAV AHU, VFD, (10) VAV boxes, and hypothetical supply ductwork layout.
[3]Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

Commercial Variable Air Volume Ventilation

- Variable air volume (VAV) ventilation systems are the most common multi-zone system type specified today for conditioning commercial buildings. These systems provide conditioned air to multiple zone terminal units (VAV boxes) that use dampers to modulate the amount of cool air to each zone. An individual zone thermostat controls the VAV box damper to allow more or less cooling. If a zone requires heating then the VAV box provides the minimum flow rate and typically includes a reheat coil to meet space temperature setpoint. As VAV box dampers close in the system, a variable frequency drive reduces fan speed and flow continuously to meet current requirements.
- This analysis examines only the fan energy of the VAV system. VAV systems vary fan speeds between about 30-100% speed (and flow); most hours of operation being much lower than full speed. Since fan power varies with the cube of fan speed according to fan affinity laws, SAIC estimated the fan-power equivalent full load hours (EFLH) of 887 hours given an annual runtime of 3800 hours and a typical VAV operating profile. The unit characterized in this report is a 15,000 CFM VAV system.
- A 15,000 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $59,000 (RS Means 2012). Ductwork, (10) VAV boxes with reheat, and a VFD would cost approximately $32,000 additional ($91,000 total).
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power for VAV systems (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2011 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor VFD efficiency.

Commercial Fan Coil Unit

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Survey Base	Survey Base	Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	800	800	800	800	800	800	800	800	800	800	800
System Fan Power (W)	315	304	875	241	148	232	143	223	136	215	130
Specific Fan Power (W/CFM)	0.394	0.380	1.094	0.302	0.185	0.290	0.178	0.279	0.171	0.268	0.163
Annual Fan Energy Use (kWh/yr)[1]	709	684	1,969	543	333	522	321	502	307	483	293
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Total Installed Cost ($)[2]	$2,400	$2,400	$2,400	$2,400	$2,600	$2,400	$2,600	$2,400	$2,600	$2,400	$2,600
Annual Maintenance Cost ($)	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100	$50-100

[1] Based on 2250 effective full load hours per year (operating 2250 hours per year at constant load) (ADL, 1999).
[2] Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.
[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

Commercial Fan Coil Unit

- Commercial fan coil units (FCUs) are self-contained, mass-produced assemblies that provide cooling, heating, or cooling and heating, but do not include the source of cooling or heating. The unit characterized in this report is a cooling only (2-pipe), horizontal unit with housing and controls. Fan coil units are typically installed in or adjacent to the space being served and have no (or very limited) ductwork.
- Four-pipe units have separate circuits for heating and cooling. Two-pipe units with electric heat are a low-cost alternative to four-pipe units but may use more energy.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons.
- Fan coil unit fan motors can be shaded pole, a single phase AC motor with offset start winding and no capacitor; PSC, a single phase AC motor with offset start winding with capacitor; or ECM, an AC electronically commutated permanent magnet DC motor. PSC motors are currently the most common motor type in FCUs, but most manufacturers offer ECM as an option. This analysis examines only the fan energy of the CAV system.
- Fan coil units have higher maintenance costs than central air systems due to the distributed nature of the system. For each unit the filters must be changed and drain systems must be flushed periodically.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2011 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type configuration, filter and coil pressure drops, and motor efficiency.

Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

Data Sources » Residential General Service Incandescent Lamps (60 Watts)

DATA SOURCES	2005	2009	2011			2014*		2020**	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	60W	60W	60W	60W	60W	60W	60W	60W	60W
Lamp Wattage	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Lumens									
Lamp Efficacy (lm/W)			Calculated						
Lamp Price			Distributor Websites						
Lamp Cost ($/klm)			Calculated						
Average Lamp Life (1000 hrs)			Product Catalogs						
CRI									

Data Sources » Residential General Service Incandescent Lamps (75 Watts)

DATA SOURCES	2005	2009	2011			2013*		2020**	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	75W	75W	75W	75W	75W	75W	75W	75W	75W
Lamp Wattage	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Lumens									
Lamp Efficacy (lm/W)			Calculated						
Lamp Price			Distributor Websites						
Lamp Cost ($/klm)			Calculated						
Average Lamp Life (1000 hrs)			Product Catalogs						
CRI									

DATA SOURCES	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	2008 EIA Reference Case				Product Catalogs		
Lamp Lumens							
Lamp Efficacy (lm/W)					Calculated		
Lamp Price					Distributor Websites		
Lamp Cost ($/klm)					Calculated		
Average Lamp Life (1000 hrs)					Product Catalogs		
CRI							

DATA SOURCES	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	NCI, 2012								
Lamp Lumens									
Lamp Efficacy (lm/W)									
Lamp Price									
Lamp Cost ($/klm)									
Average Lamp Life (1000 hrs)									
CRI									

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th>2009</th><th colspan="4">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Energy Star</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th><th>13W</th></tr>
<tr><td>Lamp Wattage</td><td colspan="2" rowspan="7">2008 EIA Reference Case</td><td rowspan="2">Product Catalogs</td><td colspan="3" rowspan="2">Product Catalogs</td><td colspan="6" rowspan="7">NCI, 2012</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>Calculated</td><td colspan="3">Calculated</td></tr>
<tr><td>Lamp Price</td><td rowspan="2"></td><td colspan="3">Distributor Websites</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td rowspan="2">Product Catalogs</td><td colspan="3" rowspan="2">Product Catalogs</td></tr>
<tr><td>CRI</td></tr>
</table>

Data Sources » Residential Linear Fluorescent Lamps (T12 and T8)

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th colspan="2">2009</th><th colspan="6">2011</th></tr>
<tr><th colspan="3">Installed Base</th><th>Current Standard</th><th>Mid-Level T12</th><th>High T12</th><th>Baseline T8</th><th>Mid-Level T8</th><th>High T8</th></tr>
<tr><th>32WT8</th><th>40WT12</th><th>32WT8</th><th>40WT12</th><th>40WT12</th><th>34WT12</th><th>32WT8</th><th>32WT8</th><th>28WT8</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="12">2008 EIA Reference Case</td><td colspan="8" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>System Wattage</td><td colspan="8" rowspan="4">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Price ($)</td><td colspan="8">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>Ballast Price ($)</td><td colspan="8">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="8">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="8" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="8">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
</table>

DATA SOURCES	2020		2030		2040	
	Typical T8	High T8	Typical T8	High T8	Typical T8	High T8
	32WT8	28WT8	32WT8	28WT8	32WT8	28WT8
Lamp Wattage	NCI, 2012					
Lamp Lumens						
System Wattage						
System Lumens						
Lamp Efficacy (lm/W)						
System Efficacy (lm/W)						
Lamp Price ($)						
Ballast Price ($)						
Lamp Cost ($/klm)						
Average Lamp Life (1000 hrs)						
CRI						
Ballast Efficiency (BLE)						

Data Sources » Residential Linear Fluorescent Lamps (T5)

DATA SOURCES	2005	2009	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
Lamp Wattage	DOE GSFL and IRL Energy Conservation Standard, 2009				NCI, 2012					
Lamp Lumens										
System Wattage	Calculated									
System Lumens										
Lamp Efficacy (lm/W)										
System Efficacy (lm/W)										
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009									
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011									
Lamp Cost ($/klm)	Calculated									
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009									
CRI										
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011									

DATA SOURCES	2005	2009			2011		
	Installed Base				Typical	Typical	Typical
	Typical	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	2008 EIA Reference Case				Product Catalogs		
Lamp Lumens							
Lamp Efficacy (lm/W)					Calculated		
Lamp Price					Distributor Websites		
Lamp Cost ($/klm)					Calculated		
Average Lamp Life (1000 hrs)					Product Catalogs		
CRI							

DATA SOURCES	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	NCI, 2012								
Lamp Lumens									
Lamp Efficacy (lm/W)									
Lamp Price									
Lamp Cost ($/klm)									
Average Lamp Life (1000 hrs)									
CRI									

Data Sources » Residential Solid State Lighting (LED A19 and PAR38 Replacements)

DATA SOURCES	2005	2009	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	LED	LED	LED	LED	LED
Typical Wattage	2008 EIA Reference Case	Calculated				
Lumens		Product Catalogs				
Efficacy (lm/W)		2012 SSL MYPP				
Lamp Price ($)		Calculated				
Cost ($/klm)		2012 SSL MYPP			2012 Energy Savings Forecast Model	
Average Life (1000 hrs)		Product Catalogs		2012 Energy Savings Forecast Model		
CRI				NCI, 2012		
CCT						

Data Sources » Commercial General Service Incandescent Lighting

DATA SOURCES	2003	2007	2011			2020	
	Installed Base		Low	Typical	High	Typical	High
	Typical	Typical	Low	Typical	High	72W Inc	72W Inc
System Wattage	2008 EIA Reference Case		Distributor Websites; Calculated			NCI, 2012	
System Lumens							
Lamp Efficacy (lm/W)			Distributor Websites; Calculated				
System Efficacy (lm/W)							
Lamp Cost ($/klm)							
System Cost ($/klm)							
Average Lamp Life (1000 hrs)			Distributor Websites				
CRI							
Total Installed Cost ($)			Distributor Websites; NCI 2012; RSMeans 2007; Calculated				
Annual Maintenance Cost ($)							

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
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<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">Distributor Websites; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
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<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">Distributor Websites; NCI 2012; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial Halogen Lighting (PAR 38)

<table>
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<tr><th colspan="4">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th><th>90W Halogen</th><th>70W HIR</th></tr>
<tr><td>System Wattage</td><td rowspan="10" colspan="4">2008 EIA Reference Case</td><td rowspan="2" colspan="2">Distributor Websites; Calculated</td><td rowspan="10" colspan="6">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="4" colspan="2">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td rowspan="2" colspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2" colspan="2">NCI 2012; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial Halogen Lighting (Edison)

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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>90W Edison</th><th>90W Halogen</th><th>90W Halogen</th><th>90W Halogen</th><th>90W Halogen</th><th>90W Halogen</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td rowspan="2">Distributor Websites; Calculated</td><td colspan="3" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="4">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td rowspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
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<tr><td>Annual Maintenance Cost ($)</td></tr>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>LED</th><th>BR30 LED</th><th>BR30 LED</th><th>BR30 LED</th><th>BR30 LED</th><th>BR30 LED</th></tr>
<tr><td>Wattage</td><td rowspan="9">2008 EIA Reference Case</td><td colspan="5">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="5">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td colspan="2" rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3" rowspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial 4-ft T8 Linear Fluorescent Lighting

DATA	2003	2007	2011				
	Installed Base		Baseline	High Efficiency	HE w/ Occ. Sensor	HE w/ Spec. Reflector	HE w/ OS & Spec. Ref.
	32WT8	32WT8	32WT8	28WT8	28WT8	28WT8	28WT8
System Wattage	2008 EIA Reference Case	DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated					
System Lumens							
Lamp Efficacy (lm/W)		Calculated					
System Efficacy (lm/W)							
Cost ($/klm)							
Cost ($/klm l/b/f)							
Average Lamp Life (1000 hrs)		DOE GSFL and IRL Energy Conservation Standard, 2009					
CRI							
Total Installed Cost ($)		DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated					
Annual Maintenance Cost ($)							
Ballast Efficiency (BLE)		DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011					

Data Sources » Commercial 4-ft T8 Linear Fluorescent Lighting (Cont.'d)

DATA	2020					2030					2040				
	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max
	32WT8	28WT8	28WT8	28WT8	28WT8	32WT8	F28T8	F28T8	F28T8	F28T8	F32T8	F28T8	F28T8	F28T8	F28T8
System Wattage	NCI, 2012														
System Lumens															
Lamp Efficacy (lm/W)															
System Efficacy (lm/W)															
Cost ($/klm)															
Cost ($/klm l/b/f)															
Average Lamp Life (1000 hrs)															
CRI															
Total Installed Cost ($)															
Annual Maintenance Cost ($)															
Ballast Efficiency (BLE)															

Data Sources » Commercial 4-ft T5 Linear Fluorescent Lighting

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>28WT5</th><th>28WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th></tr>
<tr><td>System Wattage</td><td rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="3">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
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Data Sources » Commercial Solid State Lighting (4-ft Linear Fluorescent Lighting Substitute)

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>LED</th><th>LED 32W T8</th><th>LED 32W T8</th><th>LED 32W T8</th><th>LED 32W T8</th><th>LED 32W T8</th></tr>
<tr><td>Wattage</td><td rowspan="9">2008 EIA Reference Case</td><td colspan="5">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="5">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td colspan="2" rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3" rowspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

DATA SOURCES	2003				2007			
	Installed Base							
	75WT12	60WT12	59WT8	59WT8 HE	75WT12	60WT12	59WT8	55WT8
System Wattage	2008 EIA Reference Case				DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated			
System Lumens								
Lamp Efficacy (lm/W)					Calculated			
System Efficacy (lm/W)								
Cost ($/klm)								
Cost ($/klm l/b/f)								
Average Lamp Life (1000 hrs)					DOE GSFL and IRL Energy Conservation Standard, 2009			
CRI								
Total Installed Cost ($)					DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated			
Annual Maintenance Cost ($)								
Ballast Efficiency (BLE)					DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011			

Data Sources » Commercial 8-ft Linear Fluorescent Lighting (Cont.'d)

DATA SOURCES	2011			2020		2030		2040	
	Magnetic HE	Typical	High Efficiency	Typical	HE	Typical	HE	Typical	HE
	60WT12	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8
System Wattage	DOE Energy Conservation Standards, 2009 and 2011; Product Catalogs; Calculated			NCI, 2012					
System Lumens									
Lamp Efficacy (lm/W)	Calculated								
System Efficacy (lm/W)									
Cost ($/klm)									
Cost ($/klm l/b/f)									
Average Lamp Life (1000 hrs)	DOE Energy Conservation Standards, 2009								
CRI									
Total Installed Cost ($)	DOE Energy Conservation Standards, 2009; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)									

Data Sources » Commercial 8-ft Linear Fluorescent Lighting (High Output)

<table>
<tr><th rowspan="3">DATA SOURCES</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Magnetic HE</th><th>Typical</th><th>High Efficiency</th><th>Typical</th><th>HE</th><th>Typical</th><th>HE</th><th>Typical</th><th>HE</th></tr>
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<tr><td>System Wattage</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td><td colspan="6" rowspan="11">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="3">DOE Ballast Energy Conservation Standard, 2011</td></tr>
</table>

Data Sources » Commercial Low Bay HID Lighting (Metal Halide)

DATA SOURCES	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH
System Wattage	2008 EIA Reference Case		DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Efficacy (lm/W)											
Cost ($/klm)											
Cost ($/klm l/b/f)											
Average Lamp Life (1000 hrs)			DOE Energy Conservation Standards, 2010								
CRI			Product Catalogs								
Total Installed Cost ($)			DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

Data Sources » Commercial Low Bay HID Lighting (High Pressure Sodium)

<table>
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<tr><th colspan="3">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>175W MV</th><th>70W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3">DOE Energy Conservation Standards, 2010</td></tr>
<tr><td>CRI</td><td colspan="3">Product Catalogs</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial Solid State Lighting (Low Bay Applications)

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<tr><td>Typical Wattage</td><td colspan="2" rowspan="9">2008 EIA Reference Case</td><td colspan="4">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="4">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
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<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial High Bay HID Lighting (Metal Halide)

DATA SOURCES	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	250W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH
System Wattage	2008 EIA Reference Case		DOE Energy Conservation Standards, 2010 and 2011; Product Catalogs; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Efficacy (lm/W)											
Cost ($/klm)											
Cost ($/klm l/b/f)											
Average Lamp Life (1000 hrs)			DOE Energy Conservation Standards, 2010 and 2011								
CRI			Product Catalogs								
Total Installed Cost ($)			DOE Energy Conservation Standards, 2010 and 2011; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

Data Sources » Commercial High Bay HID Lighting (High Pressure Sodium)

DATA SOURCES	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS
System Wattage	2008 EIA Reference Case		DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Efficacy (lm/W)											
Cost ($/klm)											
Cost ($/klm l/b/f)											
Average Lamp Life (1000 hrs)			DOE Energy Conservation Standards, 2010								
CRI			Product Catalogs								
Total Installed Cost ($)			DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

Data Sources » Commercial T5 HO Lighting (High Bay Applications)

DATA SOURCES	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	54WT5HO	54WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO
System Wattage	2008 EIA Reference Case	DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated			NCI, 2012					
System Lumens										
Lamp Efficacy (lm/W)		Calculated								
System Efficacy (lm/W)										
Cost ($/klm)										
Cost ($/klm l/b/f)										
Average Lamp Life (1000 hrs)		DOE GSFL and IRL Energy Conservation Standard, 2009								
CRI										
Total Installed Cost ($)		DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)										
Ballast Efficiency (BLE)		DOE Ballast Energy Conservation Standard, 2011								

Data Sources » Commercial Solid State Lighting (High Bay Applications)

<table>
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<tr><th colspan="2">Installed Base</th><th>HPS</th><th>HPS</th><th>HPS</th><th>HPS</th></tr>
<tr><th>LED</th><th>LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th></tr>
<tr><td>Typical Wattage</td><td rowspan="9" colspan="2">2008 EIA Reference Case</td><td colspan="4">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="4">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
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<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td>DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2009 / DOE, 2011 / FMI, 2012 / NCI Analysis 2012</td></tr>
<tr><td>Median Store Size (ft³)</td><td colspan="5">Food Marketing Institute (FMI), 2012</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td rowspan="5">DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009 / NCI Analysis, 2012</td><td colspan="3" rowspan="5">DOE, 2011</td></tr>
<tr><td>Average Life (yrs)</td><td rowspan="4">NCI, 2009</td></tr>
<tr><td>Retail Equipment Cost</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td></tr>
</table>

Data Sources » Commercial Compressor Rack Systems

DATA SOURCES	2003 Typical	2007 Typical	2011 Typical	2011 High	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Total Capacity (MBtu/hr)	ADL, 1996	NCI, 2009 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012 / ADL, 1996							
Power Input (kW)	Copeland, 2008	NCI, 2009 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012 / ADL, 1996							
Energy Use (MWh/yr)	ADL, 1996 / NCI Analysis, 2008	NCI, 2009 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012 / ADL, 1996							
Average Life (yrs)	Kysor-Warren, 2008	NCI, 2009 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012 / ADL, 1996							
Total Installed Cost ($1000)	NCI, 2009 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012 / ADL, 1996							
Annual Maintenance Cost ($1000)	ADL, 1996 / NCI Analysis, 2008	ADL, 1996 / NCI Analysis, 2012	NCI, 2009 / NCI Analysis, 2012 / ADL, 1996							

Data Sources » Commercial Condensers

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="2">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Total Capacity (MBtu/hr)</td><td>NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996</td><td rowspan="5">NCI, 2009</td><td rowspan="6" colspan="8">NCI, 2009 / NCI Analysis, 2012</td></tr>
<tr><td>Power Input (kW)</td><td>NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996</td></tr>
<tr><td>Energy Use (MWh/yr)</td><td>NCI Analysis, 2008 / ADL, 1996</td></tr>
<tr><td>Average Life (yrs)</td><td>ADL, 1996 / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost ($1000)</td><td>NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td rowspan="2">ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009</td><td colspan="3" rowspan="8">DOE, 2011</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^2)</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008</td></tr>
<tr><td>Insulated Box Average Life (yrs)</td><td rowspan="2">ADL, 1996 / PG&E, 2004</td></tr>
<tr><td>Compressor Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost</td><td rowspan="2">ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / FMI, 2005 / NCI Analysis, 2008</td><td>DOE, 2011 / NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Walk-In Freezers

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008</td></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use ($kWh/yr/ft^3$)</td><td>NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
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Data Sources » Commercial Reach-In Freezers

<table>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr/ft^3)</td><td>NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
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<tr><td>Output (lbs/day)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="6">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Water Use (gal/100 lbs)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/100 lbs)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ACEEE, 2002 / NCI Analysis, 2012</td><td colspan="3" rowspan="4">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Retail Equipment Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost (with Bin)</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / NCI Analysis, 2008</td><td>NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6">DOE, 2011 / NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Beverage Merchandisers

<table>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="6">NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996 / Distributor Web Sites</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Refrigerated Vending Machines

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>DOE, 2008 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3" rowspan="2">DOE, 2009</td><td colspan="6" rowspan="7">DOE, 2009 / NCI Analysis, 2012</td></tr>
<tr><td>Can Capacity</td><td>CEC, 2005 / NREL, 2003 / FEMP, 2004</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / CEC, 2008 / NREL, 2003</td><td colspan="3">DOE, 2009 / ENERGY STAR, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>DOE, 2008</td><td colspan="3" rowspan="4">DOE, 2009</td></tr>
<tr><td>Retail Equipment Cost</td><td>Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>DOE, 2008</td></tr>
</table>

Data Sources » Commercial Constant Air Volume Ventilation

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	Assumed based on average 15,000 square foot commercial building (CBECS 2003 and BED 2007)										
System Fan Power (kW)	eQUEST/DOE-2		ASHRAE 90.1-2007	SAIC & Mfrs							
Specific Fan Power (W/CFM)											
Annual Fan Energy Use (kWh/yr)[1]	Calculated – see note 1										
Average Life (yrs)	2011 ASHRAE Handbook: HVAC Applications										
Total Installed Cost ($)[2]	RS Means 2012										
Annual Maintenance Cost ($)	Jones Lang LaSalle										

[1] Based on 3800 effective full load hours per year (operating 3800 hours per year at constant load) (ADL, 1999).
[2] Total installed cost of 15,000 CFM CAV AHU and hypothetical supply ductwork layout.
[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	Assumed based on average 15,000 square foot commercial building (CBECS 2003 and BED 2007)										
System Fan Power (kW)	eQUEST/DOE-2		ASHRAE 90.1-2007	SAIC & Mfrs							
Specific Fan Power (W/CFM)	eQUEST/DOE-2		ASHRAE 90.1-2007	SAIC & Mfrs							
Annual Fan Energy Use (kWh/yr)[1]	Calculated – see note 1										
Average Life (yrs)	2011 ASHRAE Handbook: HVAC Applications										
Total Installed Cost ($)[2]	RS Means 2012										
Annual Maintenance Cost ($)	Jones Lang LaSalle										

[1] Based on 887 effective full load hours (power-based) per year (operating 3800 hours per year at variable load).
[2] Total installed cost of 15,000 CFM VAV AHU, VFD, (10) VAV boxes, and hypothetical supply ductwork layout.
[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

<table>
<tr><th rowspan="2">DATA</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>System Airflow (CFM)</td><td colspan="11">800 CFM is typical for a 2-ton fan coil unit</td></tr>
<tr><td>System Fan Power (kW)</td><td colspan="2" rowspan="2">ADL 1999, NCI 2008</td><td rowspan="2">ASHRAE 90.1-2007</td><td colspan="8" rowspan="2">SAIC & Mfrs</td></tr>
<tr><td>Specific Fan Power (W/CFM)</td></tr>
<tr><td>Annual Fan Energy Use (kWh/yr)[1]</td><td colspan="11">Calculated – see note 1</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="11">2011 ASHRAE Handbook: HVAC Applications</td></tr>
<tr><td>Total Installed Cost ($)[2]</td><td colspan="11">RS Means 2012</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="11">ASHRAE 2000, NCI 2008</td></tr>
</table>

[1] Based on 2250 effective full load hours per year (operating 2250 hours per year at constant load) (ADL, 1999).
[2] Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.
[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

Appendix B
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1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

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