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Updated Buildings Sector Appliance and Equipment Costs and Efficiencies

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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 AEO2017 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

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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.

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 2013 dollars.

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Definitions

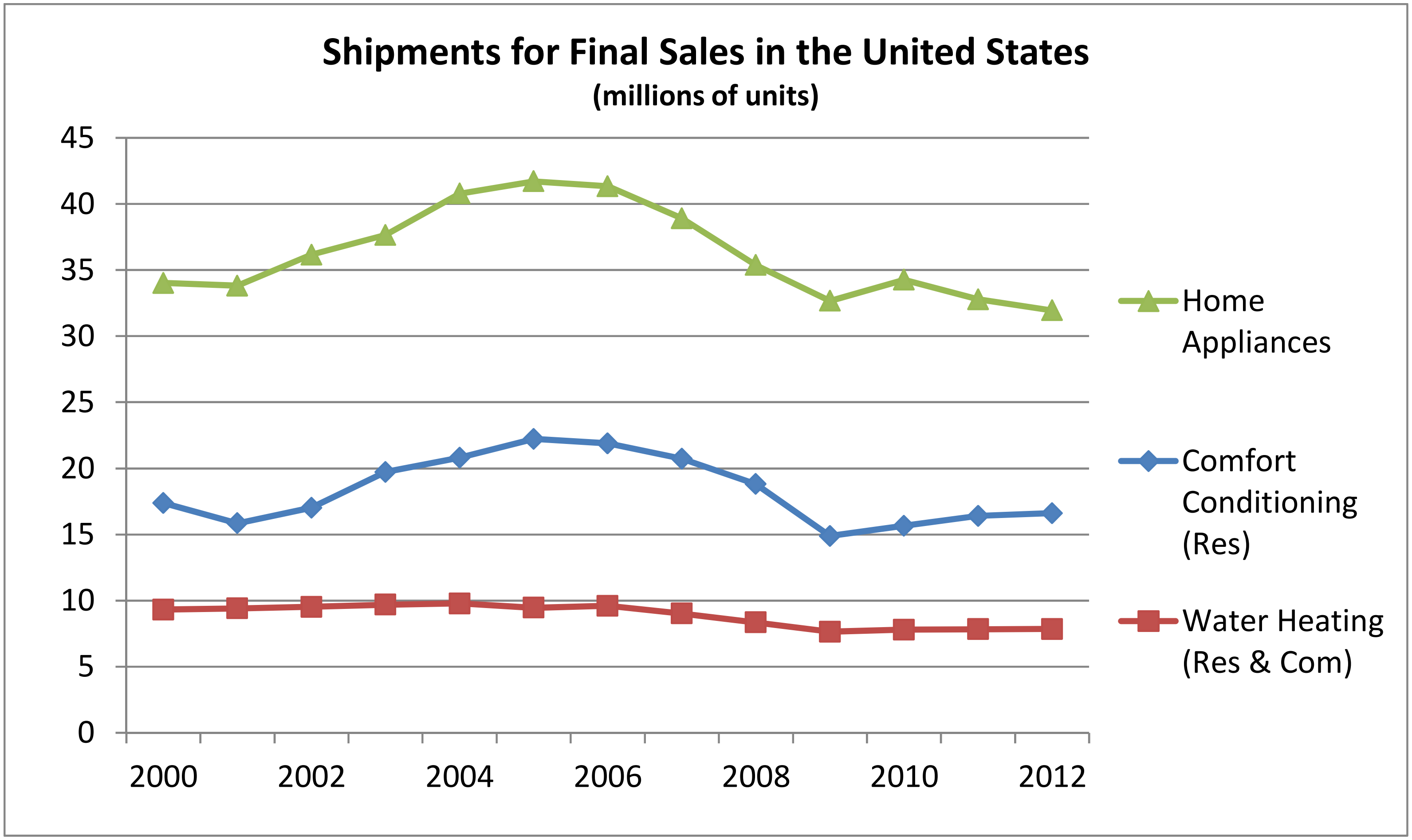
The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (or 2009 for residential products) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming 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.

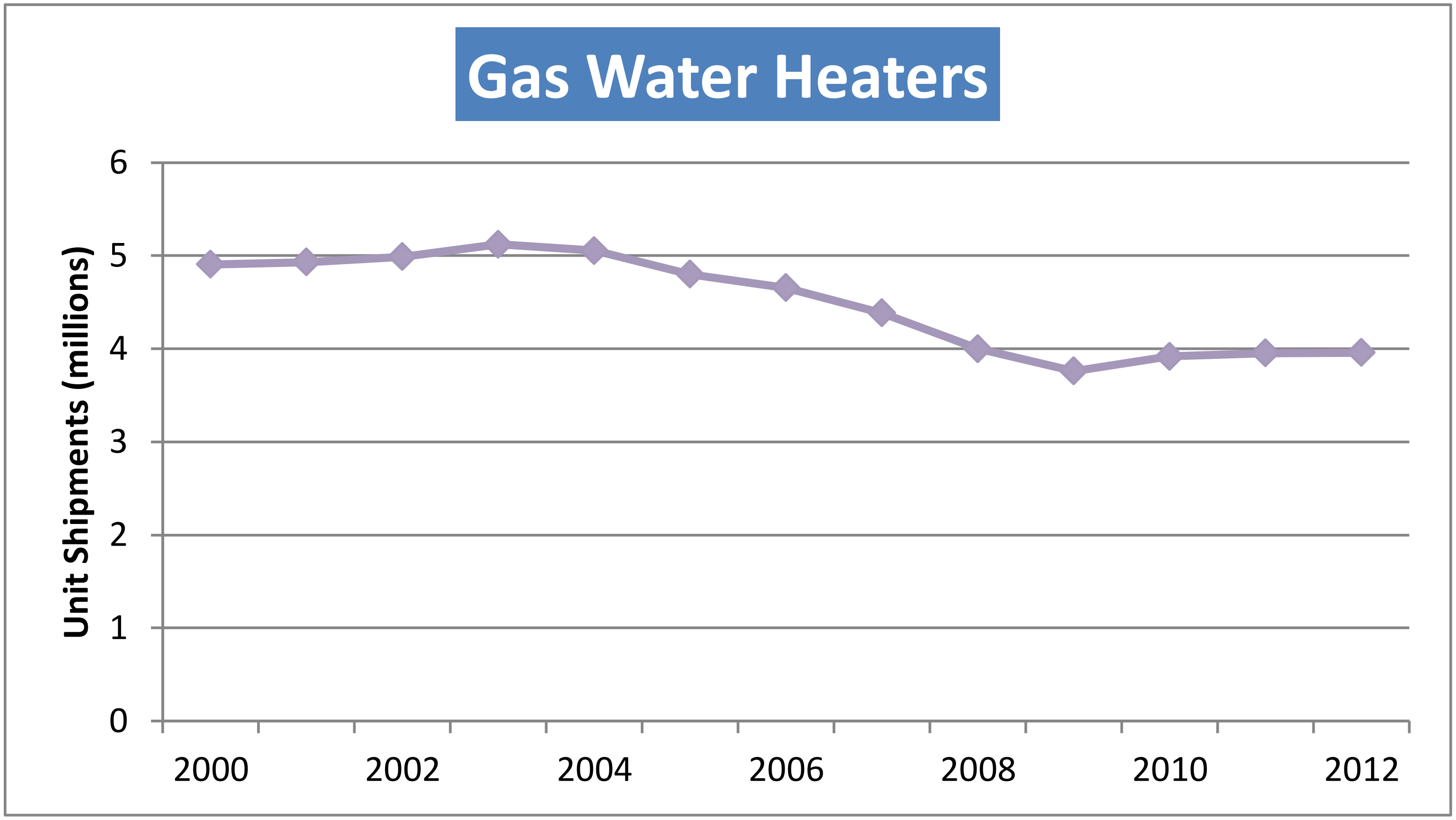
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  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

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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.

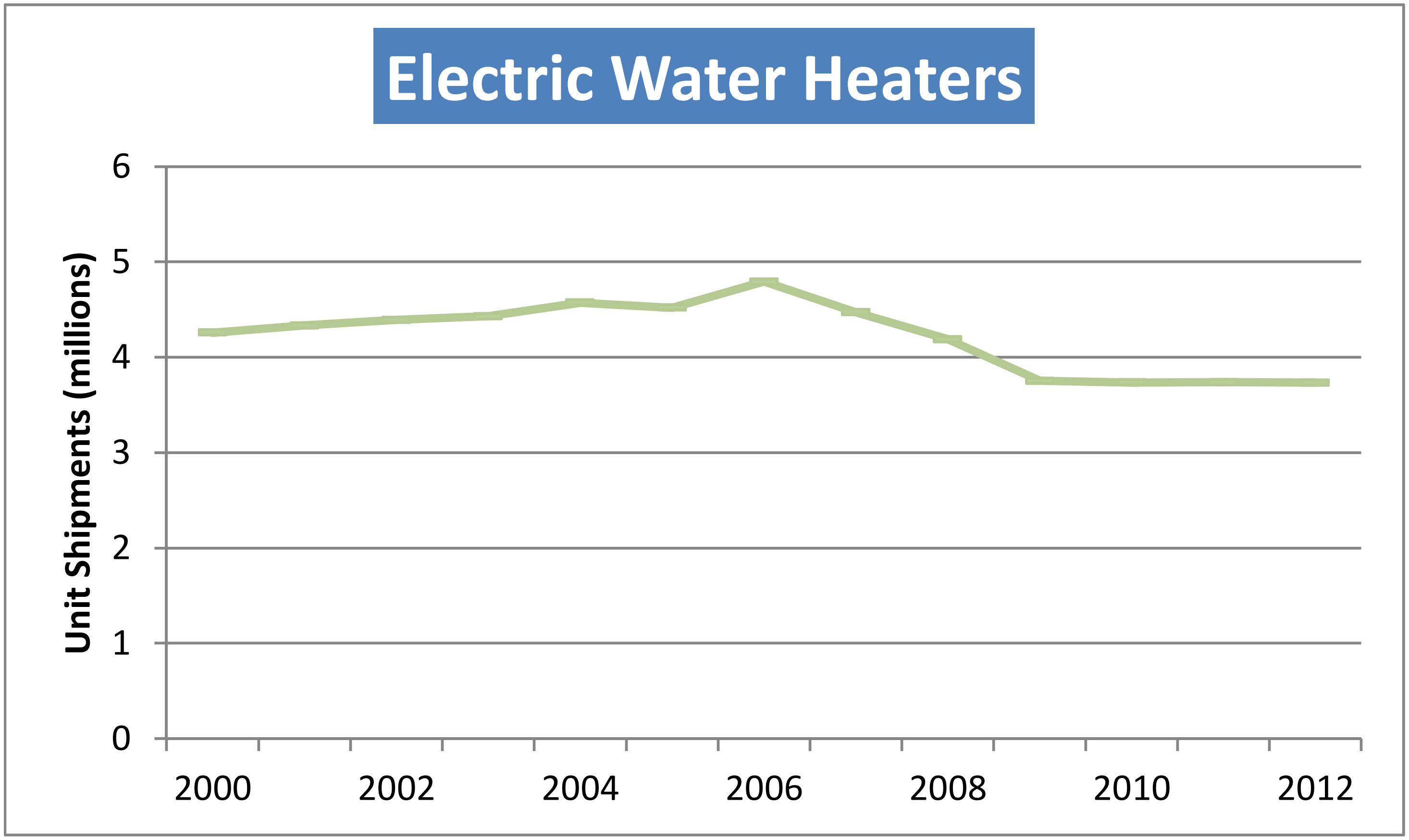
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  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.

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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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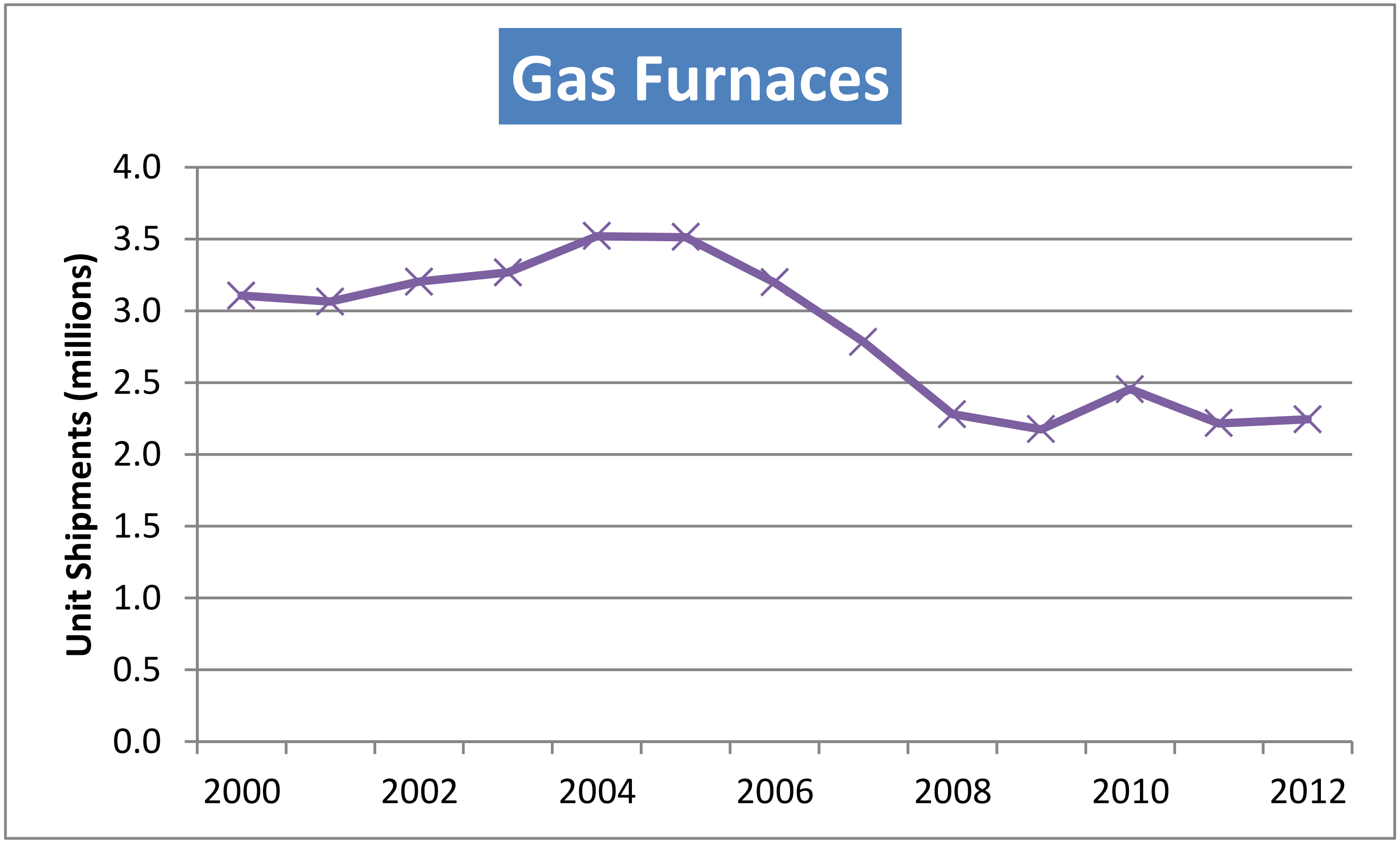
Residential Gas-Fired Furnaces

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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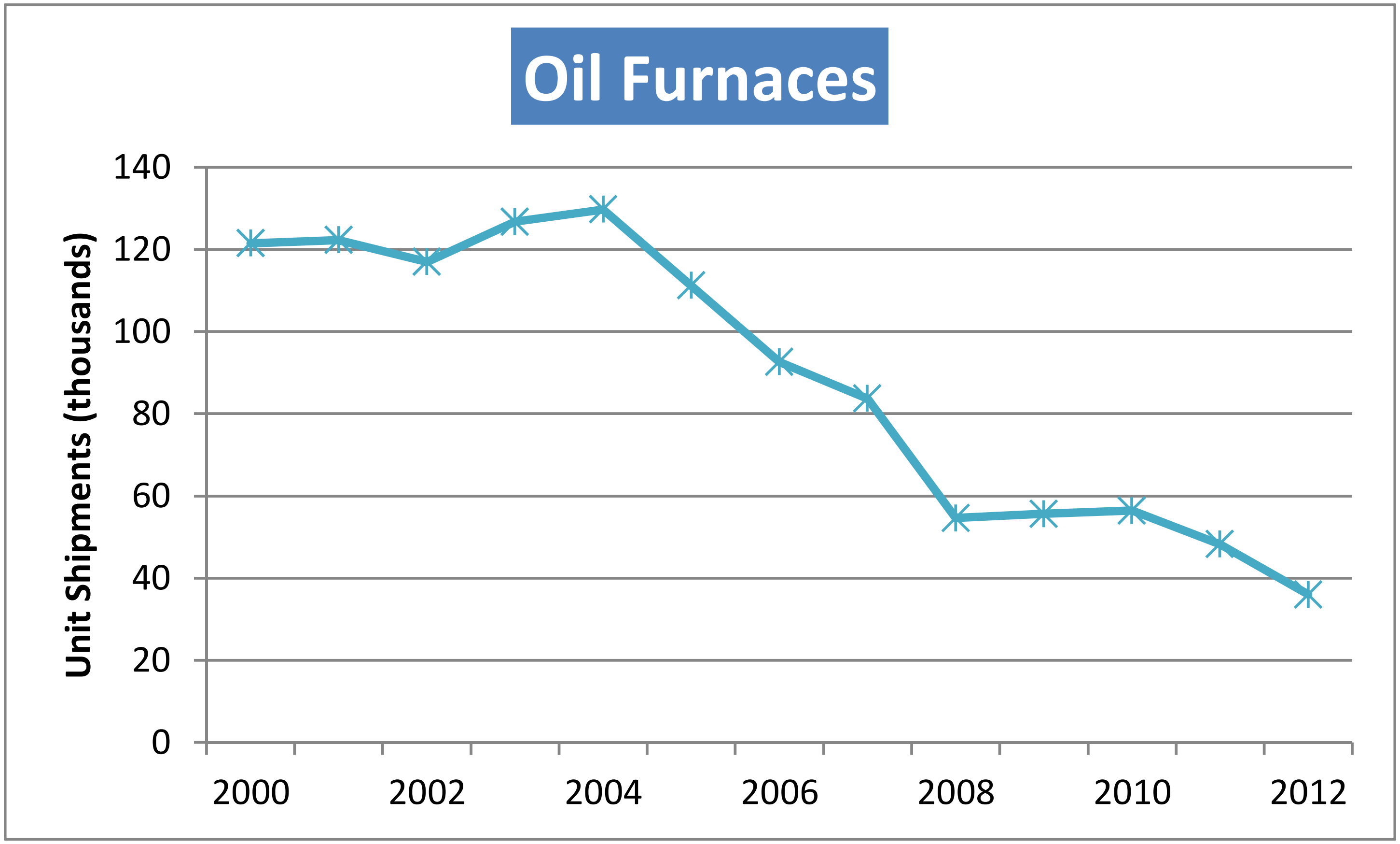
Residential Oil-Fired Furnaces

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

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)

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

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

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

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 ($)***	-	-	-	-	-	-	-	-	-	-	-

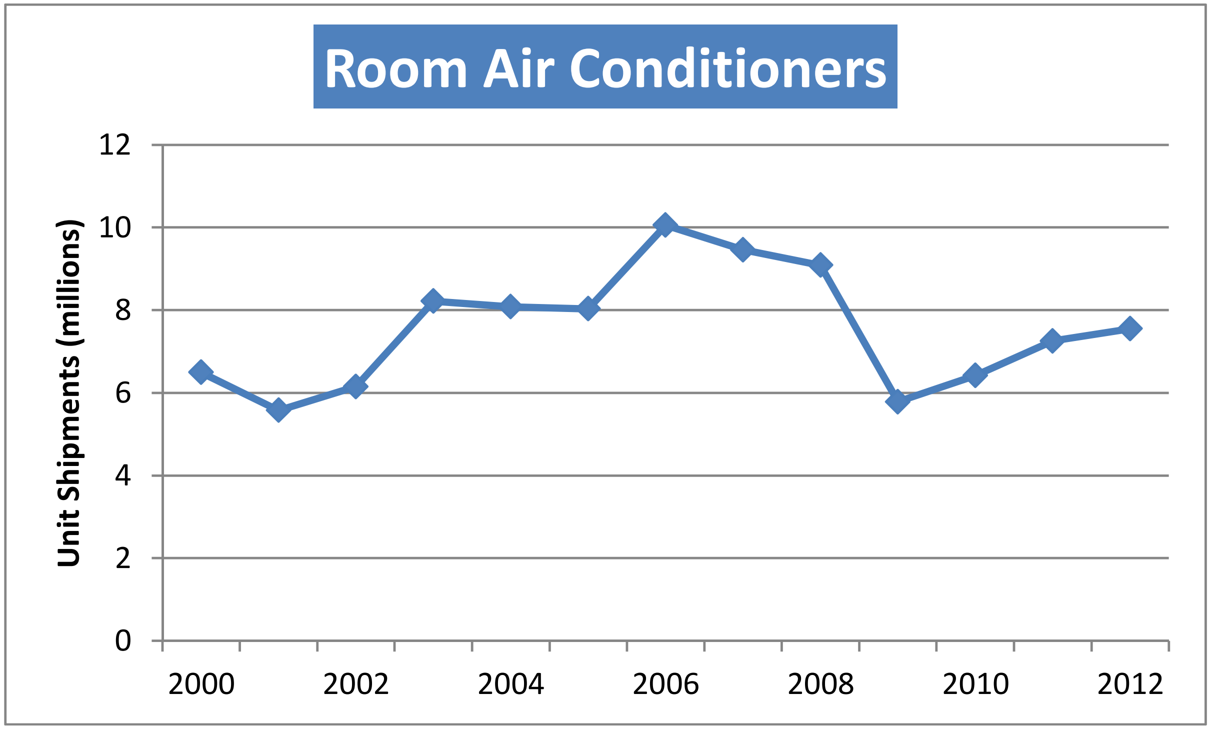
* All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).
** Italicized values are estimated. The federal standard is expressed in EER, but will be expressed in CEER beginning in 2014. The two metrics are not strictly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

Final

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.

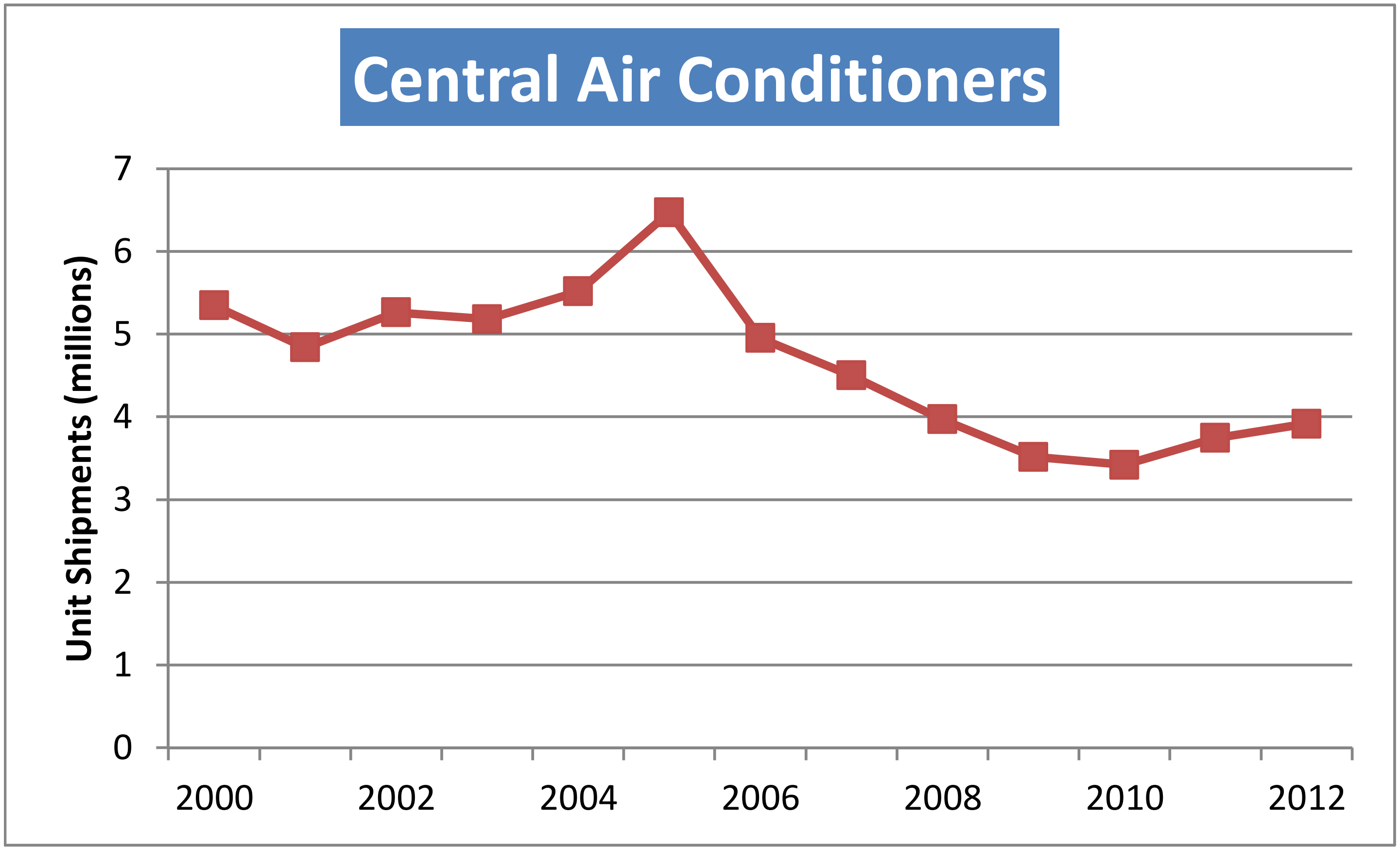
Final

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)

Final

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.

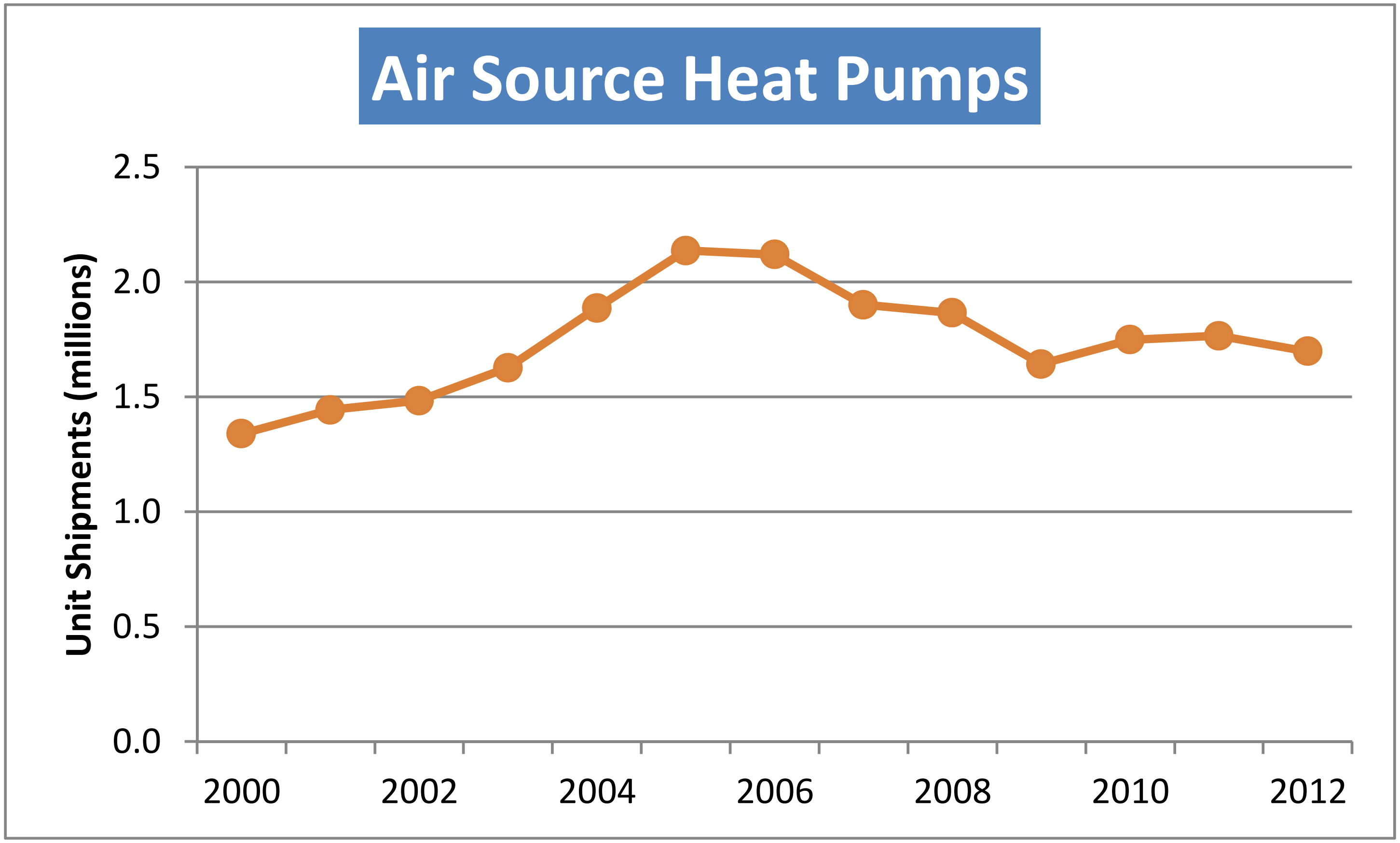
Final

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

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

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

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.

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

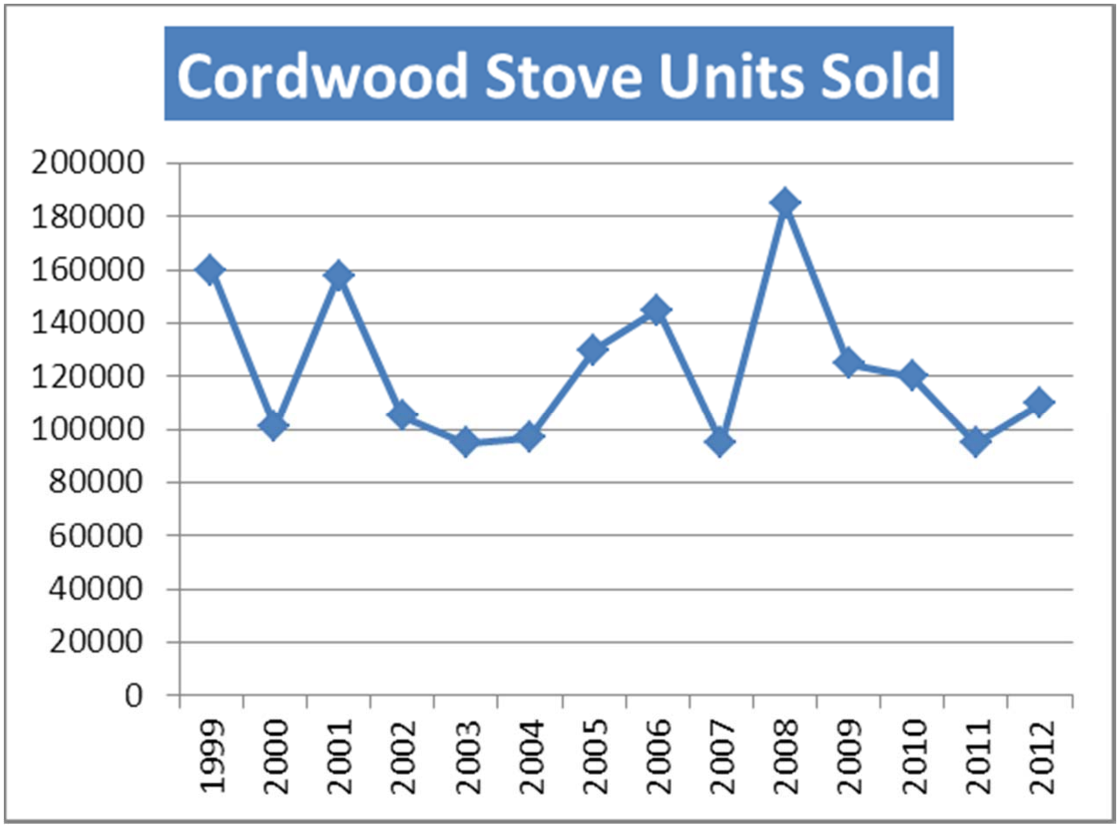
*Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
**Installed cost includes cost of hearth and stainless steel chimney liner - materials and labor.
***Annual maintenance cost of catalytic stove includes periodic cost of replacing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

- 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

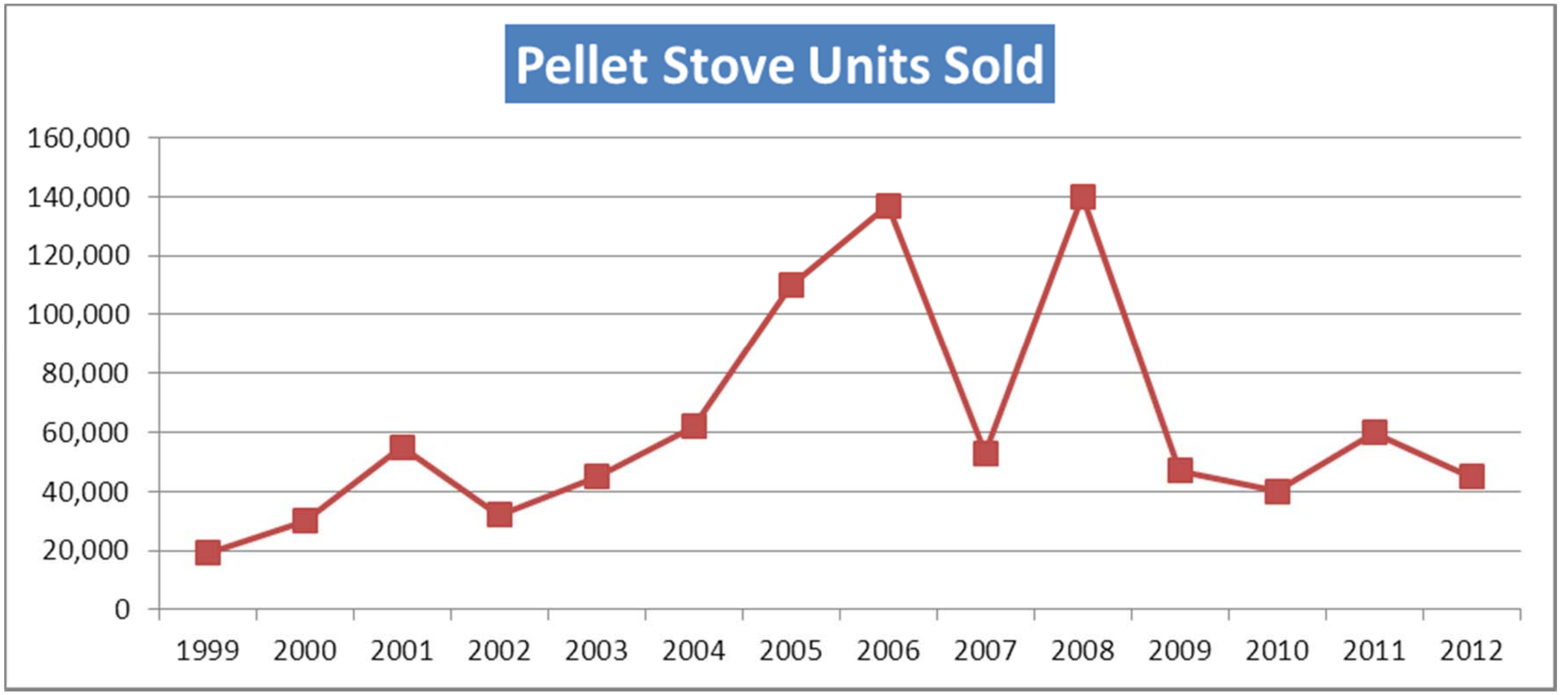
DATA	2009	2013			2020		2030		2040	
	Installed Base	EPA Certified (Default)	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)	65	78	78	81	81	84	83	86	84	87
Annual Electricity Consumption (kWh)	1,200	1,200	1,200	1,200	1,200	1,200	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.

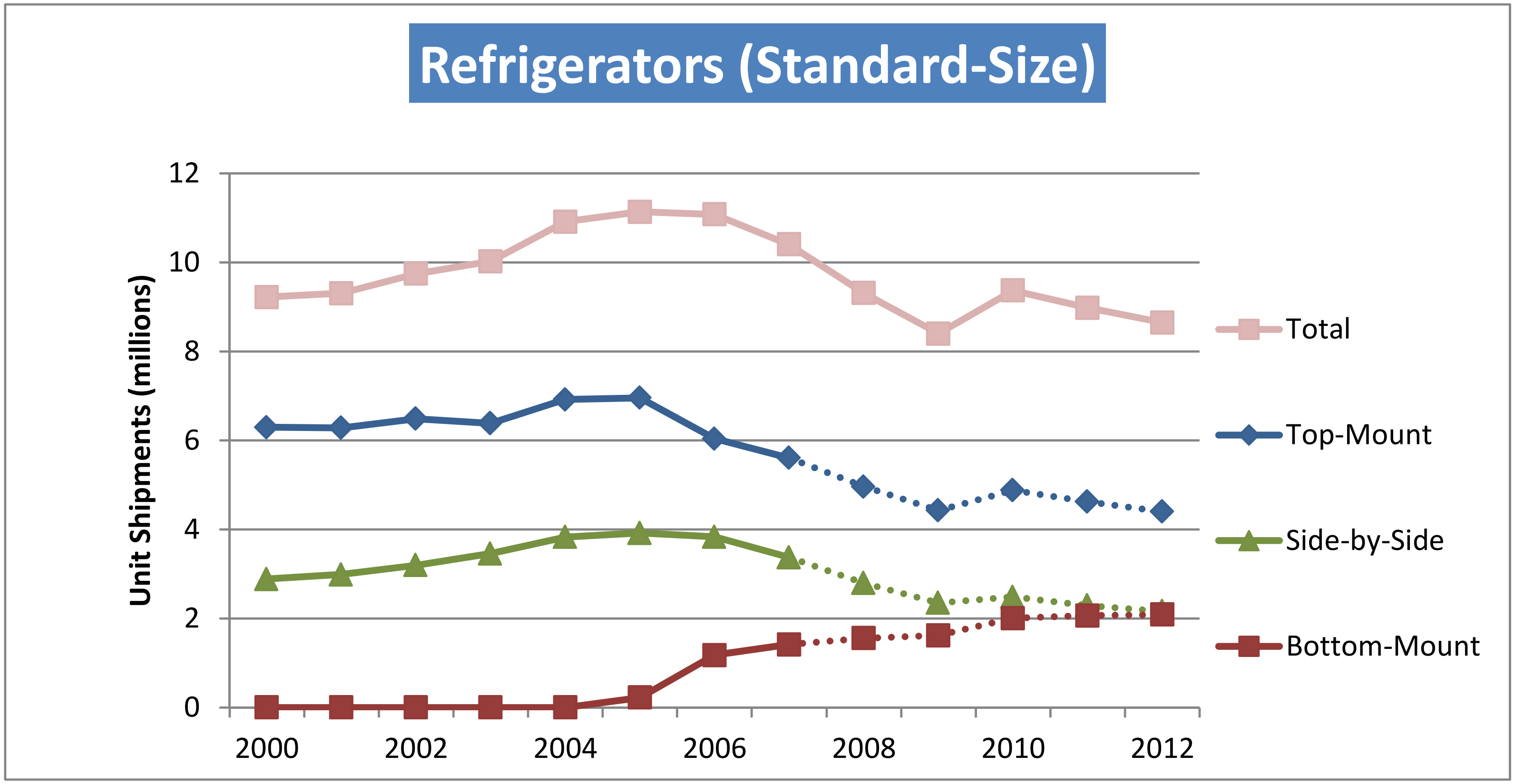
Final

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

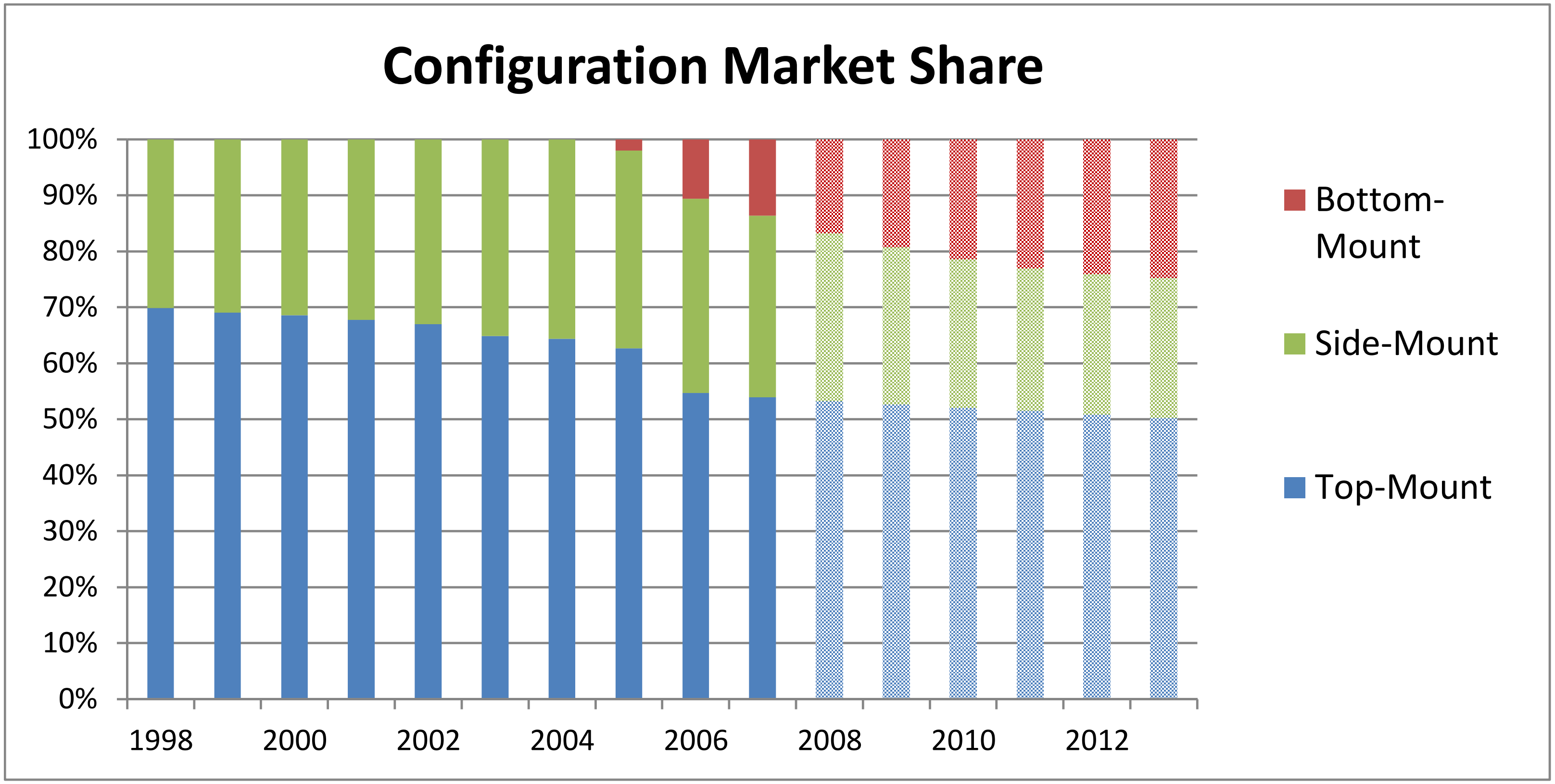
[1]Adjusted Volume (AV) = (Fresh Volume) + 1.63 × (Freezer Volume). Beginning in 2004, the 1.63 coefficient will change to 1.76.

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).

Residential Freezers

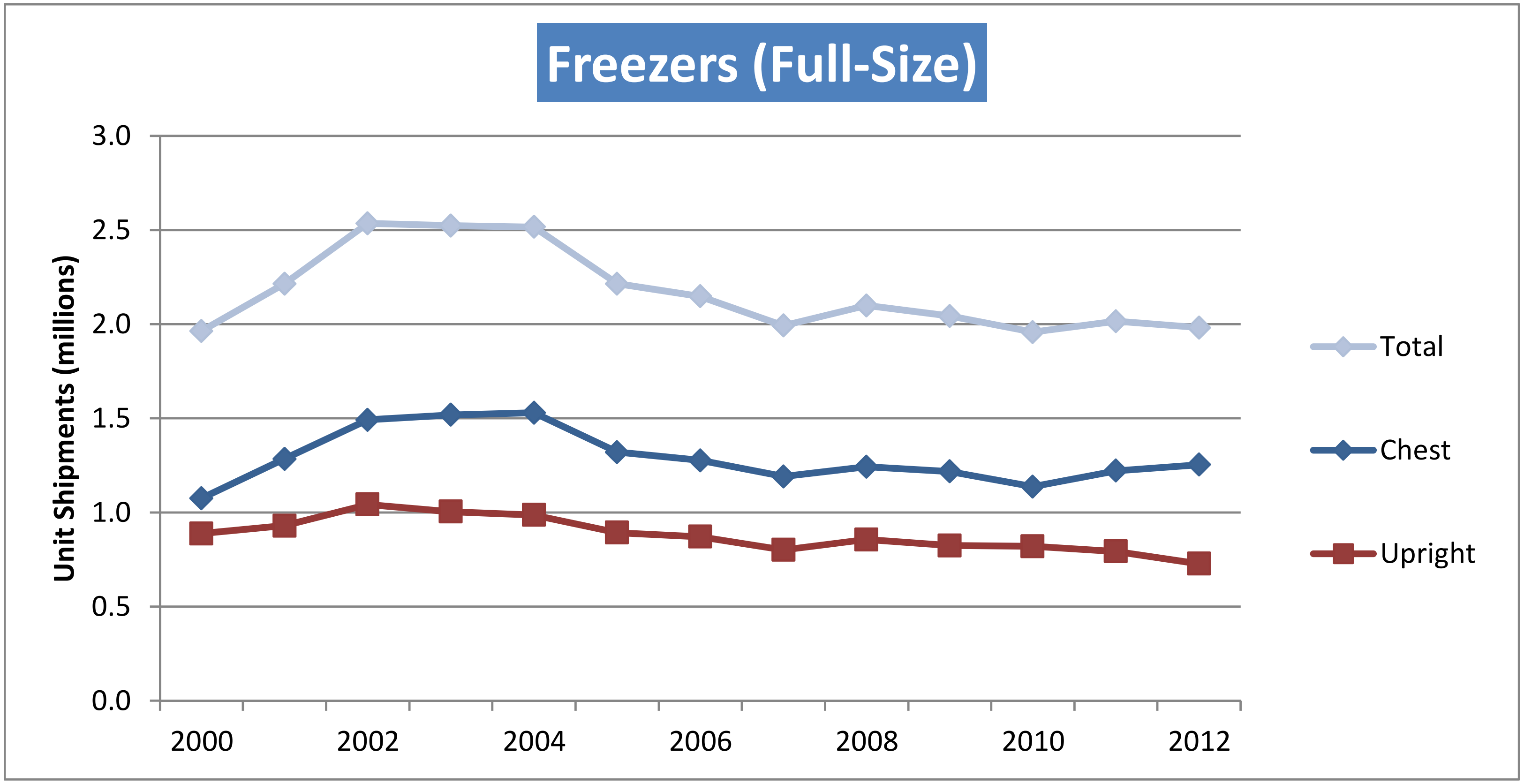
- Current Federal standards:
  - Compliance required beginning July 1, 2001
  - Models divided into 6 product classes based on size (standard or compact), orientation (chest or upright), and type of defrost (automatic or manual).
  - Limits on annual electricity consumption expressed as functions of 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.

Final

Residential Freezers

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

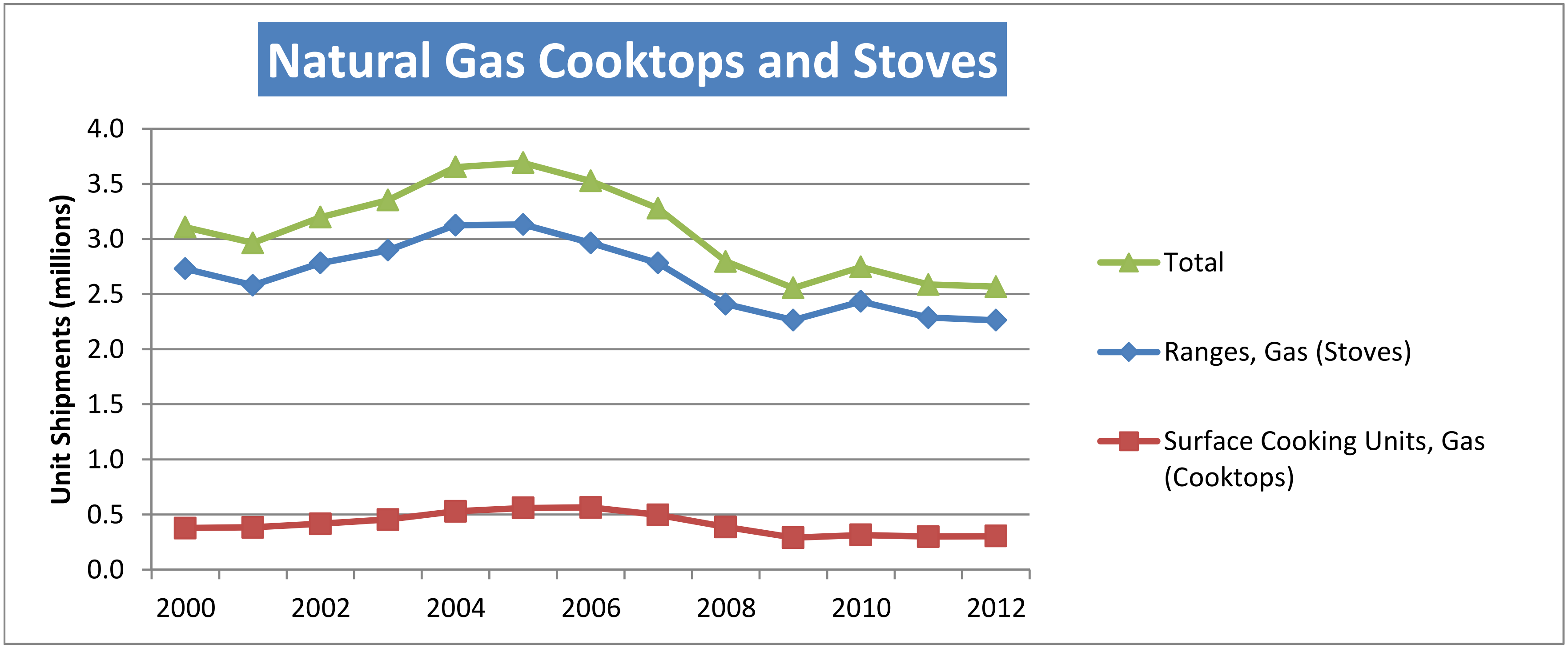
DATA	2009	2013		2020		2030		2040	
	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9
	12	12	12	12	12	12	12	12	12
Cooking Efficiency (%)	38.5	39.9	42	39.9	42	39.9	42	39.9	42
Average Life (yrs)	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	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 <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

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.

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

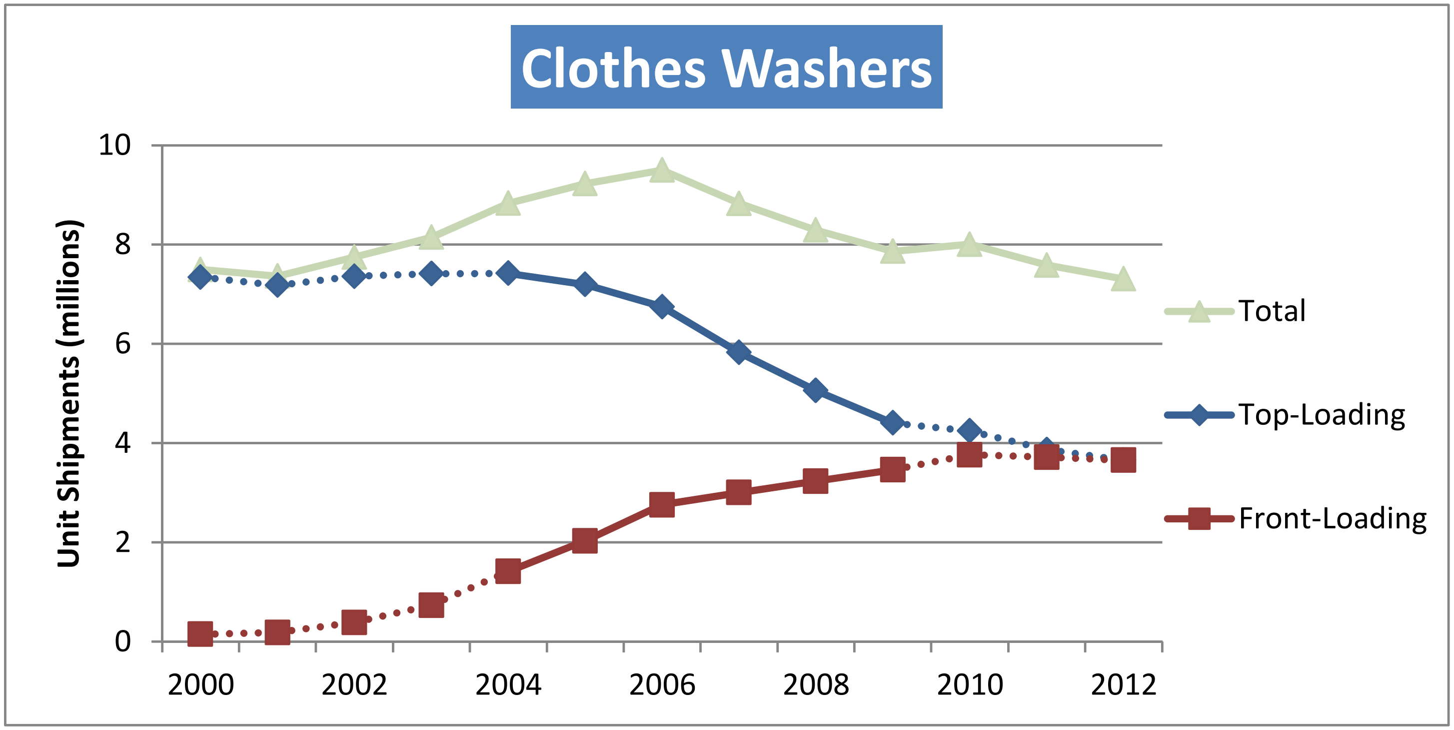
- Present analysis treats front- and top-loading models separately. Past analyses did not consider the two types separately.
- Federal standards for standard-capacity clothes washers (≥ 1.6 cubic feet):

	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 ($)**	-	-	-	-	-	-	-	-	-	-	-

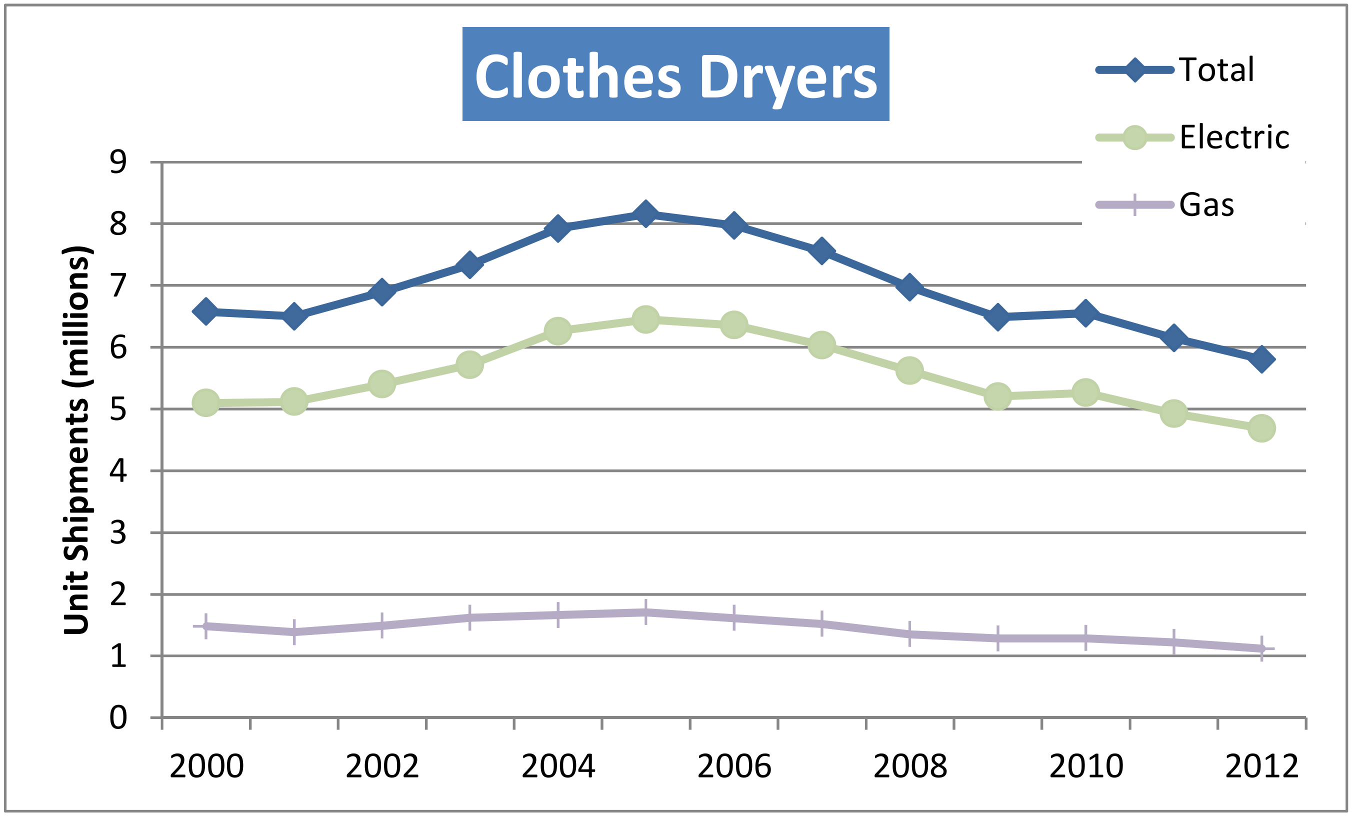
* Italicized values are estimated. The federal standard is expressed in EF, but will be expressed in CEF beginning in 2015. The two metrics are not strictly comparable, but both values are shown here to facilitate longitudinal analyses.

** 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

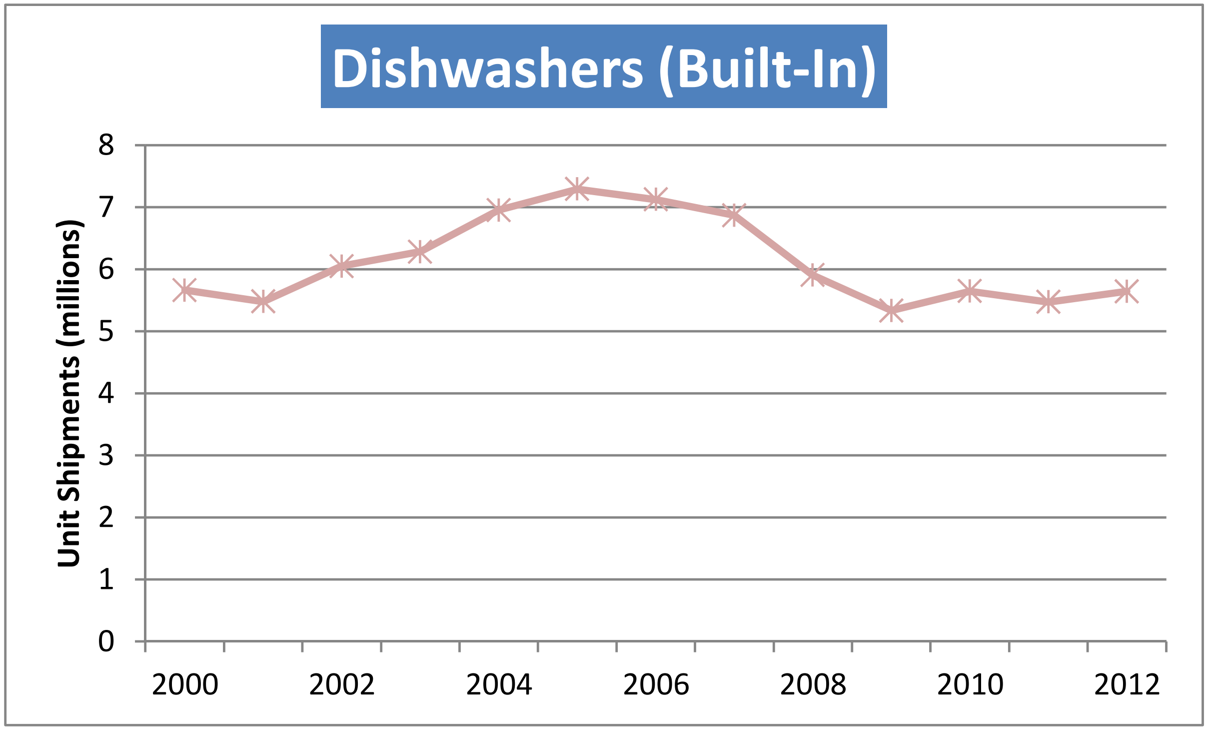
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/yr)	312	307	295	295	180	295	180	295	180	295	180
Water Consumption (gal/cycle)	4.50	5.00	4.25	4.25	2.22	4.25	2.22	4.25	2.22	4.25	2.22
Water 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*

Final

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.

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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.
- 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.
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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.

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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).

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.

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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.

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.

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

Final

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.

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

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.

Final

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.

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.

Final

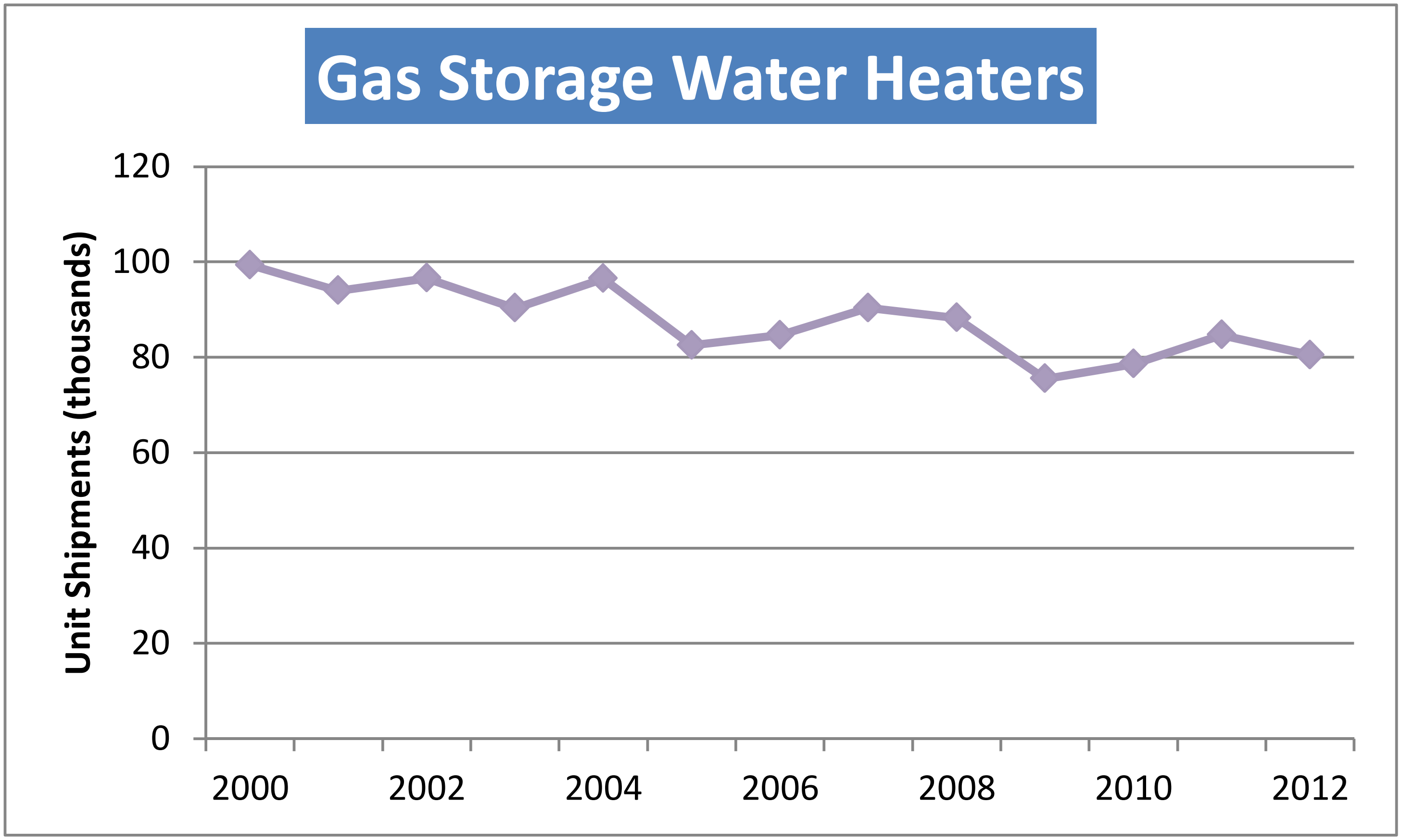
Commercial Gas Storage Water Heaters

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)

Final

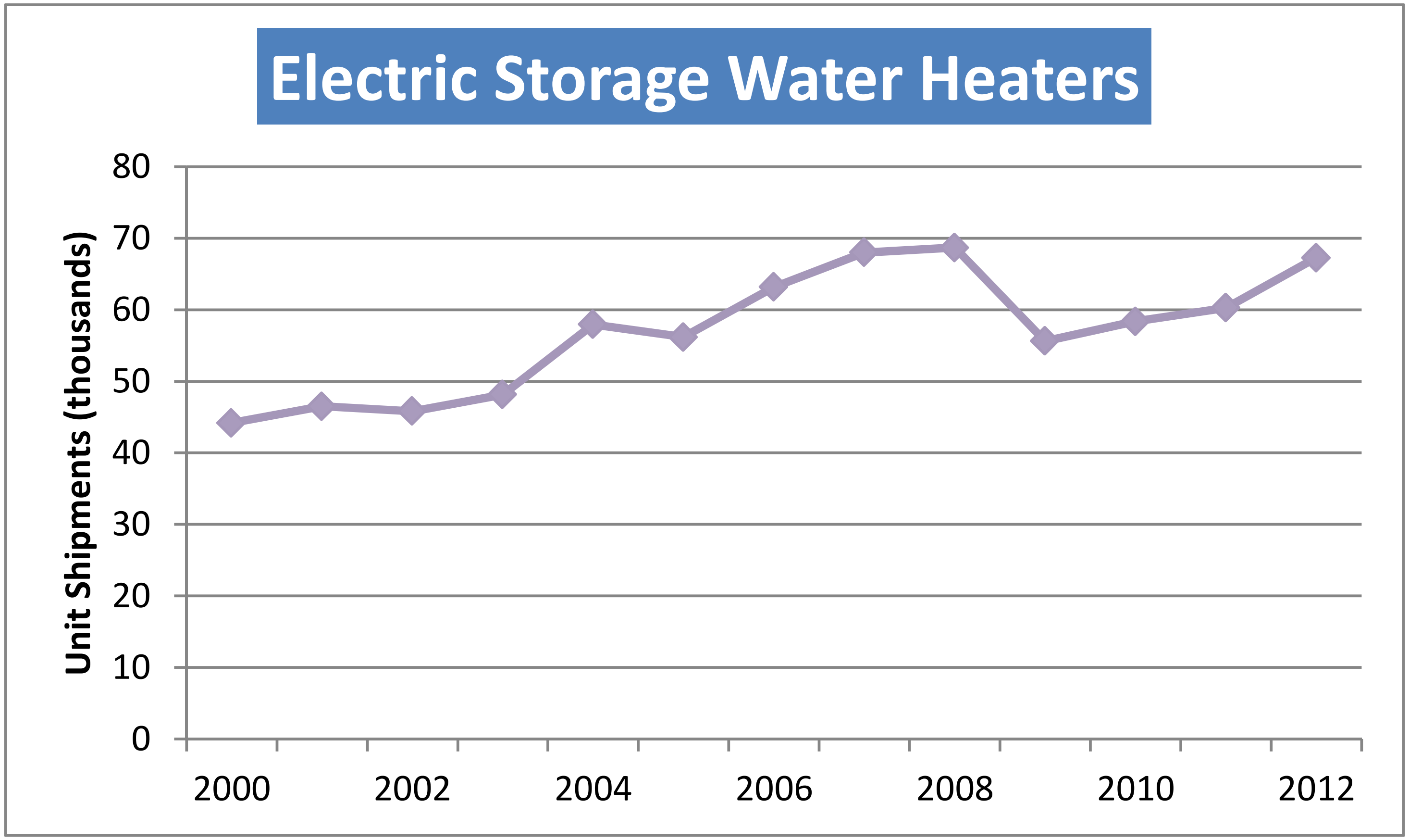
Commercial Electric Resistance Water Heaters

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)

Final

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 ($)*	–	–	–	–	–	–	–	–	–	–	–

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.

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

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

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				

Final

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							
AFUE (%)	Navigant	EERE	EERE	ENERGY STAR	ENERGY STAR	AHRI			
Electric Consumption (kWh/yr)	EERE	EERE							
Average Life (yrs)	Appliance Magazine, 2012						Navigant		
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				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

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							
SEER (Cooling)	Navigant	eCFR	CCMS	ENERGY STAR	CCMS			
HSPF (Heating)	Navigant	eCFR	EERE	ENERGY STAR	CCMS			
Average Life (yrs)	EERE / Navigant					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

<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">Distributors/SAIC</td><td colspan="3" rowspan="6">SAIC</td></tr>
<tr><td>Efficiency (%)</td><td colspan="2">SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">Technology Cost and Performance File for Commercial Model for AEO2010 (adapted for residential)</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors/RS Means 2013/SAIC</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="2">Distributors/RS Means 2013/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="2">SAIC</td></tr>
</table>

Final

Data Sources » Residential Cord Wood Stoves

<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>

Final

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

<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>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 colspan="2">EERE</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Cooking Efficiency (%)</td><td>Distributors / Product Literature</td><td colspan="2">EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3">Appliance Magazine, 2012</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE</td><td colspan="2">EERE / Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>EERE</td><td colspan="2">EERE / Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>Navigant / EERE</td><td colspan="2">Navigant / EERE</td></tr>
</table>

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

<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 (ft3)</td><td>Navigant</td><td colspan="2">CEC</td><td>CEC / Distributors</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>EF and CEF (lb/kWh)</td><td>Navigant</td><td colspan="3">EERE / Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">Appliance Magazine, 2012</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Navigant</td><td colspan="3">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Navigant</td><td colspan="3">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE</td><td colspan="3">EERE</td></tr>
</table>

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							

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					
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004	AHRI	10 CFR 431.77	AHRI			
Average Life (yrs)	EERE / Navigant				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

<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>Mid-Range</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td colspan="6">Navigant</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="2">ASHRAE Standard 90.1-2004 / Navigant</td><td>EERE</td><td colspan="3">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>CEC / RS Means 2010</td><td>RS Means 2011</td><td colspan="4">RS Means 2011</td></tr>
<tr><td>Total Installed Cost ($)</td><td>CEC / RS Means 2010</td><td>RS Means 2011</td><td colspan="4">RS Means 2011</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">Navigant</td></tr>
</table>

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>
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Final

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

SOURCES	2003	2012	2013					2020	2030	2040
	Installed Base		Current Standard	Typical	Mid	High		Typical / High		
Typical Capacity (tons)	SAIC							SAIC		
Efficiency (kW/ton)	DEER/FEMP/ Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC						
COP	DEER/FEMP/ Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC						
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 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

<table>
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<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 Output Capacity (kBtu/h)</td><td colspan="6">AHRI / Navigant</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Efficiency (EER)</td><td>ASHRAE Standard 90.1-2004</td><td>Distributors/ Navigant</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost $)</td><td>Navigant / LBNL, 2003</td><td>Distributors/ Navigant / DEER, 2008</td><td colspan="2">EERE</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Navigant / LBNL, 2003</td><td>Distributors/ Navigant / DEER, 2008</td><td colspan="2">EERE</td><td colspan="2">Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">EERE</td></tr>
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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					
Heating COP	NA	Product Literature				
Cooling COP	Product Literature/SAIC					
Average Life (yrs)	Distributors/ SAIC	Manufacturer/RS Means 2013/SAIC		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

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	AHRI / Navigant						Navigant		
Efficiency (EER)	ASHRAE Standard 90.1-2004 / Navigant		EERE		ENERGY STAR	EERE			
COP (Heating)	EERE / Navigant		EERE		ENERGY STAR	EERE			
Average Life (yrs)	EERE								
Retail Equipment Cost ($)	Distributors / RS Means 2010 / DEER / Navigant								
Total Installed Cost ($)	Distributors / RS Means 2010 / DEER / Navigant								
Annual Maintenance Cost ($)	Distributors / RS Means 2010 / DEER / Navigant								

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)								

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					
Typical Input Capacity (kBtu/h)	Navigant	AHRI / Navigant	AHRI / Navigant					
Thermal Efficiency (%)	Navigant	Navigant	AHRI / Navigant					
Average Life (yrs)	EERE					Navigant		
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

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Cooking Surface (ft^2)</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 (Btu/h/ft^2)</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 Electric Griddles

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Cooking Surface (ft^2)</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/ft^2)</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>
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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>
</table>

Appendix B
References

Navigant Consulting, Inc.
1200 19 St. NW, Suite 700
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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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

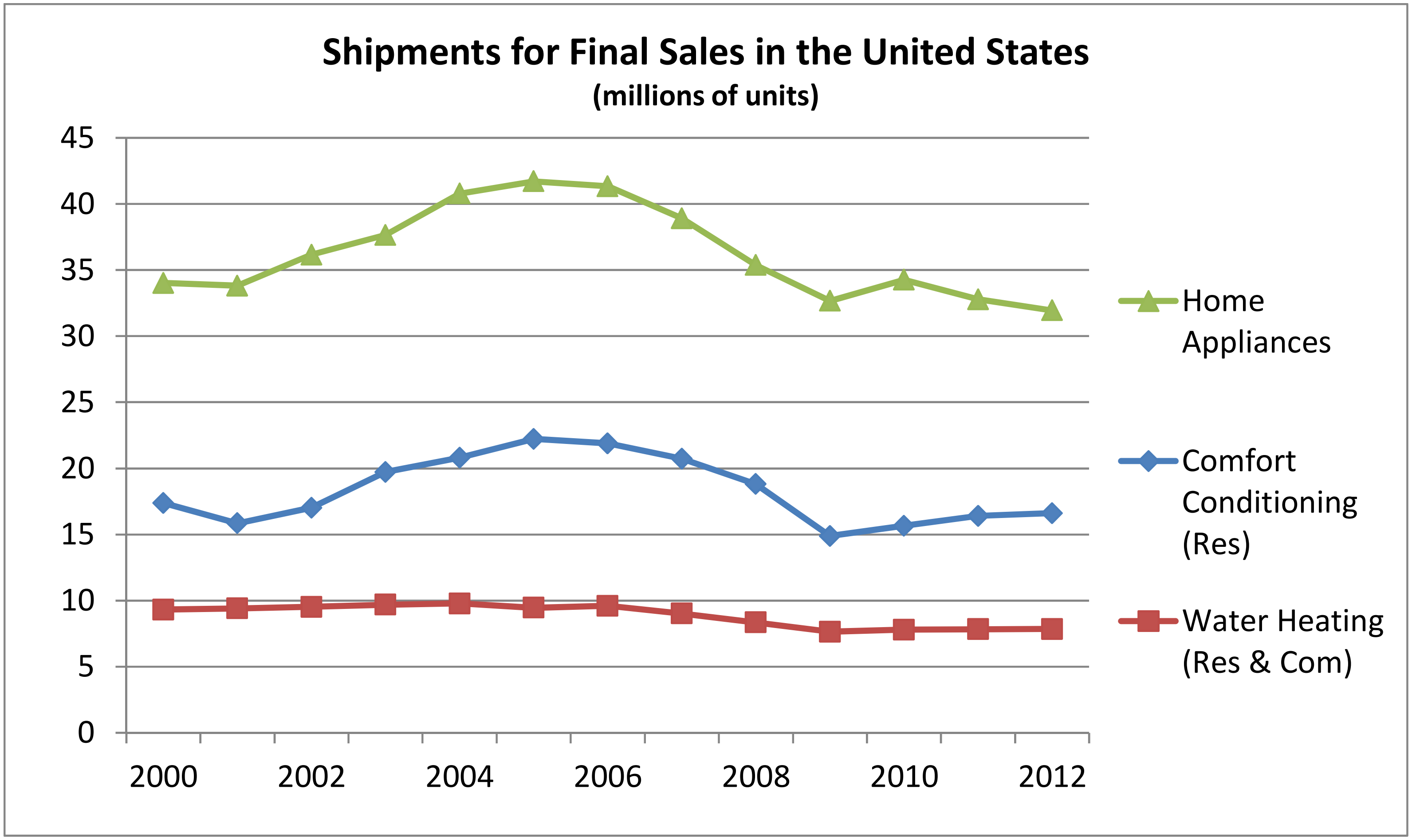
The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (or 2009 for residential products) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming 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.

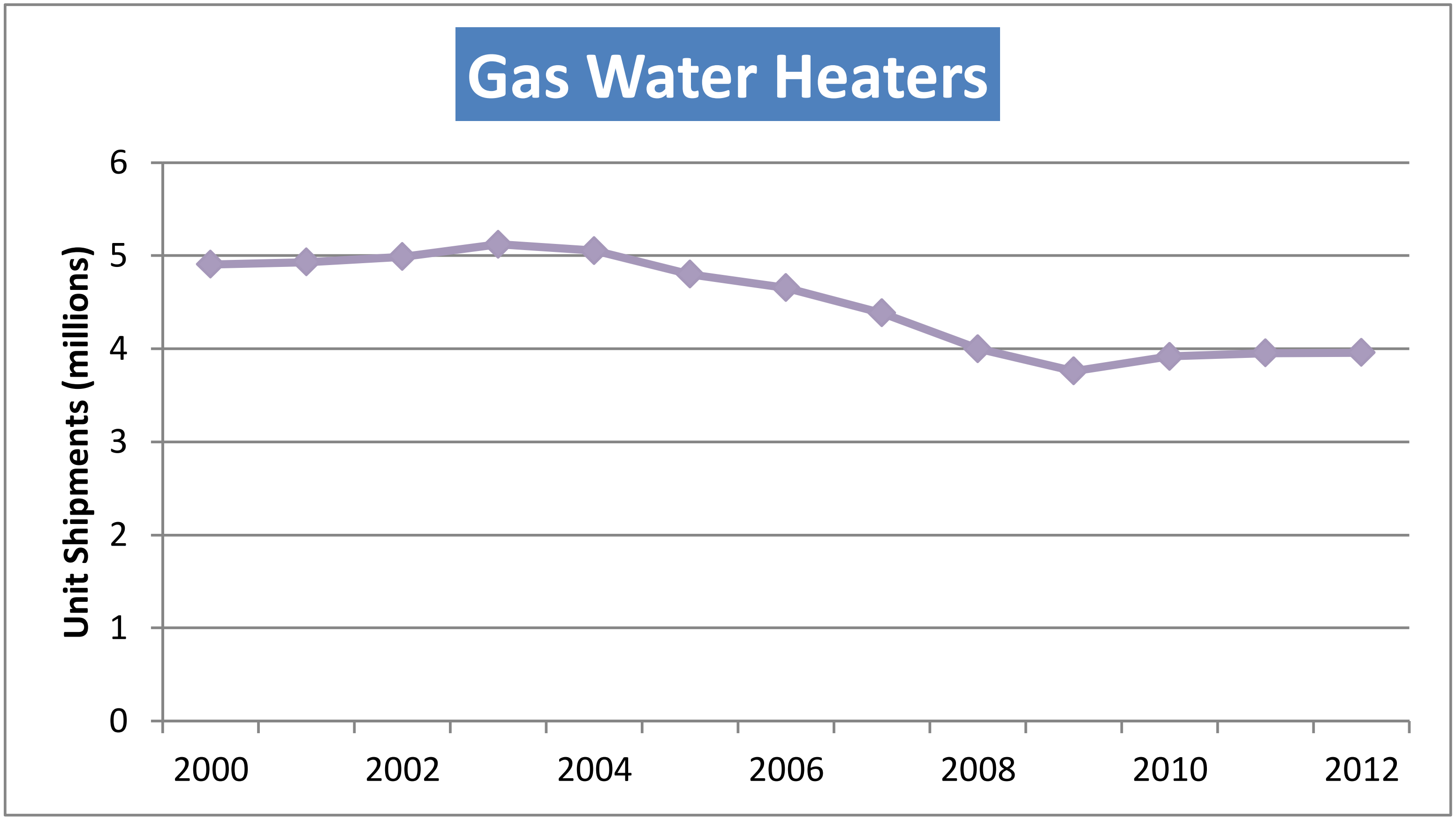
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  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.

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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.

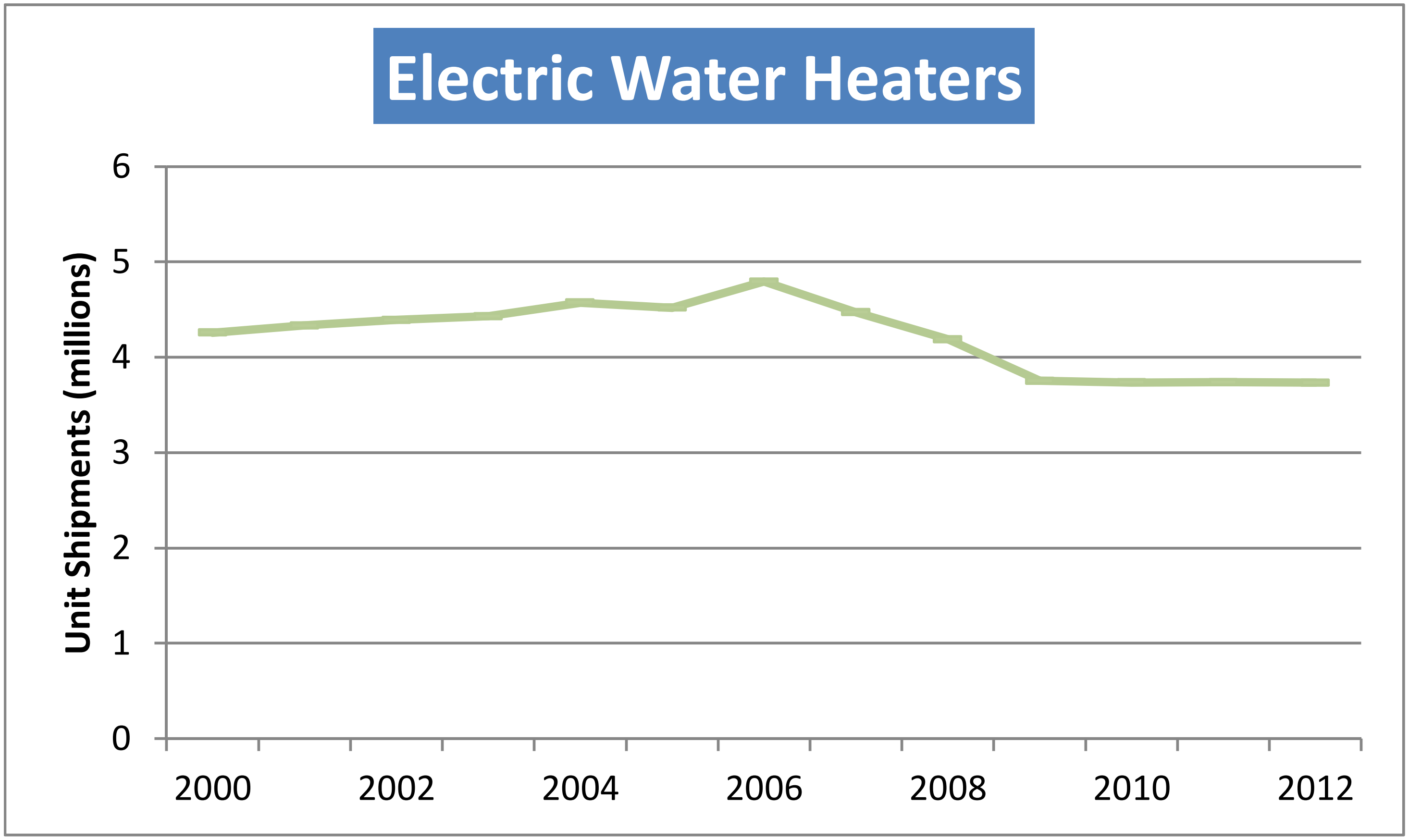
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  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

- 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

- 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.

- 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.

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

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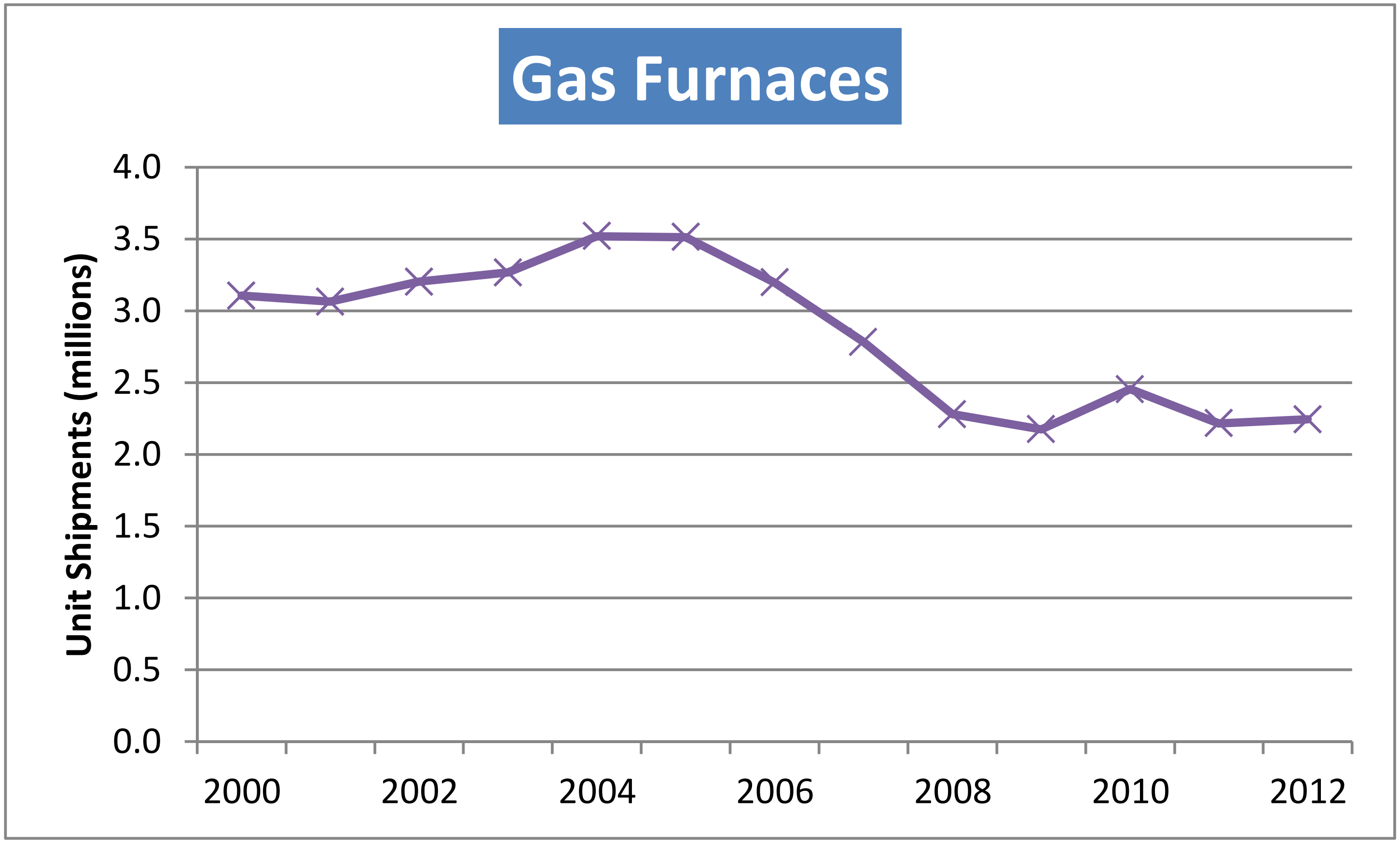
Residential Gas-Fired Furnaces

- 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

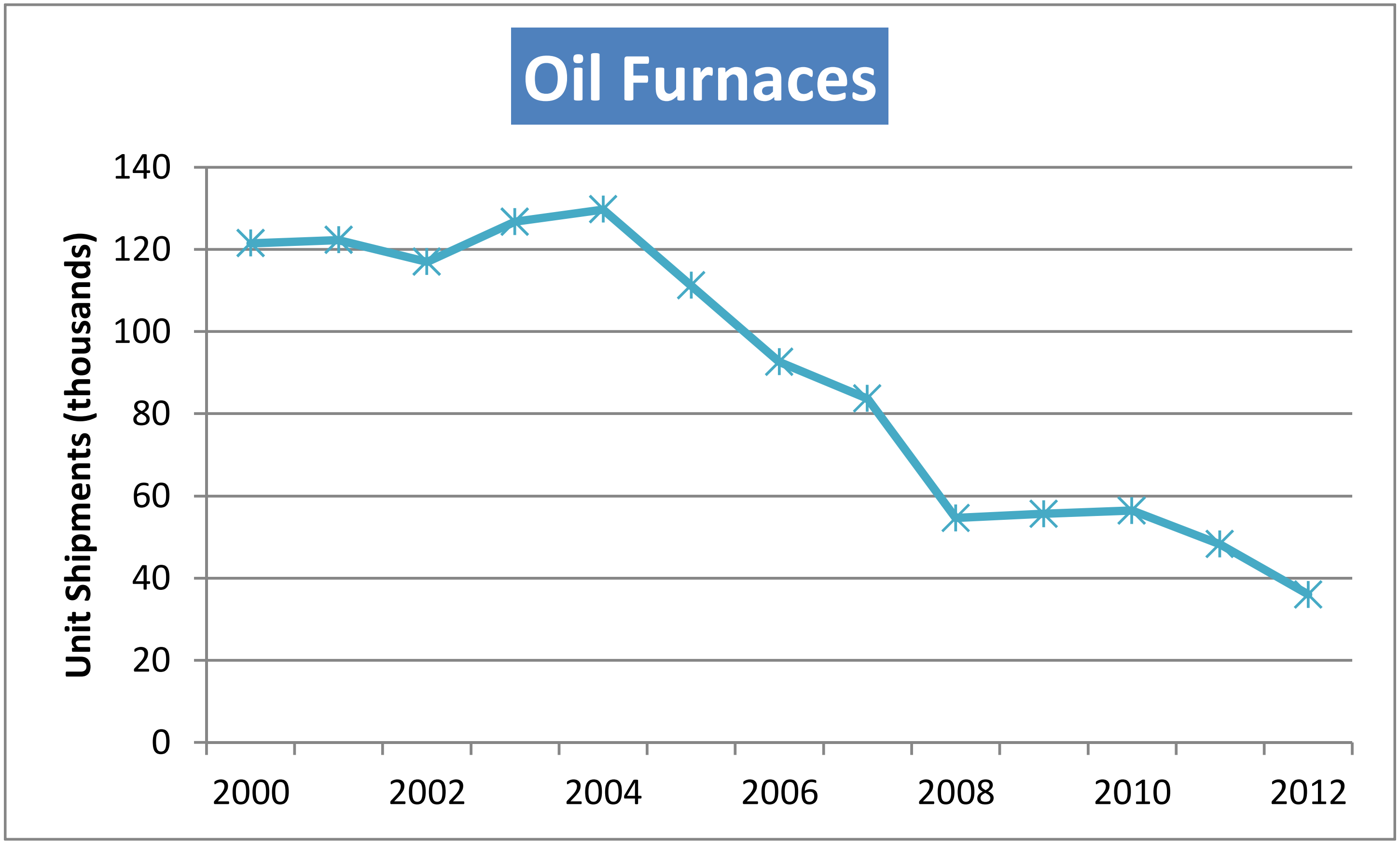
Higher typical efficiencies with the same costs as ref. case despite increased efficiency

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)

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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

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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

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

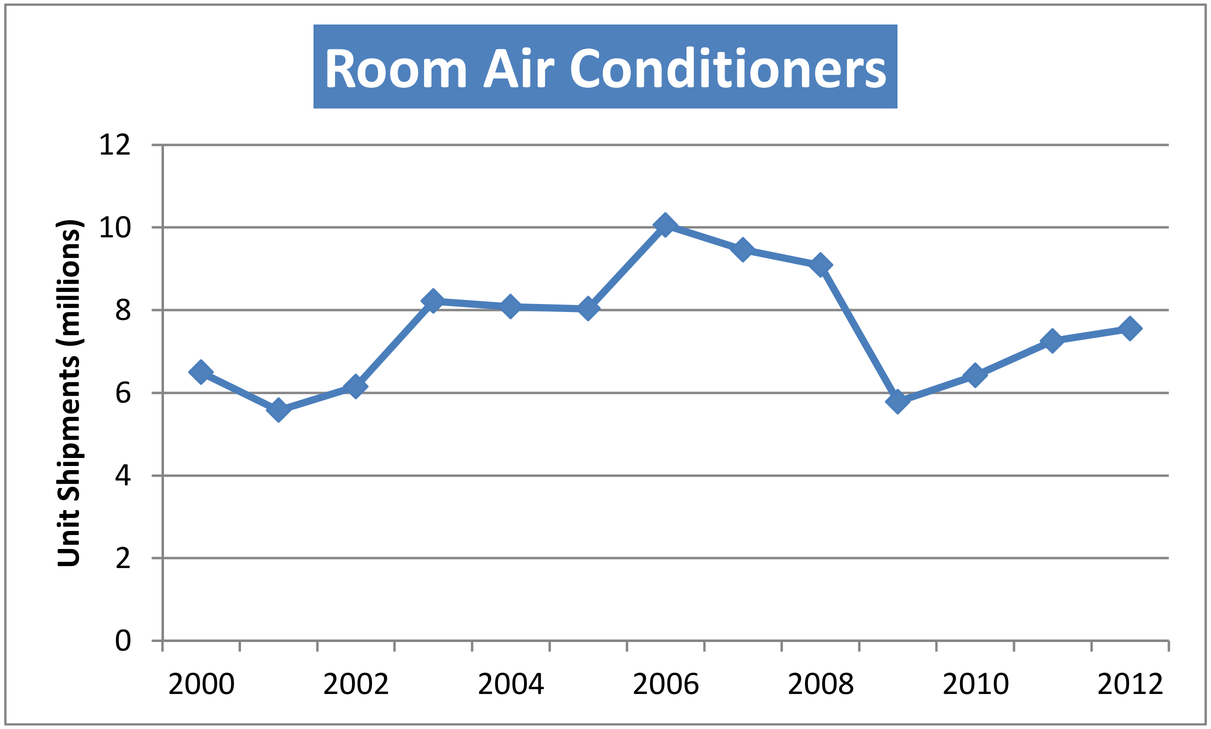
Higher typical efficiencies and lower costs for a given efficiency level

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.

- 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.

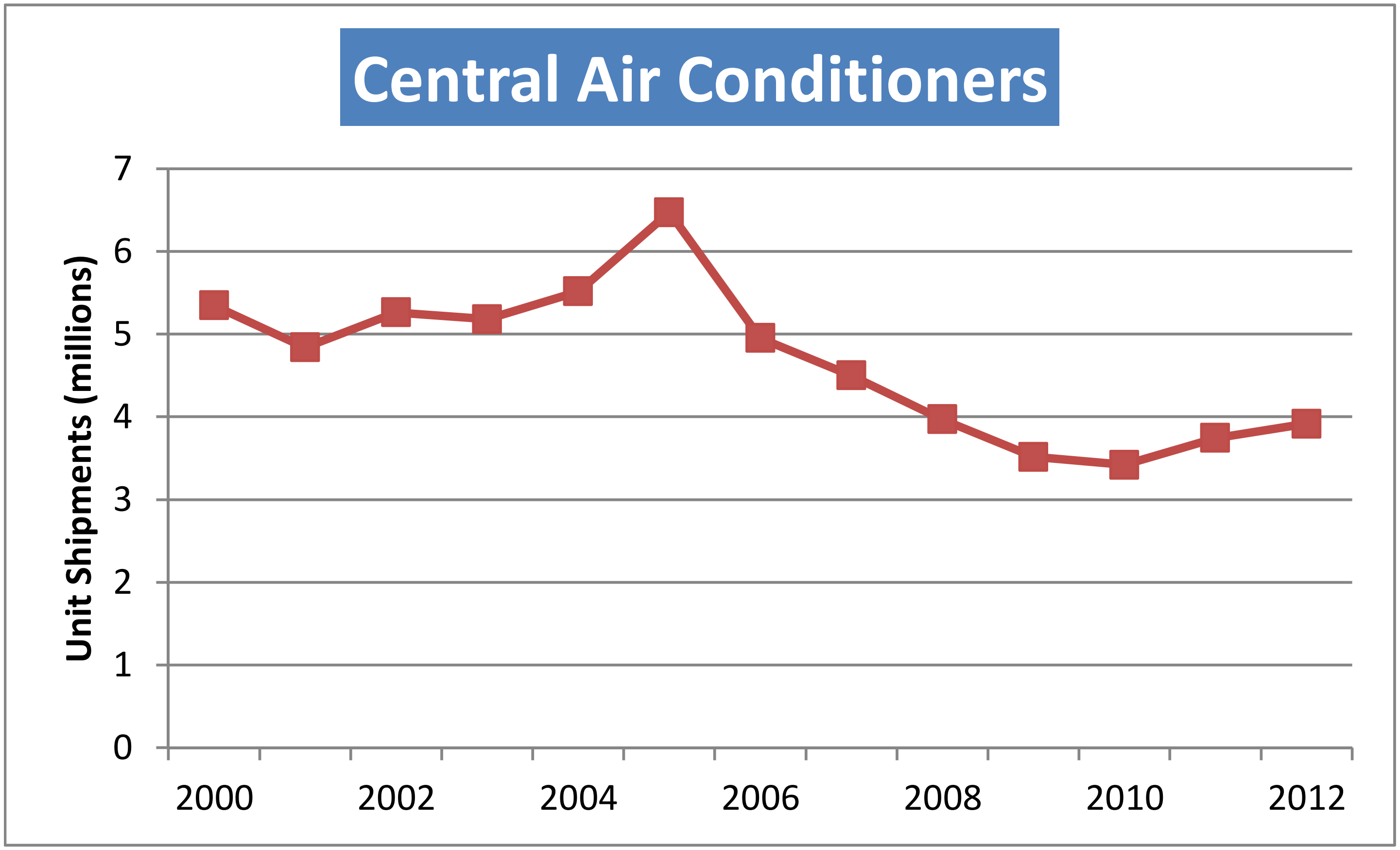
Final

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.

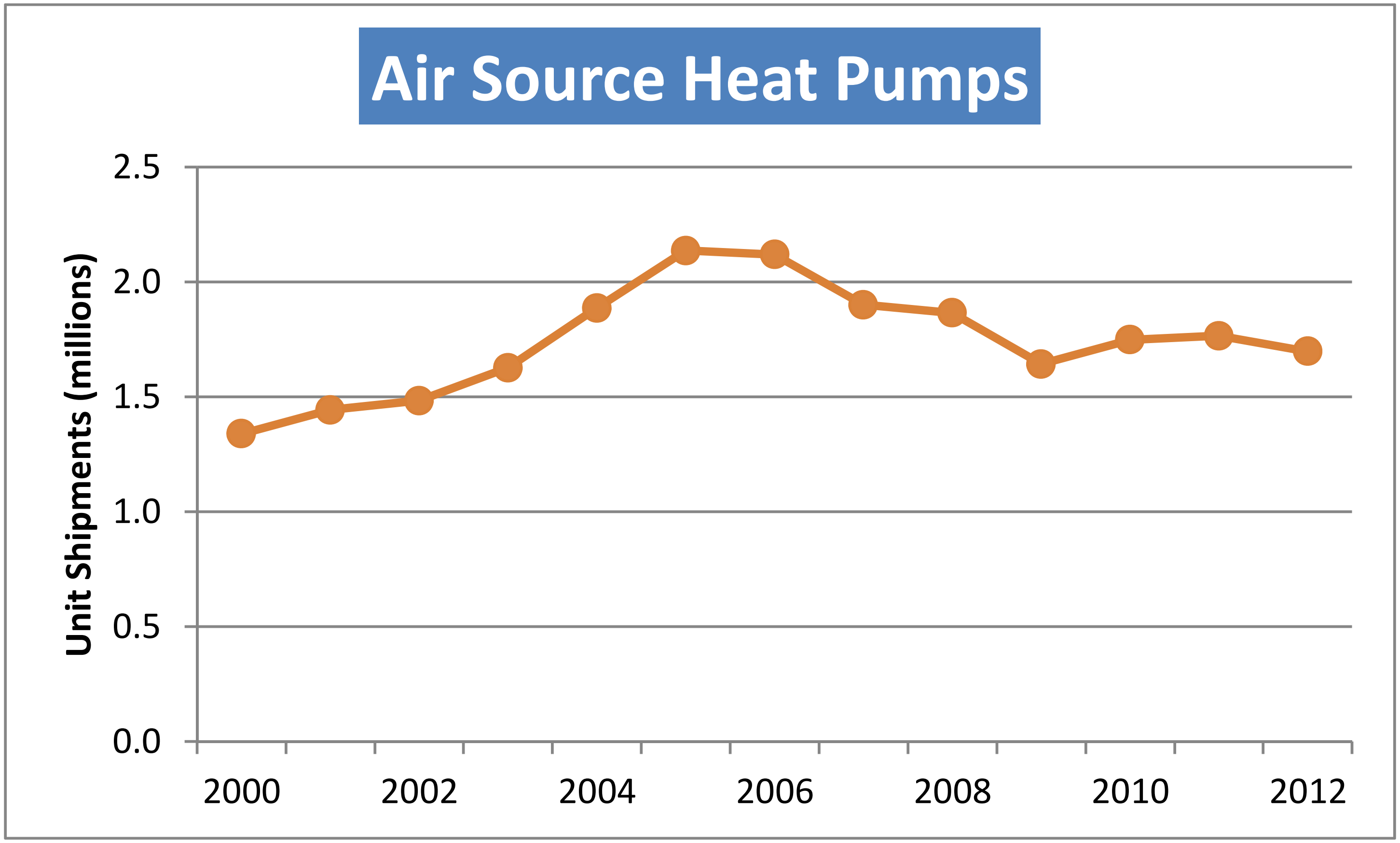
Final

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.

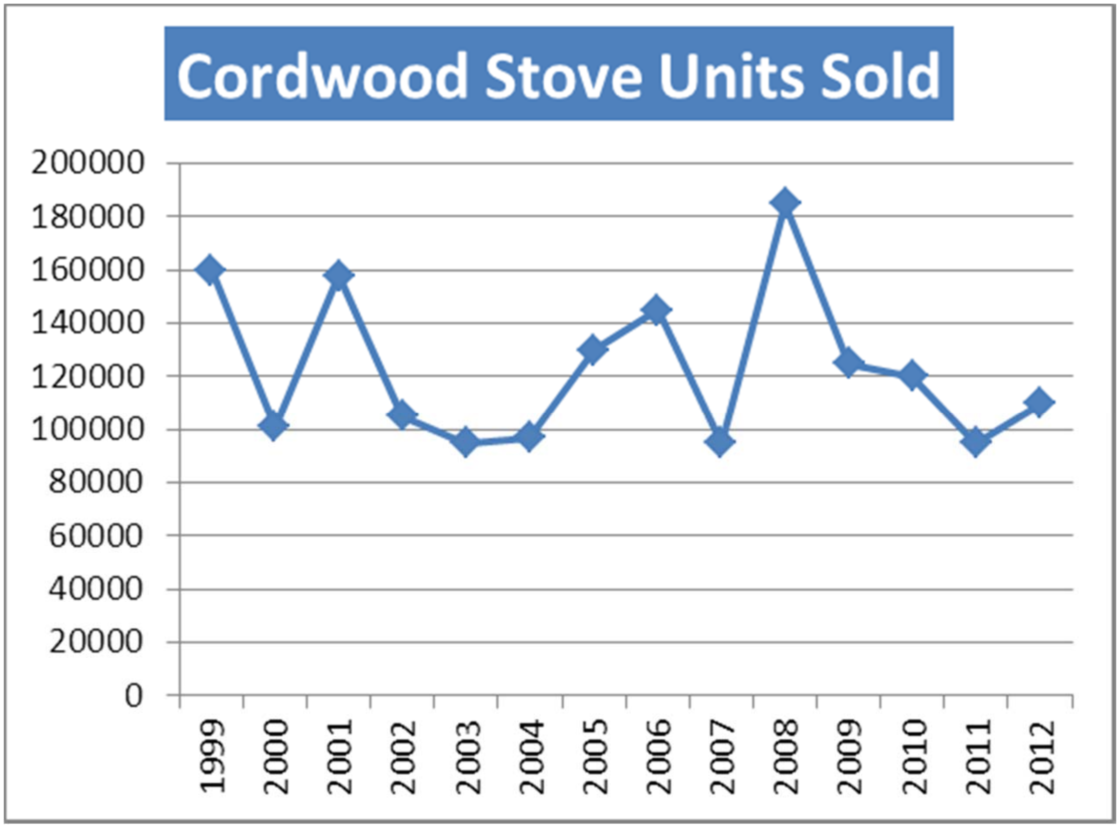
Final

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.

- 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

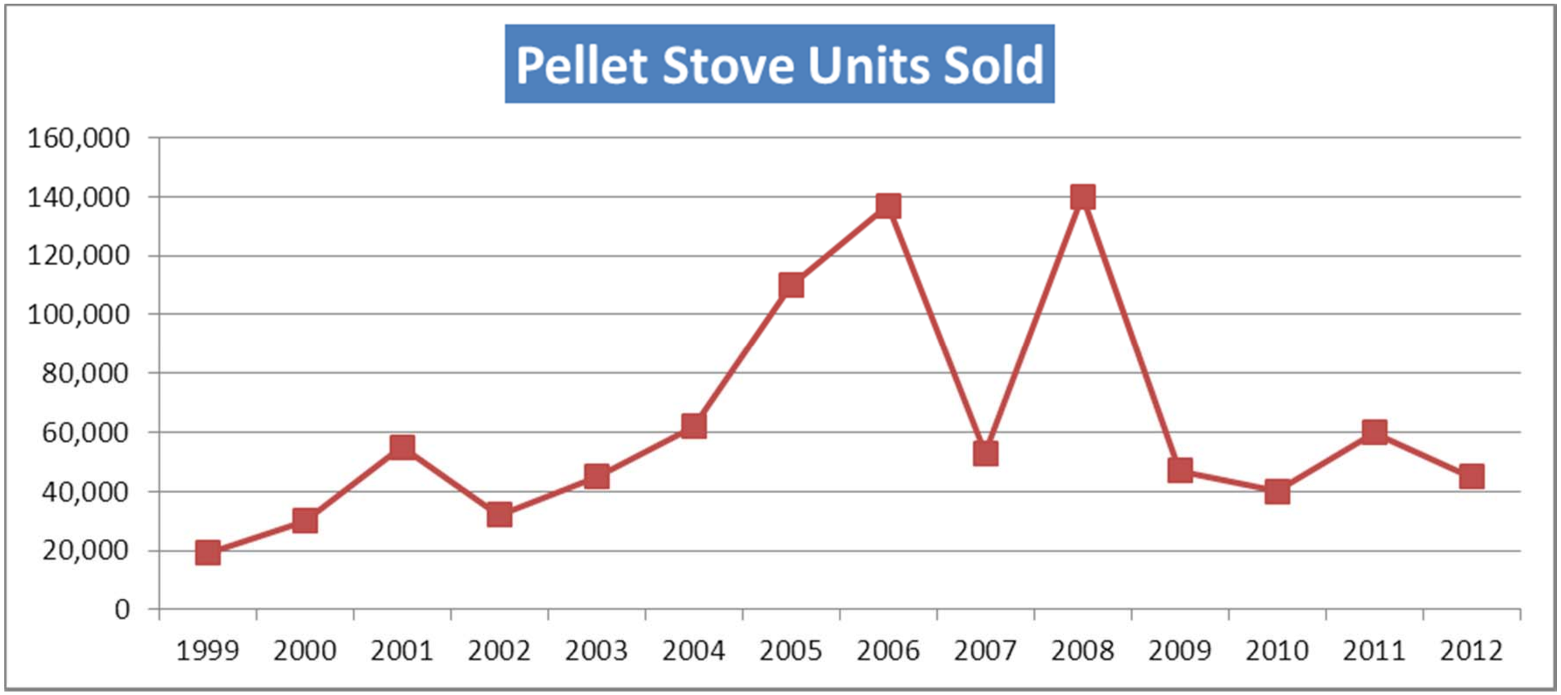
DATA	2009	2013			2020		2030		2040	
	Installed Base	EPA Certified (Default)	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)	65	78	78	81	81	84	83	86	84	87
Annual Electricity Consumption (kWh)	1,200	1,200	1,200	1,200	1,200	1,200	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.

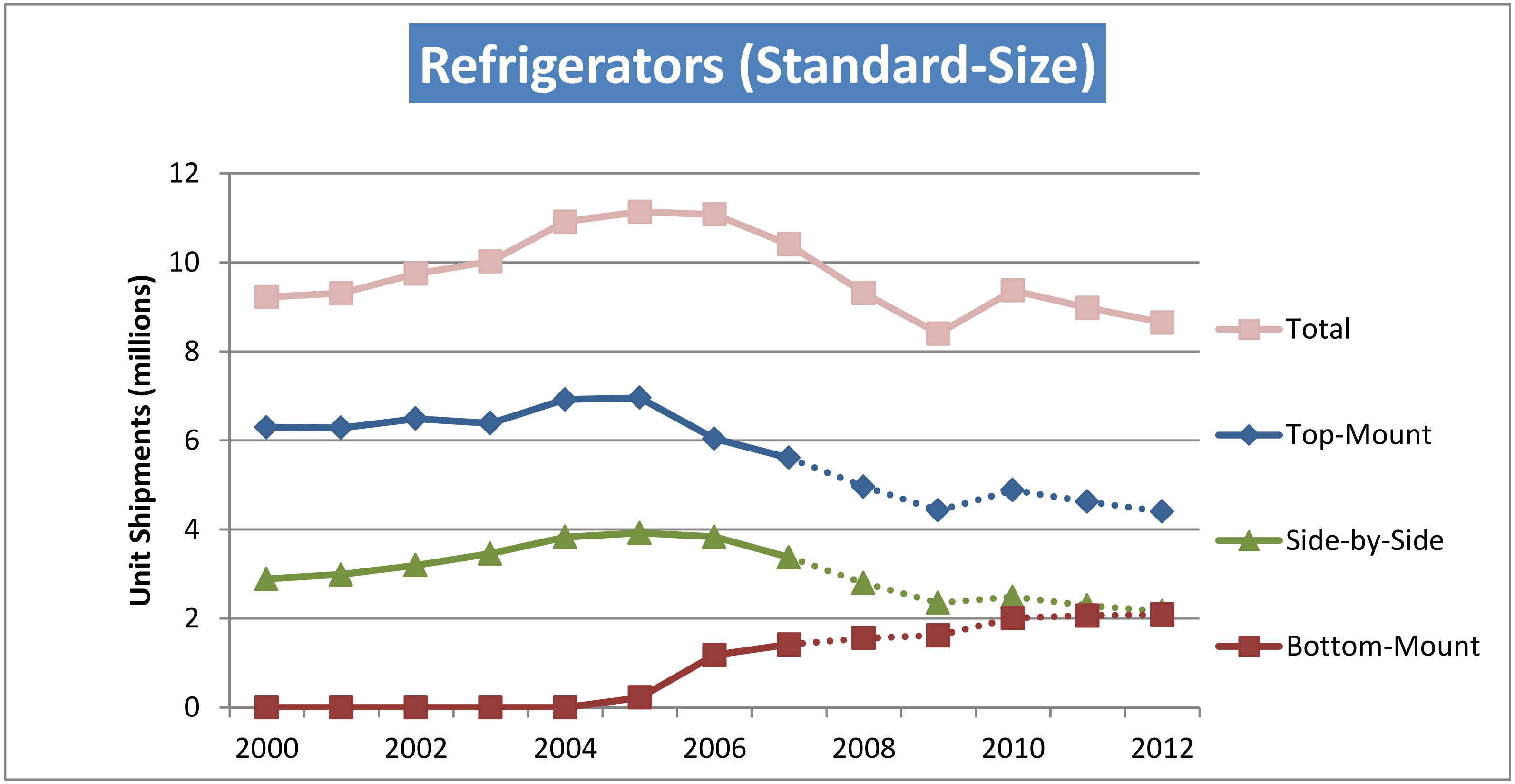
Final

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

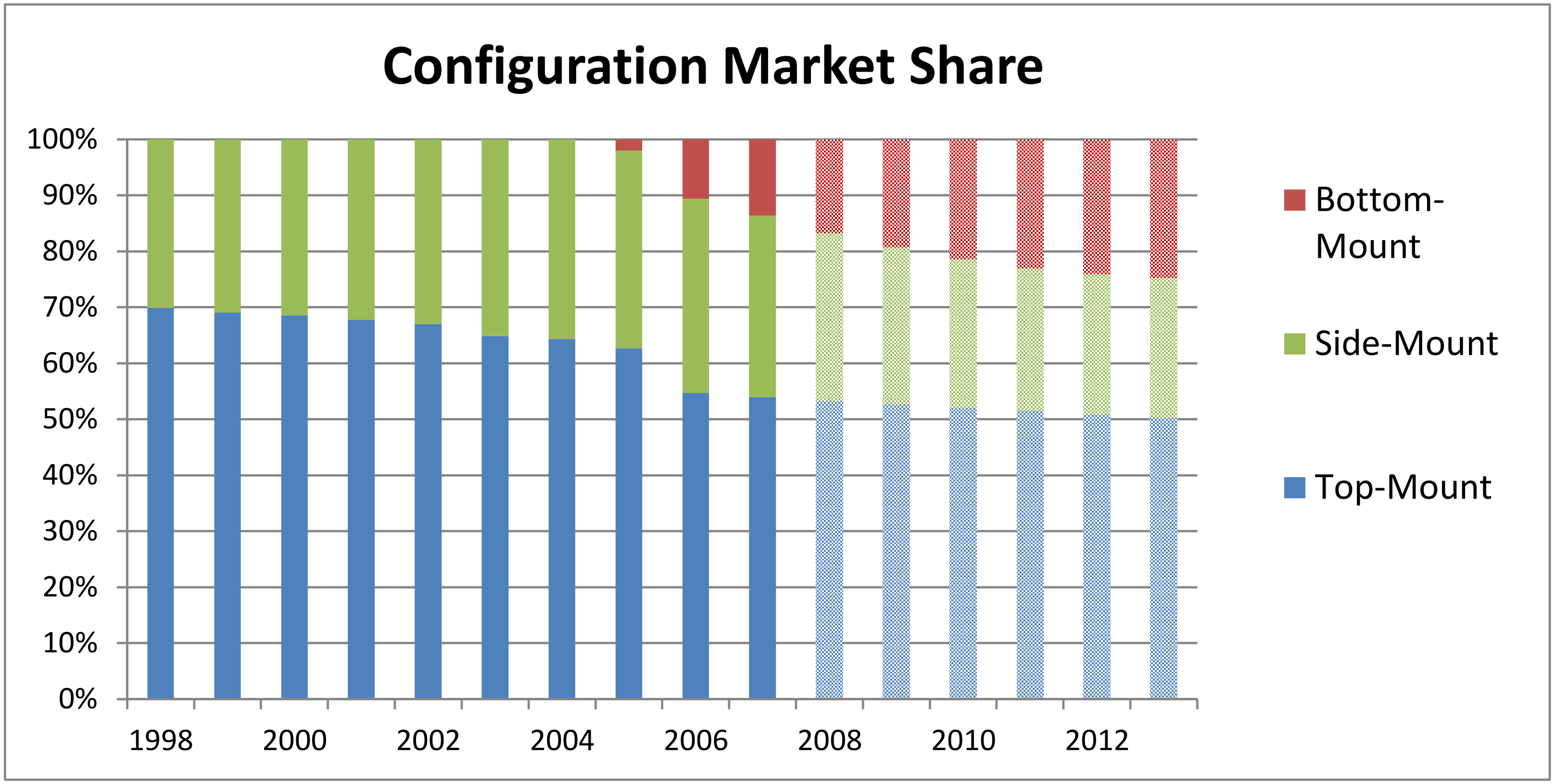
[1]Adjusted Volume (AV) = (Fresh Volume) + 1.63 × (Freezer Volume). Beginning in 2004, the 1.63 coefficient will change to 1.76.

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).

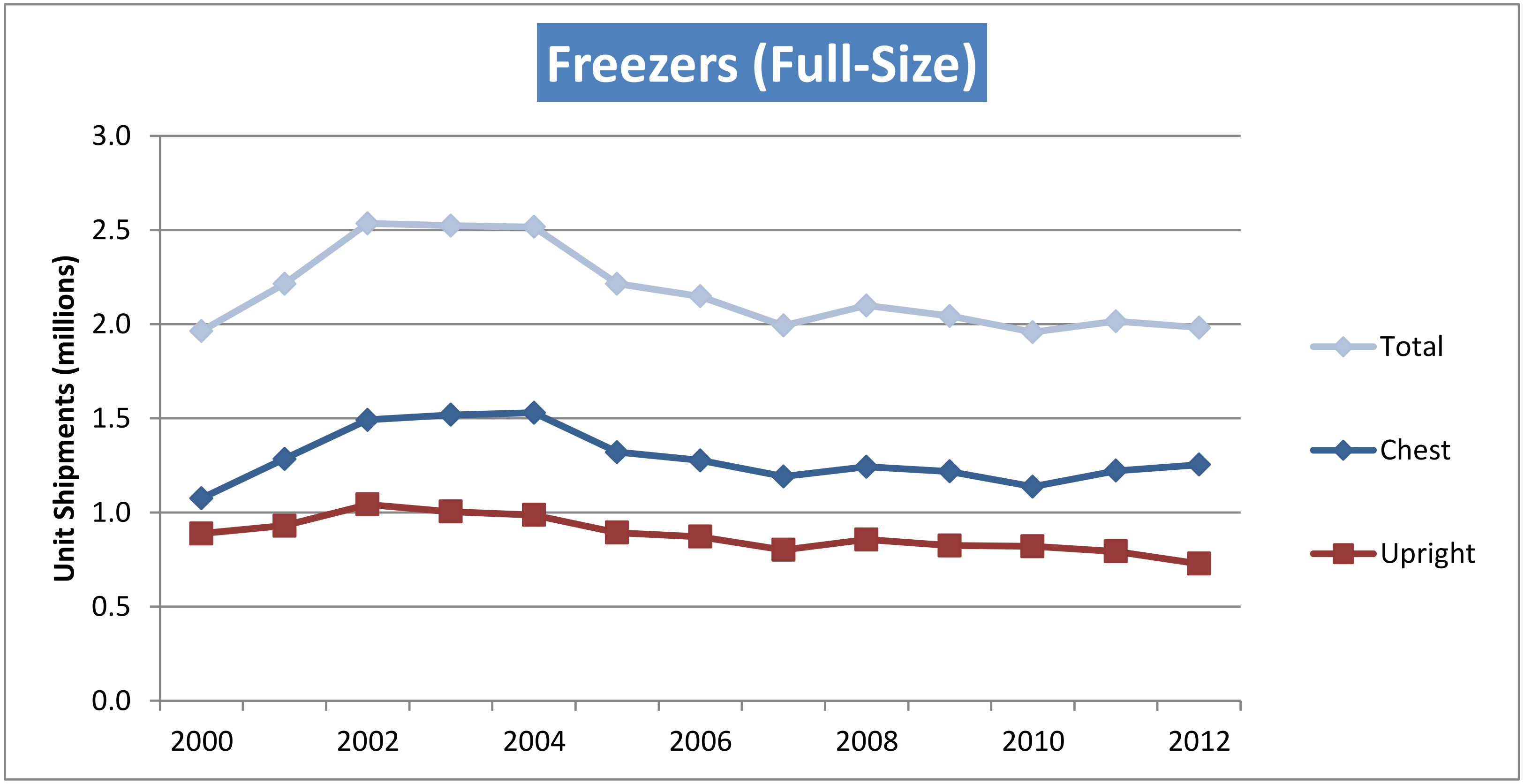
Final

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*.

Residential Natural Gas Cooktops and Stoves

Same as reference case

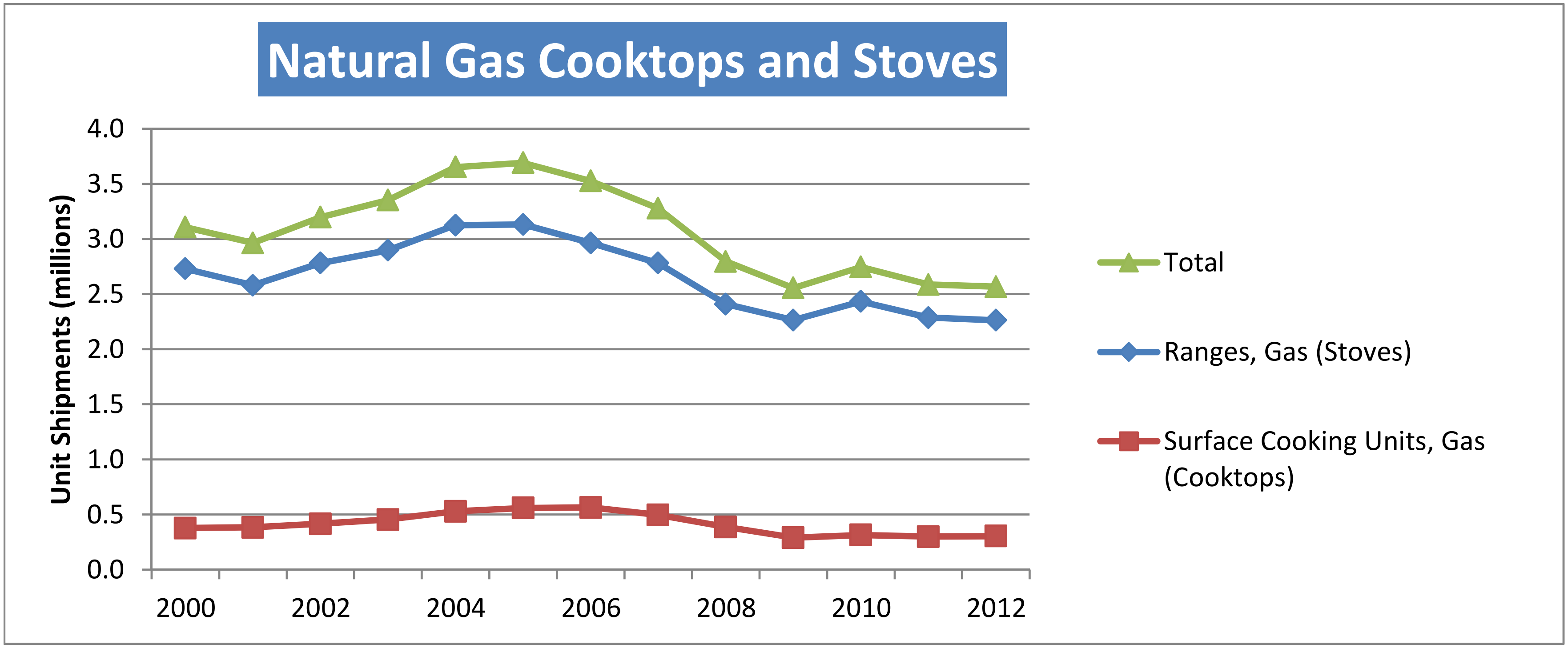
DATA	2009	2013		2020		2030		2040	
	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9
	12	12	12	12	12	12	12	12	12
Cooking Efficiency (%)	38.5	39.9	42	39.9	42	39.9	42	39.9	42
Average Life (yrs)	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	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.

Final

Residential Clothes Washers

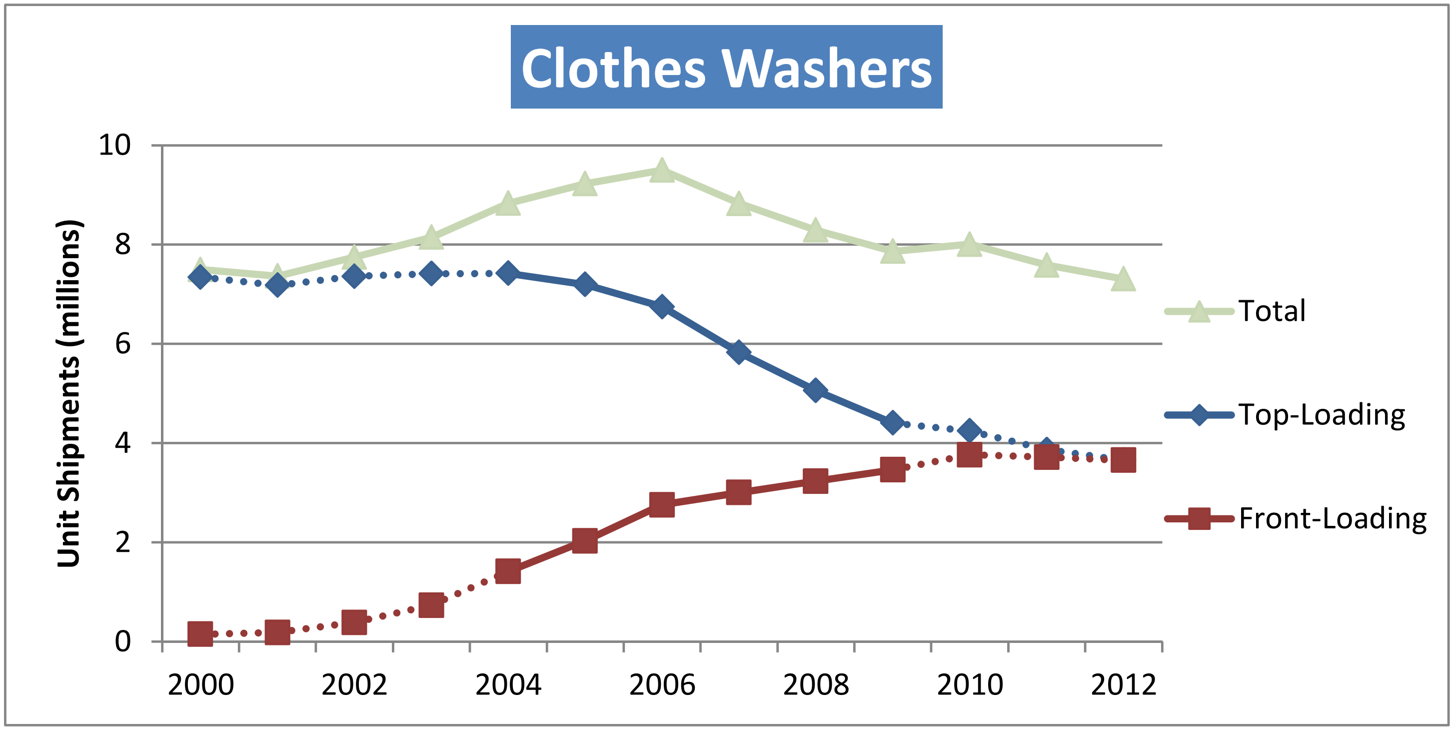
- Present analysis treats front- and top-loading models separately. Past analyses did not consider the two types separately.
- Federal standards for standard-capacity clothes washers (≥ 1.6 cubic feet):

	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

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.

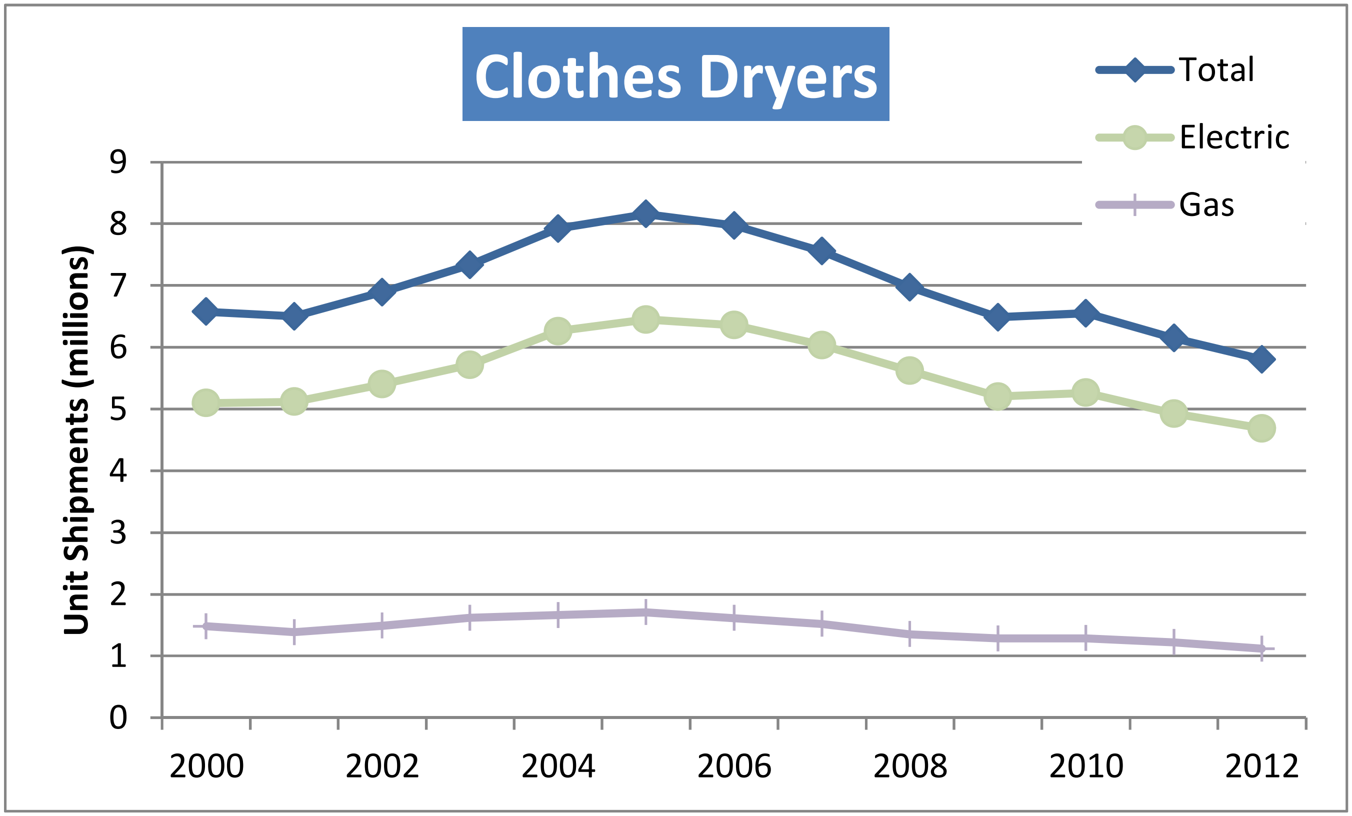
Residential Clothes Dryers

- 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.

Final

Residential Clothes Dryers

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.*

Residential Dishwashers

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

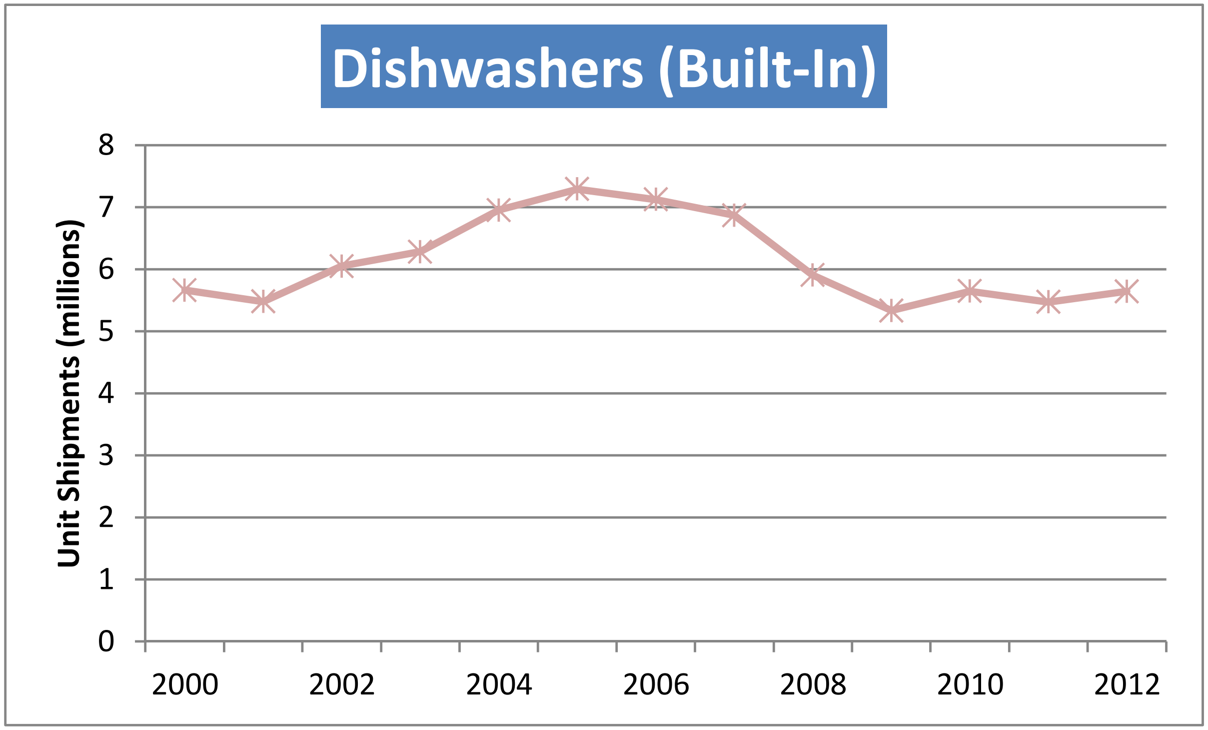
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/yr)	312	307	295	295	180	275	180	275	180	275	180
Water Consumption (gal/cycle)	4.50	5.00	4.25	4.25	2.22	4.00	2.22	4.00	2.22	4.00	2.22
Water 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

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*

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

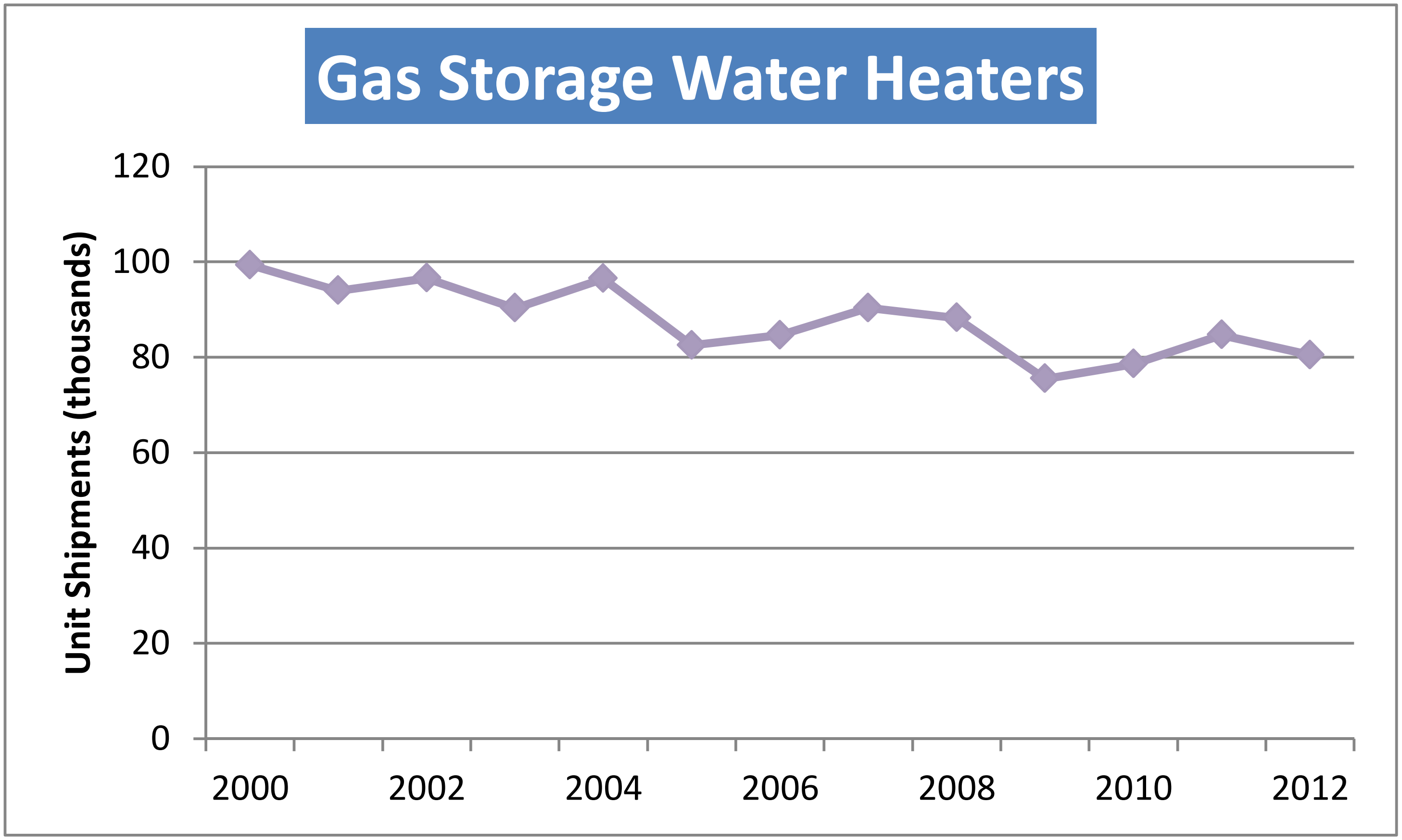
Higher typical efficiencies than ref. case

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

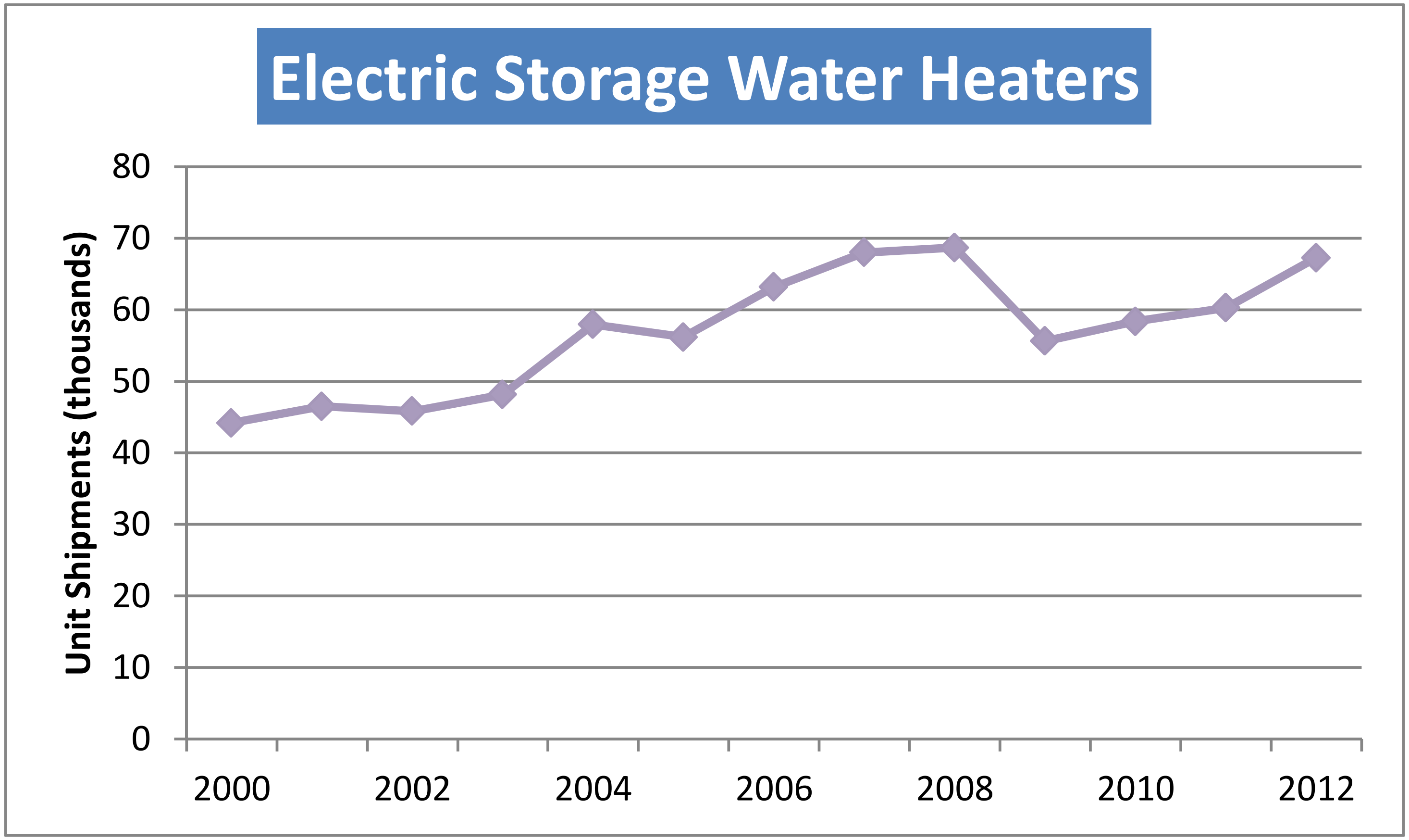
Same as reference case

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.

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.

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 $12 \leq V < 28$:
  - State standards: **$\leq 40 \times V$** (baseline)
  - ENERGY STAR: **$\leq 2.0 \times V + 254$** (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

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.

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				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

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				

Final

Data Sources » Residential Cord Wood Stoves

<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					

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							

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							

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				

Final

Data Sources » Commercial Gas-Fired Boilers

<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>Mid-Range</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td colspan="6">Navigant</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="2">ASHRAE Standard 90.1-2004 / Navigant</td><td>EERE</td><td colspan="3">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>CEC / RS Means 2010</td><td>RS Means 2011</td><td colspan="4">RS Means 2011</td></tr>
<tr><td>Total Installed Cost ($)</td><td>CEC / RS Means 2010</td><td>RS Means 2011</td><td colspan="4">RS Means 2011</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">Navigant</td></tr>
</table>

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

SOURCES	2003		2012		2013		2020	2030	2040
	Installed Base				Absorption	Engine-Driven	Absorption / Engine-Driven		
	Absorption	Engine-Driven	Absorption	Engine-Driven					
Typical Capacity (tons)	BSRIA/Distributors						SAIC		
Efficiency (kW/ton)	Product Literature/SAIC								
COP	Product Literature/SAIC								
Average Life (yrs)	2007 ASHRAE Applications Handbook/Distributors								
Retail Equipment Cost ($/ton)	Manufacturer/Distributors/RS Means 2013/GIT/SAIC								
Total Installed Cost ($/ton)	Manufacturer/Distributors/RS Means 2013/GIT/SAIC								
Annual Maintenance Cost ($/ton)	Manufacturer/Distributors/RS Means 2013/GIT/SAIC								

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

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	Mid	High	Typical / High		
Typical Capacity (tons)	SAIC						SAIC		
Efficiency (kW/ton)	DEER/FEMP/ Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC					
COP	DEER/FEMP/ Product Literature	SAIC	ASHRAE 90.1-2010	Product Literature/SAIC					
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								

Final

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

<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 Output Capacity (kBtu/h)</td><td colspan="6">AHRI / Navigant</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Efficiency (EER)</td><td>ASHRAE Standard 90.1-2004</td><td>Distributors/ Navigant</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost $)</td><td>Navigant / LBNL, 2003</td><td>Distributors/ Navigant / DEER, 2008</td><td colspan="2">EERE</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Navigant / LBNL, 2003</td><td>Distributors/ Navigant / DEER, 2008</td><td colspan="2">EERE</td><td colspan="2">Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">EERE</td></tr>
</table>

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

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBtu/h)	AHRI / Navigant						Navigant		
Efficiency (EER)	ASHRAE Standard 90.1-2004 / Navigant		EERE		ENERGY STAR	EERE			
COP (Heating)	EERE / Navigant		EERE		ENERGY STAR	EERE			
Average Life (yrs)	EERE								
Retail Equipment Cost ($)	Distributors / RS Means 2010 / DEER / Navigant								
Total Installed Cost ($)	Distributors / RS Means 2010 / DEER / Navigant								
Annual Maintenance Cost ($)	Distributors / RS Means 2010 / DEER / Navigant								

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)								

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>
</table>

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

<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 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>
</table>

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>
<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 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

<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>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<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>
</table>

SOURCES	2003	2012	2013				2020	2030	2040
	Installed Base		Current Standard	Typical	ENERGY STAR	High	Typical / High		
Interior Volume (ft^3)	FEMP						Navigant		
Maximum Idle Energy Rate (W)	CEE / Navigant		ENERGY STAR Savings Calculator			FEMP			
Average Life (yrs)	ENERGY STAR Savings Calculator								
Retail Equipment Cost ($)	Distributors / ENERGY STAR Savings Calculator / Navigant								
Total Installed Cost ($)	Navigant								
Annual Maintenance Cost ($)	FSTC								

Appendix B
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APPENDIX C

Final

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

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August 2016

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.

  - 2003/2012 (commercial) and 2009 (residential) baselines, as well as today's (2015)
    - 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.

- The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (for commercial products) 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.
  - Installed Base: the installed and “in use” equipment for that year. Represents the installed stock of equipment, but does NOT represent sales.
  - Current Standard: the minimum efficiency (or maximum energy use) required (allowed) by current DOE standards, when applicable.
  - ENERGY STAR: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable. Presented performance data represents certified products just meeting current ENERGY STAR specifications.
  - Low: The minimum available efficiency product or product mix available on the market. This typically reflects minimal compliance with DOE standards.
  - Typical: the average, or “typical,” product being sold in the particular timeframe.
  - High: the product with the highest efficiency available in the particular timeframe.
  - Lumens: All reported lumens are initial lumens.
  - Correlated Color Temperature (CCT): a specification of the color appearance of the light emitted by a lamp.
  - Color Rendering Index (CRI): a scale from 0 to 100 percent indicating how accurate a "given" light source is at rendering color when compared to a "reference" light source. The higher the CRI, the better the color rendering ability.

- The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric
  - **Lighting**
    - **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))
  - **Commercial Refrigeration**
    - **Nominal Capacity over Average Input (Btu in / Btu out)** = (Cooling or Heat Rejection Capacity)*24*365/(Annual Energy Consumption * 3412)
    - **Total Installed Cost** = Retail Equipment Cost + Labor Installation Cost
    - **Total Installed Cost ($/kBtu/hr)** = Total Installed Cost*1000 / (Cooling or Heat Rejection Capacity)
    - **Annual Maintenance Cost ($/kBtu/hr)** = Annual Maintenance Cost * 1000 / (Cooling or Heat Rejection Capacity)
  - **Ventilation**
    - **CFM out / Btu in / hr** = System Airflow / (System Fan Power * 3412)
    - **Total Installed Cost ($/1000 CFM)** = Total Installed Cost * 1000 / System Airflow
    - **Annual Maintenance Cost ($/1000 CFM)** = Annual Maintenance Cost * 1000 / System Fan Power

- The market for the reviewed products has changed since the analysis was performed in 2012. These changes are noted and reflected in the efficiency and cost characteristics.
  - DOE issued Federal minimum efficiency standards that have or will soon go into effect for General Service Fluorescent Lamps (effective 2012), Incandescent Reflector Lamps (July 2012), Fluorescent Lamp Ballasts (2014), Refrigerated Beverage Vending Machines (2012), Automatic Commercial Ice Makers (2018), Walk-In Coolers and Freezers (2017) and Commercial Refrigeration Equipment (2017). DOE published a Final Rule updating energy conservation standards for Refrigerated Beverage Vending Machines at the end of 2015, effective in 2018.

Residential Lighting

The residential general service lamps characterized in this report are a 60 watt and a 75 watt medium screw based A-type incandescent lamp and their halogen, CFL, and LED equivalents. A standard 60 watt incandescent lamp produces approximately 800 lumens. A standard 75 watt incandescent lamp produces approximately 1100 lumens (ENERGY STAR Program).

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 652 hours/year for residential general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60 watt general service lamps effective in 2014 and 75 watt lamps effective in 2013. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- 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. California's Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies 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, halogen, and CFL technologies.
- 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. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- Beginning in 2017, California's Title 24 will require all light sources to be high efficacy. All general service lamps with medium screw bases must meet the following requirements: initial efficacy ≥45 lm/W, power factor ≥0.90, CCT ≤3000K, CRI ≥90, rated life ≥15,000 hours.
- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage <15W and ≥15W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	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.

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

DATA	2009	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	14.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$0.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$0.16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$0.29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 60 watt incandescent lamps as of January 1, 2014. Starting in 2014, 60 watt incandescent lamps were replaced by halogen lamps.

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

DATA	2009	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1170	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	15.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	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 2013, 75 watt incandescent lamps were replaced by halogen lamps.

DATA	2009	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	44	N/A	43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	750	N/A	750	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	16.9	N/A	17.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$2.05	N/A	$1.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$2.73	N/A	$2.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$2.05	N/A	$1.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$1.38	N/A	$1.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$2.73	N/A	$2.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$1.83	N/A	$1.73	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 60 watt incandescent lamps as of January 1, 2014. Starting in 2014, 60 watt incandescent lamps were replaced by halogen lamps.
2. In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards cannot be met with existing commercialized halogen lamp technologies and current trends in industry lead us to believe they will not be met.

DATA	2009	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	55	N/A	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1050	N/A	1050	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	19.2	N/A	19.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$1.38	N/A	$1.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$1.32	N/A	$1.24	N/A	N/A	N/A	N/A	N/A	N/A	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 2013, 75 watt incandescent lamps were replaced by halogen lamps.
2. In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards cannot be met with existing commercialized halogen lamp technologies and current trends in industry lead us to believe they will not be met.

Performance/Cost Characteristics » Residential General Service Compact Fluorescent Lamps

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	13	14	13	13	14	13	13	12	12	11	11
Lamp Lumens	825	850	897	926	800	897	926	897	926	897	926
Lamp Efficacy (lm/W)	63.5	60.7	68.9	71.2	58.0	70.6	73.0	74.2	76.7	78.0	80.6
CRI	82	82	82	82	82	82	82	82	82	82	82
Correlated Color Temperature (CCT)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	10.0	10.0	10.0	10.0	10.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	652	652	652	652	N/A	652	652	652	652	652	652
Lamp Price ($)	$2.15	$2.74	$2.03	$5.49	N/A	$1.98	$5.35	$1.89	$5.09	$1.79	$4.84
Lamp Cost ($/klm)	$2.61	$3.22	$2.27	$5.93	N/A	$2.21	$5.78	$2.10	$5.50	$2.00	$5.23
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Installation (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($/klm)	$2.15	$2.74	$2.03	$5.49	N/A	$1.98	$5.35	$1.89	$5.09	$1.79	$4.84
Annual Maintenance Cost ($)	$0.14	$0.18	$0.13	$0.36	N/A	$0.13	$0.34	$0.11	$0.31	$0.10	$0.28
Total Installed Cost ($/klm)	$2.61	$3.22	$2.27	$5.93	N/A	$2.21	$5.78	$2.10	$5.50	$2.00	$5.23
Annual Maintenance Cost ($/klm)	$0.17	$0.21	$0.15	$0.39	N/A	$0.14	$0.37	$0.13	$0.33	$0.12	$0.30

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential General Service LED Lamps (60 Watt Equivalent)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	8	7	6	5	5	4
Lamp Lumens	800	850	837	865	800	840	840	840	840	840	840
Lamp Efficacy (lm/W)	44	64	93	104	59	102	123	131	171	161	219
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	652	652	652	652	652	652	652	652	652	652	652
Lamp Price ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$5.89	$5.89	$3.00	$3.00	$2.00	$2.00
Lamp Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$5.89	$5.89	$3.00	$3.00	$2.00	$2.00
Annual Maintenance Cost ($)	$2.22	$0.63	$0.20	$0.13	$0.31	$0.08	$0.08	$0.04	$0.04	$0.03	$0.03
Total Installed Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Annual Maintenance Cost ($/klm)	$2.77	$0.74	$0.23	$0.15	$0.39	$0.10	$0.09	$0.05	$0.05	$0.03	$0.03

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available, and meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

The residential reflector lamps characterized in this report are directional lamps that emit between approximately 550-750 lumens. Multiple baseline reflector lamps were analyzed, including: 65W Incandescent BR30, Halogen PAR30, Halogen Infrared Reflector (HIR) PAR30, CFL BR30, LED BR30, LED PAR38.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 642 hours/year for residential reflector lamps (DOE SSL Program, 2012a).

Legislation:

- 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. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for directional lamps with CRI ≥ 90 and 70 lm/W for directional lamps with CRI < 90 (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, 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.

Performance/Cost Characteristics » Residential Reflector Lamps (65W BR30 Incandescent)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	65	N/A	65	N/A	N/A	64	N/A	63	N/A	62	N/A
Lamp Lumens	620	N/A	637	N/A	N/A	637	N/A	637	N/A	637	N/A
Lamp Efficacy (lm/W)	9.5	N/A	9.8	N/A	N/A	9.9	N/A	10.1	N/A	10.3	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2700	N/A	2700	N/A	N/A	2700	N/A	2700	N/A	2700	N/A
Average Lamp Life (1000 hrs)	2.0	N/A	2.0	N/A	N/A	2.1	N/A	2.2	N/A	2.3	N/A
Annual Operating Hours (hrs/yr)	642	N/A	642	N/A	N/A	642	N/A	642	N/A	642	N/A
Lamp Price ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Lamp Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Annual Maintenance Cost ($)	$0.44	N/A	$1.08	N/A	N/A	$1.03	N/A	$0.93	N/A	$0.84	N/A
Total Installed Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Annual Maintenance Cost ($/klm)	$0.71	N/A	$1.70	N/A	N/A	$1.61	N/A	$1.46	N/A	$1.32	N/A

Performance/Cost Characteristics » Residential Reflector Lamps (PAR30 Halogen)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	50	N/A	47	N/A	N/A	46	N/A	44	N/A	42	N/A
Lamp Lumens	660	N/A	660	N/A	N/A	660	N/A	660	N/A	660	N/A
Lamp Efficacy (lm/W)	13.2	N/A	14.0	N/A	N/A	14.4	N/A	15.1	N/A	15.9	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	1.4	N/A	1.5	N/A	N/A	1.5	N/A	1.6	N/A	1.7	N/A
Annual Operating Hours (hrs/yr)	642	N/A	642	N/A	N/A	642	N/A	642	N/A	642	N/A
Lamp Price ($)	$4.19	N/A	$5.71	N/A	N/A	$5.57	N/A	$5.30	N/A	$5.04	N/A
Lamp Cost ($/klm)	$6.35	N/A	$8.65	N/A	N/A	$8.44	N/A	$8.02	N/A	$7.63	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$4.19	N/A	$5.71	N/A	N/A	$5.57	N/A	$5.30	N/A	$5.04	N/A
Annual Maintenance Cost ($)	$1.92	N/A	$2.44	N/A	N/A	$2.32	N/A	$2.10	N/A	$1.90	N/A
Total Installed Cost ($/klm)	$6.35	N/A	$8.65	N/A	N/A	$8.44	N/A	$8.02	N/A	$7.63	N/A
Annual Maintenance Cost ($/klm)	$2.91	N/A	$3.70	N/A	N/A	$3.52	N/A	$3.18	N/A	$2.88	N/A

Performance/Cost Characteristics » Residential Reflector Lamps (PAR30 Halogen Infrared Reflector (HIR)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	40	N/A	39	N/A	N/A	38	N/A	36	N/A	34	N/A
Lamp Lumens	650	N/A	650	N/A	N/A	650	N/A	650	N/A	650	N/A
Lamp Efficacy (lm/W)	16.2	N/A	16.7	N/A	N/A	17.1	N/A	18.0	N/A	18.9	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	3.9	N/A	4.0	N/A	N/A	4.1	N/A	4.3	N/A	4.5	N/A
Annual Operating Hours (hrs/yr)	642	N/A	642	N/A	N/A	642	N/A	642	N/A	642	N/A
Lamp Price ($)	$12.76	N/A	$12.38	N/A	N/A	$12.07	N/A	$11.48	N/A	$10.92	N/A
Lamp Cost ($/klm)	$19.63	N/A	$19.05	N/A	N/A	$18.57	N/A	$17.67	N/A	$16.80	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$12.76	N/A	$12.38	N/A	N/A	$12.07	N/A	$11.48	N/A	$10.92	N/A
Annual Maintenance Cost ($)	$2.11	N/A	$1.99	N/A	N/A	$1.89	N/A	$1.71	N/A	$1.55	N/A
Total Installed Cost ($/klm)	$19.63	N/A	$19.05	N/A	N/A	$18.57	N/A	$17.67	N/A	$16.80	N/A
Annual Maintenance Cost ($/klm)	$3.24	N/A	$3.05	N/A	N/A	$2.91	N/A	$2.63	N/A	$2.38	N/A

Performance/Cost Characteristics » Residential Reflector Lamps (BR30 CFL)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	16	14	15	15	15	14	15	14	14	13	13
Lamp Lumens	750	600	700	750	650	700	750	700	750	700	750
Lamp Efficacy (lm/W)	46.9	42.9	47.4	50.0	43.3	48.6	51.3	51.1	53.9	53.7	56.6
CRI	82	82	82	82	82	82	82	82	82	82	82
Correlated Color Temperature (CCT)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	8.0	10.0	10.0	10.0	10.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	642	642	642	642	N/A	642	642	642	642	642	642
Lamp Price ($)	$5.87	$6.98	$5.46	$5.60	N/A	$5.32	$5.46	$5.06	$5.19	$4.82	$4.94
Lamp Cost ($/klm)	$7.82	$11.63	$7.80	$7.47	N/A	$7.61	$7.28	$7.24	$6.93	$6.88	$6.59
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($)	$5.87	$6.98	$5.46	$5.60	N/A	$5.32	$5.46	$5.06	$5.19	$4.82	$4.94
Annual Maintenance Cost ($)	$0.47	$0.45	$0.35	$0.36	N/A	$0.33	$0.34	$0.30	$0.31	$0.27	$0.28
Total Installed Cost ($/klm)	$7.83	$11.63	$7.80	$7.47	N/A	$7.61	$7.28	$7.24	$6.93	$6.88	$6.59
Annual Maintenance Cost ($/klm)	$0.63	$0.75	$0.50	$0.48	N/A	$0.48	$0.46	$0.43	$0.41	$0.39	$0.37

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Reflector LED BR30

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	18	11	10	8	12	8	6	6	5	5	4
Lamp Lumens	600	670	794	699	605	700	700	700	700	700	700
Lamp Efficacy (lm/W)	33	59	78	89	50	91	109	117	153	144	196
CRI	80	95	84	82	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	5000	2700	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$8.63	$8.63	$4.90	$4.90	$2.80	$2.80
Lamp Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$8.63	$8.63	$4.90	$4.90	$2.80	$2.80
Annual Maintenance Cost ($)	$3.16	$0.33	$0.38	$0.54	$1.91	$0.11	$0.11	$0.06	$0.06	$0.04	$0.04
Total Installed Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Annual Maintenance Cost ($/klm)	$5.26	$0.50	$0.48	$0.77	$3.16	$0.16	$0.16	$0.09	$0.09	$0.05	$0.05

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Reflector LED PAR38

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	28	18	16	17	20	15	13	12	9	10	7
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	91	109	117	153	144	196
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Annual Maintenance Cost ($)	$5.26	$0.66	$0.64	$0.94	$0.88	$0.23	$0.23	$0.13	$0.13	$0.07	$0.07
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Annual Maintenance Cost ($/klm)	$5.26	$0.56	$0.48	$0.48	$0.84	$0.16	$0.16	$0.09	$0.09	$0.05	$0.05

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- 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.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. The LED luminaire is more efficient and cost effective for new installations or fixture retrofits.
- Labor costs for lamp changes are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore annual maintenance costs are the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 684 hours/year for residential linear systems(DOE SSL Program, 2012a).

Legislation:

- 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 (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T12	0%	0%	-0.5%	Limited as the technology is mature.
T8	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Residential Linear Fluorescent Lamp T12

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	2860	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens	3890	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	78%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	4100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours	684	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.92	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price ($)	$11.22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$25.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$9.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$68.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hr)	0.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$35.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$1.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$9.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.41	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Performance/Cost Characteristics » Residential Linear Fluorescent Lamp T8

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	32	32	32	28	32	32	28	31	27	30	27
Lamp Lumens	2520	2725	2770	2590	2800	2770	2590	2770	2590	2770	2590
Lamp Efficacy (lm/W)	79	85	87	93	88	87	93	89	95	91	97
System Wattage	65	61	61	54	60	60	53	59	52	58	51
System Lumens	4435	4796	4875	4558	4410	4875	4558	4875	4558	4875	4558
System Efficacy (lm/W)	69	79	80	85	74	81	86	82	88	84	89
Ballast Efficiency (BLE)	87%	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
CRI	75	83	85	85	80	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	3000	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	24	21	24	10	22	25	23	26	24	27
Annual Operating Hours	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$0.85	$4.99	$5.51	$8.23	$4.79	$5.37	$8.03	$5.11	$7.63	$4.86	$7.26
Ballast Price ($)	$9.94	$16.10	$16.10	$16.10	N/A	$15.70	$15.70	$14.93	$14.93	$14.20	$14.20
Fixture Price ($)	$25.01	$24.64	$24.64	$24.64	$24.98	$24.03	$24.03	$22.86	$22.86	$21.74	$21.74
Lamp Cost ($/klm)	$0.34	$1.83	$1.99	$3.18	$1.71	$1.94	$3.10	$1.85	$2.95	$1.75	$2.80
System (l/b/f) Cost ($/klm)	$14.55	$18.61	$18.69	$22.09	$12.34	$18.22	$21.54	$17.33	$20.49	$16.49	$19.48
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$98.62	$123.37	$125.20	$134.78	$88.53	$122.95	$132.28	$118.60	$127.48	$114.47	$122.92
Annual Maintenance Cost ($)	$0.06	$0.28	$0.36	$0.47	$0.66	$0.34	$0.45	$0.31	$0.40	$0.28	$0.37
Total Installed Cost ($/klm)	$22.24	$25.72	$25.68	$29.57	$20.08	$25.22	$29.02	$24.33	$27.97	$23.48	$26.97
Annual Maintenance Cost ($/klm)	$0.01	$0.06	$0.07	$0.10	$0.15	$0.07	$0.10	$0.06	$0.09	$0.06	$0.08

1. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	28	28	28	28	28	28	27	27	27	27
Lamp Lumens	2660	2446	2697	2898	2900	2697	2898	2697	2898	2697	2898
Lamp Efficacy (lm/W)	95	87	96	104	104	97	105	99	107	101	109
System Wattage	63	61	61	61	56	60	60	59	59	58	58
System Lumens	5320	4892	5394	5796	4350	5394	5796	5394	5796	5394	5796
System Efficacy (lm/W)	84	80	89	95	78	90	96	91	98	93	100
Ballast Efficiency (BLE)	89%	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
CRI	85	85	85	85	80	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	3500	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	30	30	30	10	31	31	32	32	34	34
Annual Operating Hours	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$3.18	$4.10	$5.94	$7.06	$7.20	$5.79	$6.89	$5.51	$6.55	$5.24	$6.23
Ballast Price ($)	$20.94	$26.28	$26.28	$26.28	N/A	$25.63	$25.63	$24.38	$24.38	$23.18	$23.18
Fixture Price ($)	$94.07	$92.67	$92.67	$92.67	$79.97	$90.38	$90.38	$85.96	$85.96	$81.76	$81.76
Lamp Cost ($/klm)	$0.60	$1.68	$2.20	$2.44	$2.48	$2.15	$2.38	$2.04	$2.26	$1.94	$2.15
System (l/b/f) Cost ($/klm)	$45.63	$51.98	$48.51	$45.92	$32.54	$47.31	$44.78	$45.00	$42.59	$42.80	$40.51
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$276.83	$288.40	$295.76	$300.24	$175.66	$289.29	$293.65	$276.81	$280.96	$264.94	$268.90
Annual Maintenance Cost ($)	$0.22	$0.19	$0.27	$0.32	$0.98	$0.26	$0.31	$0.23	$0.28	$0.21	$0.25
Total Installed Cost ($/klm)	$52.04	$58.95	$54.83	$51.80	$40.38	$53.63	$50.67	$51.32	$48.48	$49.12	$46.39
Annual Maintenance Cost ($/klm)	$0.04	$0.04	$0.05	$0.06	$0.23	$0.05	$0.05	$0.04	$0.05	$0.04	$0.04

1. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential Linear LED Replacement Lamp 2 Lamp System*

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	19	18	18	N/A	15	14	13	11	11	9
Lamp Lumens	1355	1743	2151	2309	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	75	92	116	132	N/A	136	151	164	199	192	230
System Wattage	36	38	37	35	N/A	31	28	26	21	22	18
System Lumens	2304	3103	3829	4110	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	64	82	104	117	N/A	128	142	158	191	184	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	70	80	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	4000	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	35	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	684	684	684	684	N/A	684	684	684	684	684	684
Lamp Price ($)	$135.83	$22.19	$34.42	$38.30	N/A	$22.76	$22.76	$10.44	$10.44	$4.79	$4.79
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$100.25	$12.73	$16.00	$16.59	N/A	$10.84	$10.84	$4.97	$4.97	$2.28	$2.28
System (l/b/f) Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor System Installation (hr) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$271.67	$44.38	$68.84	$76.60	N/A	$45.51	$45.51	$20.88	$20.88	$9.58	$9.58
Annual Maintenance Cost ($)	$5.31	$0.61	$1.05	$1.05	N/A	$0.64	$0.64	$0.29	$0.29	$0.13	$0.13
Total Installed Cost ($/klm)	$200.49	$25.46	$32.00	$33.17	N/A	$21.67	$21.67	$9.94	$9.94	$4.56	$4.56
Annual Maintenance Cost ($/klm)	$3.92	$0.35	$0.49	$0.45	N/A	$0.30	$0.30	$0.14	$0.14	$0.06	$0.06

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

Performance/Cost Characteristics » Residential Linear LED Luminaire

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	46	48	57	40	55	37	30	28	22	22	22
System Lumens	3395	4044	5697	4918	4000	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	67	84	100	122	73	137	164	181	230	225	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	87	83	83	83	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
Average Lamp Life (1000 hrs)	50	60	56	50	36	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$731.04	$439.00	$176.61	$513.45	$139.00	$98.98	$98.98	$52.60	$52.60	$27.96	$27.96
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)[5]	$215.34	$108.56	$31.00	$104.41	$34.75	$19.80	$19.80	$10.52	$10.52	$5.59	$5.59
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[5]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$765.14	$473.10	$210.71	$547.55	$173.10	$133.08	$133.08	$86.70	$86.70	$62.06	$62.06
Annual Maintenance Cost ($)	$10.46	$5.39	$2.57	$7.49	$3.29	$0.94	$0.94	$0.59	$0.59	$0.42	$0.42
Total Installed Cost ($/klm)	$225.38	$116.99	$36.99	$111.35	$43.28	$26.62	$26.62	$17.34	$17.34	$12.41	$12.41
Annual Maintenance Cost ($/klm)	$3.08	$1.33	$0.45	$1.52	$0.82	$0.19	$0.19	$0.12	$0.12	$0.08	$0.08

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Residential Outdoor Lamps

- The residential outdoor lamps characterized in this report include reflector and general service lamps used for security and/or porch lighting that can be switched on from inside the home (i.e. parking lot/garage and outdoor common area lighting at multifamily buildings are excluded) with lumen outputs of approximately 1000-1400 lumens. Multiple baseline lamps were analyzed according to estimates of installed base average lumens by lamp type, including:

Security (Reflector Lamps)	Porch (General Service Lamps)
Incandescent BR30	Incandescent A-Type
Halogen PAR38	Halogen A-Type
Halogen Infrared Reflector (HIR) PAR38	CFL Bare Spiral
CFL PAR38	LED A-Type Lamp
LED PAR38	

- In 2010, it was estimated that over 96% of residential outdoor lamps were incandescent, halogen, or CFL technologies. Approximately, 51% of residential outdoor lamps were general service and 24% were reflector lamps. The remaining share was made up of primarily decorative and miscellaneous lamp types (DOE, 2012(3)).

Performance:

- 65W BR30 is the only viable incandescent reflector lamp due to exemption from EISA 2007. The lumen output of this lamp type is well below other reflector lamp technologies characterized for residential outdoor spaces, thus its use is limited for this application.
- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 1059 hours/year for residential reflector lamps (DOE SSL Program, 2012b).

Legislation:

- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for directional lamps with CRI ≥ 90 and 70 lm/W for directional lamps with CRI < 90 (ENERGY STAR).
- Additionally, all lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent Omnidirectional	0%	+0.5%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Incandescent Directional	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, 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.

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: Incandescent BR30)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	65	N/A	65	N/A	N/A	64	N/A	63	N/A	62	N/A
Lamp Lumens	620	N/A	637	N/A	N/A	637	N/A	637	N/A	637	N/A
Lamp Efficacy (lm/W)	9.5	N/A	9.8	N/A	N/A	9.9	N/A	10.1	N/A	10.3	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2700	N/A	2700	N/A	N/A	2700	N/A	2700	N/A	2700	N/A
Average Lamp Life (1000 hrs)	2.0	N/A	2.0	N/A	N/A	2.1	N/A	2.2	N/A	2.3	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Lamp Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Annual Maintenance Cost ($)	$0.73	N/A	$1.78	N/A	N/A	$1.70	N/A	$1.54	N/A	$1.39	N/A
Total Installed Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Annual Maintenance Cost ($/klm)	$1.17	N/A	$2.80	N/A	N/A	$2.66	N/A	$2.41	N/A	$2.18	N/A

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: Halogen PAR38)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	90	N/A	72	N/A	N/A	70	N/A	67	N/A	63	N/A
Lamp Lumens	1320	N/A	1350	N/A	N/A	1350	N/A	1350	N/A	1350	N/A
Lamp Efficacy (lm/W)	14.7	N/A	18.8	N/A	N/A	19.3	N/A	20.3	N/A	21.3	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2900	N/A	2900	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	2.4	N/A	2.4	N/A	N/A	2.5	N/A	2.6	N/A	2.7	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$4.47	N/A	$5.61	N/A	N/A	$5.47	N/A	$5.20	N/A	$4.95	N/A
Lamp Cost ($/klm)	$3.39	N/A	$4.16	N/A	N/A	$4.05	N/A	$3.85	N/A	$3.67	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$4.47	N/A	$5.61	N/A	N/A	$5.47	N/A	$5.20	N/A	$4.95	N/A
Annual Maintenance Cost ($)	$1.97	N/A	$2.47	N/A	N/A	$2.35	N/A	$2.13	N/A	$1.93	N/A
Total Installed Cost ($/klm)	$3.39	N/A	$4.16	N/A	N/A	$4.05	N/A	$3.85	N/A	$3.67	N/A
Annual Maintenance Cost ($/klm)	$1.50	N/A	$1.83	N/A	N/A	$1.74	N/A	$1.58	N/A	$1.43	N/A

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: HIR PAR38)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	70	N/A	70	N/A	N/A	68	N/A	65	N/A	62	N/A
Lamp Lumens	1358	N/A	1453	N/A	N/A	1453	N/A	1453	N/A	1453	N/A
Lamp Efficacy (lm/W)	19.4	N/A	20.8	N/A	N/A	21.3	N/A	22.4	N/A	23.6	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	3.4	N/A	4.4	N/A	N/A	4.5	N/A	4.7	N/A	5.0	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$13.63	N/A	$9.16	N/A	N/A	$8.93	N/A	$8.50	N/A	$8.08	N/A
Lamp Cost ($/klm)	$10.04	N/A	$6.30	N/A	N/A	$6.15	N/A	$5.85	N/A	$5.56	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$13.63	N/A	$9.16	N/A	N/A	$8.93	N/A	$8.50	N/A	$8.08	N/A
Annual Maintenance Cost ($)	$4.24	N/A	$2.20	N/A	N/A	$2.10	N/A	$1.90	N/A	$1.72	N/A
Total Installed Cost ($/klm)	$10.04	N/A	$6.30	N/A	N/A	$6.15	N/A	$5.85	N/A	$5.56	N/A
Annual Maintenance Cost ($/klm)	$3.12	N/A	$1.52	N/A	N/A	$1.44	N/A	$1.31	N/A	$1.18	N/A

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: CFL PAR38)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	19	N/A	23	N/A	23	22	N/A	21	N/A	20	N/A
Lamp Lumens	1300	N/A	1300	N/A	1300	1300	N/A	1300	N/A	1300	N/A
Lamp Efficacy (lm/W)	54.9	N/A	56.5	N/A	56.5	57.9	N/A	60.9	N/A	64.0	N/A
CRI	82	N/A	82	N/A	82	82	N/A	82	N/A	82	N/A
Correlated Color Temperature (CCT)	2700	N/A	2700	N/A	2700	2700	N/A	2700	N/A	2700	N/A
Average Lamp Life (1000 hrs)	9.7	N/A	10.0	N/A	10.0	10.3	N/A	10.8	N/A	11.3	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$7.18	N/A	$6.97	N/A	N/A	$6.80	N/A	$6.47	N/A	$6.15	N/A
Lamp Cost ($/klm)	$5.53	N/A	$5.36	N/A	N/A	$5.23	N/A	$4.97	N/A	$4.73	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$7.18	N/A	$6.97	N/A	N/A	$6.80	N/A	$6.47	N/A	$6.15	N/A
Annual Maintenance Cost ($)	$0.78	N/A	$0.74	N/A	N/A	$0.70	N/A	$0.64	N/A	$0.57	N/A
Total Installed Cost ($/klm)	$5.53	N/A	$5.36	N/A	N/A	$5.23	N/A	$4.97	N/A	$4.73	N/A
Annual Maintenance Cost ($/klm)	$0.60	N/A	$0.57	N/A	N/A	$0.54	N/A	$0.49	N/A	$0.44	N/A

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: LED PAR38[1])

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	18	16	17	20	15	13	12	9	10	7
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	91	109	117	153	144	196
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Annual Maintenance Cost ($)	$8.68	$1.09	$1.05	$1.55	$1.46	$0.37	$0.37	$0.21	$0.21	$0.12	$0.12
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Annual Maintenance Cost ($/klm)	$8.68	$0.93	$0.79	$0.79	$1.39	$0.27	$0.27	$0.15	$0.15	$0.08	$0.08

1. Data based on an indoor LED PAR38 lamp with adjustments for annual operating hours.
2. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: Incandescent A19)

DATA	2009	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1170	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	15.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$0.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.45	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: Halogen A19)

DATA	2009	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	55	N/A	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1050	N/A	1050	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	19.2	N/A	19.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$2.25	N/A	$2.12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$2.14	N/A	$2.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.
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 halogen lamp technologies and current trends in industry lead us to believe they will not be met.

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: CFL Bare Spiral)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	19	19	19	18	20	18	18	17	17	16	16
Lamp Lumens	1216	1200	1216	1300	1200	1216	1300	1216	1300	1216	1300
Lamp Efficacy (lm/W)	63.5	63.2	65.4	72.2	60.0	67.1	74.0	70.5	77.8	74.1	81.8
CRI	82	82	82	82	82	82	82	82	82	82	82
Correlated Color Temperature (CCT)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	10	10.0	10.0	10.0	10.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	N/A	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$3.32	$3.24	$3.22	$6.49	N/A	$3.14	$6.33	$2.99	$6.02	$2.84	$5.73
Lamp Cost ($/klm)	$2.73	$2.70	$2.65	$4.99	N/A	$2.58	$4.87	$2.46	$4.63	$2.34	$4.40
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($)	$3.32	$3.24	$3.22	$6.49	N/A	$3.14	$6.33	$2.99	$6.02	$2.84	$5.73
Annual Maintenance Cost ($)	$0.36	$0.34	$0.34	$0.69	N/A	$0.32	$0.65	$0.29	$0.59	$0.27	$0.54
Total Installed Cost ($/klm)	$2.73	$2.70	$2.65	$4.99	N/A	$2.58	$4.87	$2.46	$4.63	$2.34	$4.40
Annual Maintenance Cost ($/klm)	$0.30	$0.29	$0.28	$0.53	N/A	$0.27	$0.50	$0.24	$0.45	$0.22	$0.41

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: LED A-Type[1])

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	9	8	7	6	6	4
Lamp Lumens	964	964	964	964	964	964	964	964	964	964	964
Lamp Efficacy (lm/W)	44	64	93	104	71	102	123	131	171	161	219
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$6.76	$6.76	$3.44	$3.44	$2.30	$2.30
Lamp Cost ($/klm)	$85.00	$24.90	$9.00	$5.18	$12.43	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$6.76	$6.76	$3.44	$3.44	$2.30	$2.30
Annual Maintenance Cost ($)	$3.60	$1.02	$0.37	$0.21	$0.51	$0.15	$0.15	$0.07	$0.07	$0.05	$0.05
Total Installed Cost ($/klm)	$70.54	$24.90	$9.00	$5.18	$12.43	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Annual Maintenance Cost ($/klm)	$3.73	$1.05	$0.38	$0.22	$0.53	$0.15	$0.15	$0.08	$0.08	$0.05	$0.05

1. Data based on an indoor 100W Equivalent LED A-type lamp, scaled to lumen output reported for the building exterior low-output technologies in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)
2. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Commercial Lighting

Performance/Cost Characteristics » Commercial General Service Lamps in Recessed Can Fixtures

This section characterizes commercial omnidirectional incandescent, halogen, CFL, and LED screw based general service lamps emitting approximately 1600 lumens (equivalent to a 100W incandescent lamp) used in recessed can fixtures. A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, an omnidirectional lamp is not well suited for use in such fixtures, as light that emits upwards and out of the sides must be reflected downwards and out of the fixture and some light is absorbed in the process. A fixture efficiency of 61% is used to characterize these lumen losses for all omnidirectional lamps. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3868 hours/year for commercial general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- 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. California's Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies 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, halogen, and CFL technologies.
- 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. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- For ENERGY STAR qualification, general service, omnidirectional lamps, must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥15 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	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.

DATA	2003	2012[1]	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1620	1620	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	16.2	16.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens	988	988	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	9.9	9.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	0.8	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	3868	3868	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.37	$0.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.23	$0.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$17.07	$20.81	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hr)	1.0	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0.05	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$82.22	$97.61	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$18.78	$22.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$83.20	$98.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$19.00	$23.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	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 incandescent lamps will be replaced by halogen lamps.

Performance/Cost Characteristics » Commercial General Service Halogen Lamp (100W Incandescent Equivalent) in Recessed Can Fixture

DATA	2003	2012[1]	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	90	72	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1620	1490	N/A	1490	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	18.0	20.7	N/A	20.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	90	72	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens	988	909	N/A	909	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	11.0	12.6	N/A	12.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	3868	3868	N/A	3868	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$8.07	$1.97	N/A	$2.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	$22.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$4.98	$1.32	N/A	$1.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$24.86	$24.17	N/A	$27.03	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	$81.95	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hr)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0.05	0.05	N/A	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$89.92	$99.02	N/A	$106.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$43.85	$22.51	N/A	$23.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$90.99	$108.94	N/A	$117.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$44.37	$24.77	N/A	$25.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	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 incandescent lamps will be replaced by halogen lamps.
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 halogen lamp technologies and current trends in industry lead us to believe they will not be met.

Performance/Cost Characteristics » Commercial General Service 100W Equivalent CFL Bare Spiral in Recessed Can Fixture

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	26	25	27	23	23	26	23	22	22	21	21	20
Lamp Lumens	1750	1680	1700	1611	1640	1686	1611	1640	1611	1640	1611	1640
Lamp Efficacy (lm/W)	67.3	68.1	63.7	68.9	71.3	65.0	70.7	73.1	74.3	76.8	78.1	80.8
System Wattage	26	25	27	23	23	26	23	22	22	21	21	20
System Lumens	1068	1025	1037	983	1000	1028	983	1000	983	1000	983	1000
System Efficacy (lm/W)	41.1	41.6	38.9	42.7	43.5	39.6	43.1	44.6	45.3	46.9	47.6	49.3
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	82	82	82	82	82	81	82	82	82	82	82	82
Correlated Color Temperature (CCT)	3000	3000	3000	3000	3000	2700	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	10.0	10.0	10.0	10.0	10.0	12.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	3868	3868	3868	3868	3868	N/A	3868	3868	3868	3868	3868	3868
Lamp Price ($)	$7.02	$2.60	$3.30	$3.33	$3.50	N/A	$3.24	$3.41	$3.08	$3.24	$2.93	$3.08
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	$22.56	$22.56	$22.56	N/A	$22.00	$22.00	$20.93	$20.93	$19.90	$19.90
Lamp Cost ($/klm)	$4.01	$1.55	$1.94	$2.06	$2.13	N/A	$2.01	$2.08	$1.91	$1.98	$1.82	$1.88
System (l/b/f) Cost ($/klm)	$22.02	$22.05	$24.94	$26.34	$26.04	N/A	$25.69	$25.40	$24.43	$24.16	$23.24	$22.98
Labor Cost ($/hr)	$65.35	$77.05	$81.95	$81.95	$81.95	N/A	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)	1.0	1.0	1.0	1.0	1.0	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr)	0.05	0.05	0.05	0.05	0.05	N/A	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost ($)	$88.87	$99.65	$107.81	$107.84	$108.01	N/A	$107.19	$107.36	$105.96	$106.12	$104.79	$104.94
Annual Maintenance Cost ($)	$3.98	$2.50	$2.86	$2.87	$2.94	N/A	$2.77	$2.83	$2.58	$2.63	$2.40	$2.45
Total Installed Cost ($/klm)	$83.21	$97.22	$103.96	$109.73	$107.96	N/A	$109.07	$107.32	$107.82	$106.08	$106.62	$104.89
Annual Maintenance Cost ($/klm)	$3.73	$2.44	$2.76	$2.92	$2.94	N/A	$2.82	$2.83	$2.62	$2.63	$2.44	$2.45

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	27	17	15	16	23	12	11	9	8	7	7
Lamp Lumens	N/A	1600	1580	1646	1710	1600	1600	1600	1600	1600	1600	1600
Lamp Efficacy (lm/W)	N/A	60	92	108	110	71	137	150	176	209	216	230
System Wattage	N/A	27	17	15	16	23	12	11	9	8	7	7
System Lumens	N/A	976	964	1004	1043	976	976	976	976	976	976	976
System Efficacy (lm/W)	N/A	36.6	56.4	66.2	67.3	43.4	83.3	91.6	107.4	127.4	131.6	140.3
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	80	84	83	81	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	3000	3000	2700	2700	3000	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	N/A	22	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868
Lamp Price ($)	N/A	$40.00	$14.71	$15.30	$15.99	$22.99	$11.22	$11.22	$5.71	$5.71	$3.81	$3.81
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$25.00	$9.31	$9.30	$9.35	$14.37	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
System (l/b/f) Cost ($/klm)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost ($)	N/A	$43.85	$18.81	$19.40	$20.09	$27.09	$15.32	$15.32	$9.81	$9.81	$7.91	$7.91
Annual Maintenance Cost ($)	N/A	$7.71	$2.91	$3.00	$3.11	$4.19	$1.23	$1.21	$0.76	$0.76	$0.61	$0.61
Total Installed Cost ($/klm)	N/A	$44.93	$19.51	$19.33	$19.26	$27.75	$15.70	$15.70	$10.05	$10.05	$8.10	$8.10
Annual Maintenance Cost ($/klm)	N/A	$7.90	$3.02	$2.99	$2.98	$4.29	$1.27	$1.24	$0.78	$0.78	$0.63	$0.63

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For new installations or retrofits where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

This section characterizes commercial halogen, Halogen infrared reflector (HIR), and LED screw based reflector lamps emitting approximately 1400 lumens used in recessed can fixtures.

- 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.
- A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, a reflector lamp, which employs reflective coating to direct light out in only one direction, is well suited for use in such fixtures. However, some light is not able to escape the fixture, and a fixture efficiency of 93% is used to characterize these minimal lumen losses. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3860 hours/year for commercial reflector lamps (DOE SSL Program, 2012a).

Legislation:

- 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. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for omnidirectional lamps with CRI ≥ 90 and 70 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Performance/Cost Characteristics » Commercial Reflector Lamps in Recessed Can Fixtures

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
HIR	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	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.

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	90	90	N/A	72	N/A	N/A	70	N/A	67	N/A	63	N/A
Lamp Lumens	1314	1323	N/A	1350	N/A	N/A	1350	N/A	1350	N/A	1350	N/A
Lamp Efficacy (lm/W)	14.6	14.7	N/A	18.8	N/A	N/A	19.3	N/A	20.3	N/A	21.3	N/A
System Wattage	90	90	N/A	72	N/A	N/A	70	N/A	67	N/A	63	N/A
System Lumens	1222	1230	N/A	1256	N/A	N/A	1256	N/A	1256	N/A	1256	N/A
System Efficacy (lm/W)	13.5	13.7	N/A	17.5	N/A	N/A	17.9	N/A	18.8	N/A	19.8	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2900	2900	N/A	2900	N/A	N/A	2900	N/A	2900	N/A	2900	N/A
Average Lamp Life (1000 hrs)	2.4	2.4	N/A	2.4	N/A	N/A	2.5	N/A	2.6	N/A	2.7	N/A
Annual Operating Hours (hrs/yr)	3860	3860	N/A	3860	N/A	N/A	3860	N/A	3860	N/A	3860	N/A
Lamp Price ($)	$6.54	$3.78	N/A	$5.61	N/A	N/A	$5.47	N/A	$5.20	N/A	$4.95	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	$22.56	N/A	N/A	$22.00	N/A	$20.93	N/A	$19.90	N/A
Lamp Cost ($/klm)	$4.98	$2.86	N/A	$4.16	N/A	N/A	$4.05	N/A	$3.85	N/A	$3.67	N/A
System (l/b/f) Cost ($/klm)	$18.86	$19.33	N/A	$22.44	N/A	N/A	$21.88	N/A	$20.81	N/A	$19.79	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	$81.95	N/A	N/A	$81.95	N/A	$81.95	N/A	$81.95	N/A
Labor System Installation (hr)	1.0	1.0	N/A	1.0	N/A	N/A	1.0	N/A	1.0	N/A	1.0	N/A
Labor Lamp Change (hr)	0.0615	0.0615	N/A	0.0615	N/A	N/A	0.0615	N/A	0.0615	N/A	0.0615	N/A
Total Installed Cost ($)	$88.39	$100.83	N/A	$110.12	N/A	N/A	$109.42	N/A	$108.08	N/A	$106.80	N/A
Annual Maintenance Cost ($)	$16.99	$13.71	N/A	$17.13	N/A	N/A	$16.49	N/A	$15.29	N/A	$14.18	N/A
Total Installed Cost ($/klm)	$72.33	$81.95	N/A	$87.71	N/A	N/A	$87.15	N/A	$86.08	N/A	$85.07	N/A
Annual Maintenance Cost ($/klm)	$13.90	$11.14	N/A	$13.64	N/A	N/A	$13.13	N/A	$12.18	N/A	$11.30	N/A

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	70	70	N/A	70	N/A	N/A	68	N/A	65	N/A	62	N/A
Lamp Lumens	1260	1407	N/A	1453	N/A	N/A	1453	N/A	1453	N/A	1453	N/A
Lamp Efficacy (lm/W)	18.0	20.1	N/A	20.8	N/A	N/A	21.3	N/A	22.4	N/A	23.6	N/A
System Wattage	70	70	N/A	70	N/A	N/A	68	N/A	65	N/A	62	N/A
System Lumens	1172	1309	N/A	1351	N/A	N/A	1351	N/A	1351	N/A	1351	N/A
System Efficacy (lm/W)	16.7	18.7	N/A	19.3	N/A	N/A	19.8	N/A	20.8	N/A	21.9	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	3.0	3.6	N/A	4.4	N/A	N/A	4.5	N/A	4.7	N/A	5.0	N/A
Annual Operating Hours (hrs/yr)	3860	3860	N/A	3860	N/A	N/A	3860	N/A	3860	N/A	3860	N/A
Lamp Price ($)	$8.52	$15.66	N/A	$9.16	N/A	N/A	$8.93	N/A	$8.50	N/A	$8.08	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	$22.56	N/A	N/A	$22.00	N/A	$20.93	N/A	$19.90	N/A
Lamp Cost ($/klm)	$6.76	$11.13	N/A	$6.30	N/A	N/A	$6.15	N/A	$5.85	N/A	$5.56	N/A
System (l/b/f) Cost ($/klm)	$21.35	$27.25	N/A	$23.47	N/A	N/A	$22.89	N/A	$21.77	N/A	$20.71	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	$81.95	N/A	N/A	$81.95	N/A	$81.95	N/A	$81.95	N/A
Labor System Installation (hr)	1.0	1.0	N/A	1.0	N/A	N/A	1.0	N/A	1.0	N/A	1.0	N/A
Labor Lamp Change (hr)	0.0615	0.0615	N/A	0.0615	N/A	N/A	0.0615	N/A	0.0615	N/A	0.0615	N/A
Total Installed Cost ($)	$90.37	$112.71	N/A	$113.67	N/A	N/A	$112.88	N/A	$111.37	N/A	$109.93	N/A
Annual Maintenance Cost ($)	$16.13	$21.87	N/A	$12.46	N/A	N/A	$11.96	N/A	$11.02	N/A	$10.16	N/A
Total Installed Cost ($/klm)	$77.11	$86.14	N/A	$84.12	N/A	N/A	$83.54	N/A	$82.42	N/A	$81.35	N/A
Annual Maintenance Cost ($/klm)	$13.76	$16.72	N/A	$9.22	N/A	N/A	$8.85	N/A	$8.16	N/A	$7.52	N/A

Final

Performance/Cost Characteristics » Commercial LED Reflector Lighting (PAR38)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	17	18	16	17	20	13	12	10	9	8	7
Lamp Lumens	N/A	1045	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	N/A	61	64	83	116	53	105	116	136	162	167	209
System Wattage	N/A	17	18	16	17	20	13	12	10	9	8	7
System Lumens	N/A	972	1090	1235	1821	977	1302	1302	1302	1302	1302	1302
System Efficacy (lm/W)	N/A	57	59	78	108	49	98	108	127	151	156	194
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	83	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	N/A	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	N/A	22	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860
Lamp Price ($)	N/A	$52.25	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$50.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
System (l/b/f) Cost ($/klm)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total Installed Cost ($)	N/A	$56.99	$30.72	$32.93	$41.63	$39.51	$22.30	$22.30	$14.84	$14.84	$10.64	$10.64
Annual Maintenance Cost ($)	N/A	$10.00	$4.74	$4.54	$6.43	$6.10	$1.76	$1.76	$1.15	$1.15	$0.82	$0.82
Total Installed Cost ($/klm)	N/A	$58.64	$28.19	$26.66	$22.86	$40.46	$17.13	$17.13	$11.40	$11.40	$8.17	$8.17
Annual Maintenance Cost ($/klm)	N/A	$10.29	$4.35	$3.68	$3.53	$6.25	$1.35	$1.35	$0.88	$0.88	$0.63	$0.63

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For new installations or retrofits where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

Performance/Cost Characteristics » Commercial 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. 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.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4055 hours/year for commercial 4ft linear systems (DOE SSL Program, 2012a).

Legislation:

- 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.
- 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 does not cover commercial linear luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F32 Commodity	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F32 High Efficiency/High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5 F28	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial 4-ft T8 F32 Commodity in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	32	32	32	32	32	N/A	32	32	31	31	30	30
Lamp Lumens	2520	2725	2725	2770	2915	N/A	2770	2915	2770	2915	2770	2915
Lamp Efficacy (lm/W)	79	85	85	87	91	N/A	87	92	89	94	91	96
System Wattage	65	56	55	55	55	N/A	55	55	54	54	53	53
System Lumens	3282	4796	4349	4421	4652	N/A	4421	4652	4421	4652	4421	4652
System Efficacy (lm/W)	50	86	79	80	84	N/A	81	85	82	87	84	88
Ballast Efficiency (BLE)	86%	91%	92%	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	75	83	83	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	24	24	21	24	N/A	22	25	23	26	24	27
Annual Operating Hours	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	$0.96	$6.58	$4.99	$5.51	$9.54	N/A	$5.37	$9.30	$5.11	$8.85	$4.86	$8.42
Ballast Price ($)	$17.25	$16.49	$16.10	$16.10	$16.10	N/A	$15.70	$15.70	$14.93	$14.93	$14.20	$14.20
Fixture Price ($)	$26.17	$25.02	$24.64	$24.64	$24.64	N/A	$24.03	$24.03	$22.86	$22.86	$21.74	$21.74
Lamp Cost ($/klm)	$0.38	$2.41	$1.83	$1.99	$3.27	N/A	$1.94	$3.19	$1.85	$3.04	$1.75	$2.89
System (l/b/f) Cost ($/klm)	$13.81	$20.06	$18.61	$18.69	$20.52	N/A	$18.22	$20.01	$17.33	$19.04	$16.49	$18.10
Labor Cost ($/hr)	$57.34	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	N/A	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.4	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	$74.00	$80.64	$79.83	$80.35	$84.38	N/A	$79.21	$83.14	$77.00	$80.74	$74.90	$78.46
Annual Maintenance Cost ($)	$3.03	$6.59	$6.26	$7.35	$7.80	N/A	$7.12	$7.53	$6.68	$7.02	$6.27	$6.55
Total Installed Cost ($/klm)	$22.55	$16.81	$18.36	$18.18	$18.14	N/A	$17.92	$17.87	$17.42	$17.35	$16.94	$16.86
Annual Maintenance Cost ($/klm)	$0.92	$1.37	$1.44	$1.66	$1.68	N/A	$1.61	$1.62	$1.51	$1.51	$1.42	$1.41

Performance/Cost Characteristics » Commercial 4-ft T8 F32 High-efficiency/High-output in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	28	N/A	28	N/A	N/A	28	N/A	27	N/A	27	N/A
Lamp Lumens	N/A	2560	N/A	2590	N/A	N/A	2590	N/A	2590	N/A	2590	N/A
Lamp Efficacy (lm/W)	N/A	91	N/A	93	N/A	N/A	93	N/A	95	N/A	97	N/A
System Wattage	N/A	50	N/A	50	N/A	N/A	49	N/A	48	N/A	47	N/A
System Lumens	N/A	4506	N/A	4229	N/A	N/A	4229	N/A	4229	N/A	4229	N/A
System Efficacy (lm/W)	N/A	90	N/A	85	N/A	N/A	86	N/A	88	N/A	89	N/A
Ballast Efficiency (BLE)	N/A	91%	N/A	92%	N/A	N/A	92%	N/A	92%	N/A	92%	N/A
CRI	N/A	85	N/A	85	N/A	N/A	85	N/A	85	N/A	85	N/A
Correlated Color Temperature (CCT)	N/A	4100	N/A	4100	N/A	N/A	4100	N/A	4100	N/A	4100	N/A
Average Lamp Life (1000 hrs)	N/A	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours	N/A	4055	N/A	4055	N/A	N/A	4055	N/A	4055	N/A	4055	N/A
Lamp Price ($)	N/A	$9.42	N/A	$8.23	N/A	N/A	$8.03	N/A	$7.63	N/A	$7.26	N/A
Ballast Price ($)	N/A	$16.49	N/A	$16.10	N/A	N/A	$15.70	N/A	$14.93	N/A	$14.20	N/A
Fixture Price ($)	N/A	$25.02	N/A	$24.64	N/A	N/A	$24.03	N/A	$22.86	N/A	$21.74	N/A
Lamp Cost ($/klm)	N/A	$3.68	N/A	$3.18	N/A	N/A	$3.10	N/A	$2.95	N/A	$2.80	N/A
System (l/b/f) Cost ($/klm)	N/A	$23.57	N/A	$22.09	N/A	N/A	$21.54	N/A	$20.49	N/A	$19.48	N/A
Labor Cost ($/hr)	N/A	$65.10	N/A	$68.20	N/A	N/A	$68.20	N/A	$68.20	N/A	$68.20	N/A
Labor System Installation (hr)	N/A	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Labor Lamp Change (hr)	N/A	0.4	N/A	0.4	N/A	N/A	0.4	N/A	0.4	N/A	0.4	N/A
Total Installed Cost ($)	N/A	$83.48	N/A	$83.07	N/A	N/A	$81.86	N/A	$79.52	N/A	$77.30	N/A
Annual Maintenance Cost ($)	N/A	$7.55	N/A	$7.35	N/A	N/A	$7.10	N/A	$6.64	N/A	$6.20	N/A
Total Installed Cost ($/klm)	N/A	$18.53	N/A	$19.64	N/A	N/A	$19.36	N/A	$18.80	N/A	$18.28	N/A
Annual Maintenance Cost ($/klm)	N/A	$1.67	N/A	$1.74	N/A	N/A	$1.68	N/A	$1.57	N/A	$1.47	N/A

Performance/Cost Characteristics » Commercial 4-ft T5 F28 in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	28	28	28	28	N/A	28	28	27	27	27	27
Lamp Lumens	2660	2697	2446	2697	2898	N/A	2697	2898	2697	2898	2697	2898
Lamp Efficacy (lm/W)	95	96	87	96	104	N/A	97	105	99	107	101	109
System Wattage	66	60	60	60	60	N/A	60	60	59	59	57	57
System Lumens	4698	5394	4892	5394	5796	N/A	5394	5796	5394	5796	5394	5796
System Efficacy (lm/W)	71	89	81	89	96	N/A	90	97	92	99	94	101
Ballast Efficiency (BLE)	89%	92%	92%	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	85	85	85	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	30	30	30	30	N/A	31	31	32	32	34	34
Annual Operating Hours	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	$4.08	$5.51	$4.10	$5.94	$7.06	N/A	$5.79	$6.89	$5.51	$6.55	$5.24	$6.23
Ballast Price ($)	$28.17	$26.93	$26.28	$26.28	$26.28	N/A	$25.63	$25.63	$24.38	$24.38	$23.18	$23.18
Fixture Price ($)	$98.42	$94.07	$92.67	$92.67	$92.67	N/A	$90.38	$90.38	$85.96	$85.96	$81.76	$81.76
Lamp Cost ($/klm)	$1.53	$2.04	$1.68	$2.20	$2.44	N/A	$2.15	$2.38	$2.04	$2.26	$1.94	$2.15
System (l/b/f) Cost ($/klm)	$28.68	$48.95	$51.98	$48.51	$45.92	N/A	$47.31	$44.78	$45.00	$42.59	$42.80	$40.51
Labor Cost ($/hr)	$60.42	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	N/A	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.4	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	$164.95	$159.06	$157.15	$158.99	$160.11	N/A	$155.90	$156.99	$149.94	$150.98	$144.28	$145.27
Annual Maintenance Cost ($)	$2.81	$4.98	$4.77	$5.26	$5.57	N/A	$5.09	$5.38	$4.78	$5.04	$4.48	$4.71
Total Installed Cost ($/klm)	$35.11	$29.49	$32.12	$29.48	$27.62	N/A	$28.90	$27.09	$27.80	$26.05	$26.75	$25.06
Annual Maintenance Cost ($/klm)	$0.60	$0.92	$0.97	$0.98	$0.96	N/A	$0.94	$0.93	$0.89	$0.87	$0.83	$0.81

Final

Performance/Cost Characteristics » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	21	19	18	18	N/A	15	14	13	11	11	9
Lamp Lumens	N/A	2091	1743	2151	2303	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	N/A	101	92	116	132	N/A	136	151	164	199	192	230
System Wattage	N/A	42	38	37	35	N/A	31	28	26	21	22	18
System Lumens	N/A	3555	3102	3829	4099	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	N/A	85	82	104	117	N/A	128	142	158	191	184	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	86	80.1	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	4100	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	N/A	50	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	N/A	$234.66	$22.19	$34.42	$38.30	N/A	$22.76	$22.76	$10.44	$10.44	$4.79	$4.79
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$112.20	$12.73	$16.00	$16.63	N/A	$10.84	$10.84	$4.97	$4.97	$2.28	$2.28
System (l/b/f) Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	$495.15	$71.43	$95.90	$103.65	N/A	$49.81	$49.81	$37.49	$37.49	$31.84	$31.84
Annual Maintenance Cost ($)	N/A	$40.16	$5.79	$8.64	$8.41	N/A	$4.12	$4.12	$3.04	$3.04	$2.58	$2.58
Total Installed Cost ($/klm)	N/A	$236.76	$40.98	$44.57	$45.01	N/A	$23.72	$23.72	$17.85	$17.85	$15.16	$15.16
Annual Maintenance Cost ($/klm)	N/A	$19.20	$3.32	$4.02	$3.65	N/A	$1.96	$1.96	$1.45	$1.45	$1.23	$1.23

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

Performance/Cost Characteristics » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems*

Final

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	51	48	57	40	N/A	37	30	28	22	22	22
System Lumens	548	4818	4044	5697	4918	N/A	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	15	94	84	100	122	N/A	137	164	181	230	225	230
Ballast Efficiency (BLE) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	84	82.7	83	83	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	N/A	3500	3500	3500	3500	3500	3500
Average Lamp Life (1000 hrs)	50	67	60	56	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	$215.19	$610.32	$439.00	$176.61	$513.45	N/A	$98.98	$98.98	$52.60	$52.60	$27.96	$27.96
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$108.56	$31.00	$104.41	N/A	$19.80	$19.80	$10.52	$10.52	$5.59	$5.59
Labor Cost ($/hr)	$110.50	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	N/A	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$642.87	$473.10	$210.71	$547.55	N/A	$133.08	$133.08	$86.70	$86.70	$62.06	$62.06
Annual Maintenance Cost ($)	21.934591	$38.91	$31.98	$15.26	$44.41	N/A	$5.56	$5.56	$3.52	$3.52	$2.52	$2.52
Total Installed Cost ($/klm)	$493.50	$133.43	$116.99	$36.99	$111.35	N/A	$26.62	$26.62	$17.34	$17.34	$12.41	$12.41
Annual Maintenance Cost ($/klm)	40.026627	$8.08	$7.91	$2.68	$9.03	N/A	$1.11	$1.11	$0.70	$0.70	$0.50	$0.50

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Commercial 8-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 8ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. 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.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4147 hours/year for commercial 8ft linear systems (DOE SSL Program, 2012a).

Legislation:

- 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.
- 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 does not cover commercial linear luminaires (ENERGY STAR, 2012).

Performance/Cost Characteristics » Commercial 8-foot Linear 2-Lamp Lighting Systems

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F59 Typical Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F59 High Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F96 High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial 8-ft T8 F59 Typical Efficiency in a 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	60	59	59	59	59	N/A	58	58	57	57	56	56
Lamp Lumens	5214	5430	5220	5490	5650	N/A	5490	5650	5490	5650	5490	5650
Lamp Efficacy (lm/W)	87	92	88	93	96	N/A	94	97	96	99	98	101
System Wattage	113	107	107	107	107	N/A	105	105	103	103	101	101
System Lumens	8300	9448	9083	9553	9831	N/A	9553	9831	9553	9831	9553	9831
System Efficacy (lm/W)	73	88	85	90	92	N/A	91	93	92	95	94	97
Ballast Efficiency (BLE)	89%	93%	93%	93%	93%	N/A	93%	93%	93%	93%	93%	93%
CRI	75	82	80	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	15	24	24	24	24	N/A	25	25	26	26	27	27
Annual Operating Hours (hrs/yr)	4147	4147	4147	4147	4147	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	$4.16	$12.39	$10.48	$11.74	$14.18	N/A	$11.45	$13.83	$10.89	$13.15	$10.36	$12.51
Ballast Price ($)	$20.51	$19.61	$19.14	$19.14	$19.14	N/A	$18.67	$18.67	$17.75	$17.75	$16.89	$16.89
Fixture Price ($)	$23.99	$22.93	$22.59	$22.59	$22.59	N/A	$22.03	$22.03	$20.95	$20.95	$19.93	$19.93
Lamp Cost ($/klm)	$0.80	$2.28	$2.01	$2.14	$2.51	N/A	$2.09	$2.45	$1.98	$2.33	$1.89	$2.21
System (l/b/f) Cost ($/klm)	$6.36	$12.40	$12.01	$11.88	$12.40	N/A	$11.58	$12.10	$11.02	$11.51	$10.48	$10.94
Labor Cost ($/hr)	$57.31	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.9	0.9	0.9	0.9	0.9	N/A	0.9	0.9	0.9	0.9	0.9	0.9
Labor Lamp Change (hr)	0.3	0.3	0.3	0.3	0.3	N/A	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost ($)	$105.35	$114.60	$114.72	$115.98	$118.42	N/A	$114.66	$117.04	$112.11	$114.37	$109.68	$111.84
Annual Maintenance Cost ($)	$4.39	$7.43	$6.92	$7.36	$8.20	N/A	$7.08	$7.88	$6.55	$7.28	$6.07	$6.73
Total Installed Cost ($/klm)	$12.69	$12.13	$12.63	$12.14	$12.05	N/A	$12.00	$11.91	$11.74	$11.63	$11.48	$11.38
Annual Maintenance Cost ($/klm)	$0.53	$0.79	$0.76	$0.77	$0.83	N/A	$0.74	$0.80	$0.69	$0.74	$0.64	$0.68

Performance/Cost Characteristics » Commercial 8-ft T8 F59 High Efficiency in a 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	60	59	59	59	59	N/A	58	58	57	57	56	56
Lamp Lumens	5892	5430	5220	5490	5650	N/A	5490	5650	5490	5650	5490	5650
Lamp Efficacy (lm/W)	98	92	88	93	96	N/A	94	97	96	99	98	101
System Wattage	100	107	105	94	94	N/A	93	93	91	91	89	89
System Lumens	8311	9448	9083	8455	8701	N/A	8455	8701	8455	8701	8455	8701
System Efficacy (lm/W)	83	88	86	90	93	N/A	91	94	93	95	95	97
Ballast Efficiency (BLE)	89%	93%	94%	94%	94%	N/A	94%	94%	94%	94%	94%	94%
CRI	85	82	80	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	18	24	24	24	24	N/A	25	25	26	26	27	27
Annual Operating Hours (hrs/yr)	4147	4147	4147	4147	4147	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	$7.27	$12.39	$10.48	$11.74	$14.18	N/A	$11.45	$13.83	$10.89	$13.15	$10.36	$12.51
Ballast Price ($)	$20.51	$19.61	$19.14	$19.14	$19.14	N/A	$18.67	$18.67	$17.75	$17.75	$16.89	$16.89
Fixture Price ($)	$23.85	$22.79	$22.45	$22.45	$22.45	N/A	$21.90	$21.90	$20.83	$20.83	$19.81	$19.81
Lamp Cost ($/klm)	$1.23	$2.28	$2.01	$2.14	$2.51	N/A	$2.09	$2.45	$1.98	$2.33	$1.89	$2.21
System (l/b/f) Cost ($/klm)	$7.09	$12.37	$11.98	$11.85	$12.38	N/A	$11.56	$12.07	$10.99	$11.48	$10.46	$10.92
Labor Cost ($/hr)	$57.64	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.9	0.9	0.9	0.9	0.9	N/A	0.9	0.9	0.9	0.9	0.9	0.9
Labor Lamp Change (hr)	0.3	0.3	0.3	0.3	0.3	N/A	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost ($)	$111.74	$114.47	$114.59	$115.85	$118.29	N/A	$114.53	$116.91	$111.99	$114.25	$109.57	$111.72
Annual Maintenance Cost ($)	$4.22	$7.43	$6.92	$7.36	$8.20	N/A	$7.08	$7.88	$6.55	$7.28	$6.07	$6.73
Total Installed Cost ($/klm)	$13.44	$12.12	$12.62	$13.70	$13.60	N/A	$13.55	$13.44	$13.25	$13.13	$12.96	$12.84
Annual Maintenance Cost ($/klm)	$0.51	$0.79	$0.76	$0.87	$0.94	N/A	$0.84	$0.91	$0.78	$0.84	$0.72	$0.77

Performance/Cost Characteristics » Commercial 8-ft T8 F96 High-Output in a 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	86	86	85	86	N/A	85	85	83	83	81	82
Lamp Lumens	N/A	7600	7342	7600	7800	N/A	7600	7800	7600	7800	7600	7800
Lamp Efficacy (lm/W)	N/A	88	85	89	91	N/A	90	92	92	93	93	95
System Wattage	N/A	148	179	172	179	N/A	170	178	167	174	163	171
System Lumens	N/A	12026	13949	14000	14820	N/A	14000	14820	14000	14820	14000	14820
System Efficacy (lm/W)	N/A	81	78	82	83	N/A	82	83	84	85	86	87
Ballast Efficiency (BLE)	N/A	92%	92%	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	N/A	78	78	78	78	N/A	78	78	78	78	78	78
Correlated Color Temperature (CCT)	N/A	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	N/A	18	18	18	18	N/A	18	18	19	19	20	20
Annual Operating Hours (hrs/yr)	N/A	4147	4147	4147	4147	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	N/A	$17.05	$8.63	$13.19	$16.61	N/A	$12.86	$16.20	$12.23	$15.41	$11.64	$14.65
Ballast Price ($)	N/A	$15.64	$17.49	$17.49	$17.49	N/A	$17.06	$17.06	$16.22	$16.22	$15.43	$15.43
Fixture Price ($)	N/A	$22.93	$22.59	$22.59	$22.59	N/A	$22.03	$22.03	$20.95	$20.95	$19.93	$19.93
Lamp Cost ($/klm)	N/A	$2.24	$1.18	$1.74	$2.13	N/A	$1.69	$2.08	$1.61	$1.98	$1.53	$1.88
System (l/b/f) Cost ($/klm)	N/A	$9.56	$7.81	$8.74	$9.40	N/A	$8.53	$9.16	$8.11	$8.72	$7.71	$8.29
Labor Cost ($/hr)	N/A	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	N/A	1.0	1.0	1.0	1.0	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr)	N/A	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	$120.72	$116.91	$121.47	$124.89	N/A	$120.15	$123.48	$117.61	$120.78	$115.19	$118.21
Annual Maintenance Cost ($)	N/A	$13.48	$9.87	$11.97	$13.55	N/A	$11.53	$13.03	$10.70	$12.05	$9.93	$11.16
Total Installed Cost ($/klm)	N/A	$10.04	$8.38	$8.68	$8.43	N/A	$8.58	$8.33	$8.40	$8.15	$8.23	$7.98
Annual Maintenance Cost ($/klm)	N/A	$1.12	$0.71	$0.85	$0.91	N/A	$0.82	$0.88	$0.76	$0.81	$0.71	$0.75

Performance/Cost Characteristics » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical[1]	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	36	N/A	N/A	31	28	26	21	22	17
Lamp Lumens	N/A	N/A	N/A	3975	N/A	N/A	4000	4000	4000	4000	4000	4000
Lamp Efficacy (lm/W)	N/A	N/A	N/A	111	N/A	N/A	130	144	157	190	183	230
System Wattage	N/A	N/A	N/A	71	N/A	N/A	61	56	51	42	44	35
System Lumens	N/A	N/A	N/A	7076	N/A	N/A	7520	7520	7680	7680	7680	7680
System Efficacy (lm/W)	N/A	N/A	N/A	99	N/A	N/A	122	135	150	182	176	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	80	N/A	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	N/A	N/A	N/A	5000	N/A	N/A	5000	5000	5000	5000	5000	5000
Average Lamp Life (1000 hrs)	N/A	N/A	N/A	50	N/A	N/A	50	50	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	N/A	N/A	N/A	$75.53	N/A	N/A	$51.47	$51.47	$23.61	$23.61	$10.83	$10.83
Ballast Price ($)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	N/A	N/A	$19.00	N/A	N/A	$12.87	$12.87	$5.90	$5.90	$2.71	$2.71
System (l/b/f) Cost ($/klm)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	N/A	N/A	0.4	N/A	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	N/A	N/A	$176.63	N/A	N/A	$128.52	$128.52	$72.80	$72.80	$48.72	$48.72
Annual Maintenance Cost ($)	N/A	N/A	N/A	$14.65	N/A	N/A	$10.66	$10.66	$6.04	$6.04	$4.04	$4.04
Total Installed Cost ($/klm)	N/A	N/A	N/A	$44.43	N/A	N/A	$32.13	$32.13	$18.20	$18.20	$12.18	$12.18
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$3.69	N/A	N/A	$2.66	$2.66	$1.51	$1.51	$1.01	$1.01

1. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
2. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

DATA	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical[1]	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	N/A	N/A	N/A	73	N/A	N/A	58	46	44	35	36	35
System Lumens	N/A	N/A	N/A	8000	N/A	N/A	8000	8000	8000	8000	8000	8000
System Efficacy (lm/W)	N/A	N/A	N/A	110	N/A	N/A	137	173	181	230	225	230
Ballast Efficiency (BLE) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	90	N/A	N/A	90	90	90	90	90	90
Correlated Color Temperature (CCT)	N/A	N/A	N/A	4000	N/A	N/A	4000	4000	4000	4000	4000	4000
Average Lamp Life (1000 hrs)	N/A	N/A	N/A	75	N/A	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	N/A	N/A	N/A	$640.00	N/A	N/A	$408.70	$408.70	$217.21	$217.21	$115.44	$115.44
Ballast Price ($) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	N/A	N/A	N/A	$80.00	N/A	N/A	$51.09	$51.09	$27.15	$27.15	$14.43	$14.43
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	N/A	N/A	N/A	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	N/A	N/A	N/A	$708.20	N/A	N/A	$476.90	$476.90	$285.41	$285.41	$183.64	$183.64
Annual Maintenance Cost ($)	N/A	N/A	N/A	$39.16	N/A	N/A	$20.39	$20.39	$11.84	$11.84	$7.62	$7.62
Total Installed Cost ($/klm)	N/A	N/A	N/A	$88.53	N/A	N/A	$59.61	$59.61	$35.68	$35.68	$22.95	$22.95
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$4.89	N/A	N/A	$2.55	$2.55	$1.48	$1.48	$0.95	$0.95

1. Based on the CREE CS18-80LHE found on Grainger online of 11/20/15.
2. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

The commercial low bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits between 6,000 and 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). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial Mercury Vapor Low-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	175	175	N/A	174	N/A	N/A	172	N/A	169	N/A	165	N/A
Lamp Lumens	6825	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
Lamp Efficacy (lm/W)	39	42	N/A	43	N/A	N/A	43	N/A	44	N/A	45	N/A
System Wattage	208	206	N/A	205	N/A	N/A	203	N/A	199	N/A	195	N/A
System Lumens	5176	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
System Efficacy (lm/W)	25	36	N/A	36	N/A	N/A	37	N/A	37	N/A	38	N/A
Ballast Efficiency (BLE)	85%	85%	N/A	85%	N/A	N/A	85%	N/A	85%	N/A	85%	N/A
CRI	15	33	N/A	33	N/A	N/A	33	N/A	33	N/A	33	N/A
Correlated Color Temperature (CCT)	3000	3700	N/A	3700	N/A	N/A	3700	N/A	3700	N/A	3700	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours (hrs/yr)	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$14.96	$11.77	N/A	$11.59	N/A	N/A	$11.31	N/A	$10.75	N/A	$10.23	N/A
Ballast Price ($)	$45.77	$43.76	N/A	$43.11	N/A	N/A	$42.04	N/A	$39.98	N/A	$38.03	N/A
Fixture Price ($)	$34.15	$32.65	N/A	$32.16	N/A	N/A	$31.37	N/A	$29.83	N/A	$28.37	N/A
Lamp Cost ($/klm)	$2.19	$1.59	N/A	$1.57	N/A	N/A	$1.53	N/A	$1.45	N/A	$1.38	N/A
System (l/b/f) Cost ($/klm)	$35.80	$11.92	N/A	$11.74	N/A	N/A	$11.45	N/A	$10.89	N/A	$10.36	N/A
Labor Cost ($/hr)	$95.69	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	0.5	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Total Installed Cost ($)	$328.83	$197.24	N/A	$190.35	N/A	N/A	$188.20	N/A	$184.06	N/A	$180.12	N/A
Annual Maintenance Cost ($)	$3.93	$10.09	N/A	$9.71	N/A	N/A	$9.38	N/A	$8.75	N/A	$8.17	N/A
Total Installed Cost ($/klm)	$63.53	$26.65	N/A	$25.72	N/A	N/A	$25.43	N/A	$24.87	N/A	$24.34	N/A
Annual Maintenance Cost ($/klm)	$0.76	$1.36	N/A	$1.31	N/A	N/A	$1.27	N/A	$1.18	N/A	$1.10	N/A

Performance/Cost Characteristics » Commercial Metal Halide Low-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	175	175	N/A	174	N/A	N/A	170	N/A	161	N/A	154	N/A
Lamp Lumens	8803	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
Lamp Efficacy (lm/W)	50	42	N/A	43	N/A	N/A	44	N/A	46	N/A	48	N/A
System Wattage	210	199	N/A	198	N/A	N/A	193	N/A	183	N/A	175	N/A
System Lumens	6669	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
System Efficacy (lm/W)	32	37	N/A	37	N/A	N/A	38	N/A	40	N/A	42	N/A
Ballast Efficiency (BLE)	88%	88%	N/A	88%	N/A	N/A	88%	N/A	88%	N/A	88%	N/A
CRI	65	80	N/A	80	N/A	N/A	80	N/A	80	N/A	80	N/A
Correlated Color Temperature (CCT)	3000	4000	N/A	4000	N/A	N/A	4000	N/A	4000	N/A	4000	N/A
Average Lamp Life (1000 hrs)	10	15	N/A	15	N/A	N/A	15	N/A	16	N/A	17	N/A
Annual Operating Hours (hrs/yr)	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$24.17	$20.39	N/A	$20.09	N/A	N/A	$19.59	N/A	$18.63	N/A	$17.72	N/A
Ballast Price ($)	$51.12	$48.87	N/A	$48.14	N/A	N/A	$46.95	N/A	$44.66	N/A	$42.47	N/A
Fixture Price ($)	$34.15	$32.65	N/A	$32.16	N/A	N/A	$31.37	N/A	$29.83	N/A	$28.37	N/A
Lamp Cost ($/klm)	$2.75	$2.76	N/A	$2.71	N/A	N/A	$2.65	N/A	$2.52	N/A	$2.39	N/A
System (l/b/f) Cost ($/klm)	$26.17	$13.77	N/A	$13.57	N/A	N/A	$13.23	N/A	$12.58	N/A	$11.97	N/A
Labor Cost ($/hr)	$95.78	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	0.5	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Total Installed Cost ($)	$318.18	$210.98	N/A	$203.88	N/A	N/A	$201.39	N/A	$196.60	N/A	$192.05	N/A
Annual Maintenance Cost ($)	$4.81	$20.78	N/A	$20.12	N/A	N/A	$19.36	N/A	$17.94	N/A	$16.63	N/A
Total Installed Cost ($/klm)	$47.71	$28.51	N/A	$27.55	N/A	N/A	$27.22	N/A	$26.57	N/A	$25.95	N/A
Annual Maintenance Cost ($/klm)	$0.72	$2.81	N/A	$2.72	N/A	N/A	$2.62	N/A	$2.42	N/A	$2.25	N/A

Performance/Cost Characteristics » Commercial Sodium Vapor Low-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	70	100	N/A	99	N/A	N/A	97	N/A	92	N/A	88	N/A
Lamp Lumens	5453	8550	N/A	8550	N/A	N/A	8550	N/A	8550	N/A	8550	N/A
Lamp Efficacy (lm/W)	78	86	N/A	86	N/A	N/A	88	N/A	93	N/A	97	N/A
System Wattage	93	128	N/A	127	N/A	N/A	124	N/A	118	N/A	112	N/A
System Lumens	4130	8550	N/A	8550	N/A	N/A	8550	N/A	8550	N/A	8550	N/A
System Efficacy (lm/W)	64	67	N/A	67	N/A	N/A	69	N/A	72	N/A	76	N/A
Ballast Efficiency (BLE)	78%	78%	N/A	78%	N/A	N/A	78%	N/A	78%	N/A	78%	N/A
CRI	22	22	N/A	22	N/A	N/A	22	N/A	22	N/A	22	N/A
Correlated Color Temperature (CCT)	3000	2000	N/A	2000	N/A	N/A	2000	N/A	2000	N/A	2000	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours (hrs/yr)	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$16.94	$45.56	N/A	$44.88	N/A	N/A	$43.77	N/A	$41.63	N/A	$39.59	N/A
Ballast Price ($)	$49.50	$47.33	N/A	$46.62	N/A	N/A	$45.47	N/A	$43.25	N/A	$41.13	N/A
Fixture Price ($)	$112.99	$108.03	N/A	$106.42	N/A	N/A	$103.78	N/A	$98.71	N/A	$93.88	N/A
Lamp Cost ($/klm)	$3.11	$5.33	N/A	$5.25	N/A	N/A	$5.12	N/A	$4.87	N/A	$4.63	N/A
System (l/b/f) Cost ($/klm)	$41.15	$23.50	N/A	$23.15	N/A	N/A	$22.58	N/A	$21.47	N/A	$20.42	N/A
Labor Cost ($/hr)	$95.27	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	0.5	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Total Installed Cost ($)	$312.86	$309.98	N/A	$301.40	N/A	N/A	$296.51	N/A	$287.07	N/A	$278.09	N/A
Annual Maintenance Cost ($)	$3.93	$21.47	N/A	$20.92	N/A	N/A	$20.04	N/A	$18.40	N/A	$16.90	N/A
Total Installed Cost ($/klm)	$75.75	$36.26	N/A	$35.25	N/A	N/A	$34.68	N/A	$33.58	N/A	$32.53	N/A
Annual Maintenance Cost ($/klm)	$0.95	$2.51	N/A	$2.45	N/A	N/A	$2.34	N/A	$2.15	N/A	$1.98	N/A

Performance/Cost Characteristics » Commercial LED Low-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	68	104	71	46	N/A	56	47	44	34	36	30
System Lumens	548	4877	8410	7042	6294	N/A	7000	7000	7000	7000	7000	7000
System Efficacy (lm/W)	15	72	81	100	136	N/A	125	150	160	207	194	230
Ballast Efficiency (BLE)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	85	75	81	84	N/A	81	81	81	81	81	81
Correlated Color Temperature (CCT)	4000	4000	5000	4000	4000	N/A	4000	4000	4000	4000	4000	4000
Average Lamp Life (1000 hrs)	50	50	100	60	100	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp Price ($)	$215.19	$761.95	$447.31	$267.59	$332.80	N/A	$169.86	$169.86	$90.28	$90.28	$47.98	$47.98
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$156.23	$53.19	$38.00	$52.88	N/A	$24.27	$24.27	$12.90	$12.90	$6.85	$6.85
Labor Cost ($/hr)	$36.83	$68.99	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.20	$68.20
Labor System Installation (hr)	1.5	1.5	1.5	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$865.44	$550.80	$371.08	$436.29	N/A	$273.35	$273.35	$193.76	$193.76	$150.28	$150.28
Annual Maintenance Cost ($)	$0.07	$69.95	$22.26	$25.00	$17.63	N/A	$11.39	$11.39	$7.83	$7.83	$6.07	$6.07
Total Installed Cost ($/klm)	$493.50	$177.44	$65.49	$52.70	$69.32	N/A	$39.05	$39.05	$27.68	$27.68	$21.47	$21.47
Annual Maintenance Cost ($/klm)	$0.13	$14.34	$2.65	$3.55	$2.80	N/A	$1.63	$1.63	$1.12	$1.12	$0.87	$0.87

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18//15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. LED Low-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Commercial High-Bay Lighting Systems

The commercial high-bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits greater than 10,000 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). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
T5 4xF54 HO Linear System	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	400	400	N/A	398	N/A	N/A	394	N/A	386	N/A	378	N/A
Lamp Lumens	14400	15800	N/A	15800	N/A	N/A	15800	N/A	15800	N/A	15800	N/A
Lamp Efficacy (lm/W)	36	40	N/A	40	N/A	N/A	40	N/A	41	N/A	42	N/A
System Wattage	453	449	N/A	447	N/A	N/A	442	N/A	434	N/A	425	N/A
System Lumens	13061	15800	N/A	15800	N/A	N/A	15800	N/A	15800	N/A	15800	N/A
System Efficacy (lm/W)	29	35	N/A	35	N/A	N/A	36	N/A	36	N/A	37	N/A
Ballast Efficiency (BLE)	89%	89%	N/A	89%	N/A	N/A	89%	N/A	89%	N/A	89%	N/A
CRI	50	50	N/A	50	N/A	N/A	50	N/A	50	N/A	50	N/A
Correlated Color Temperature (CCT)	3100	3900	N/A	3900	N/A	N/A	3900	N/A	3900	N/A	3900	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$16.70	$20.07	N/A	$19.77	N/A	N/A	$19.28	N/A	$18.34	N/A	$17.44	N/A
Ballast Price ($)	$48.84	$46.70	N/A	$46.00	N/A	N/A	$44.86	N/A	$42.67	N/A	$40.58	N/A
Fixture Price ($)	$94.03	$89.91	N/A	$88.56	N/A	N/A	$86.37	N/A	$82.15	N/A	$78.13	N/A
Lamp Cost ($/klm)	$1.16	$1.27	N/A	$1.25	N/A	N/A	$1.22	N/A	$1.16	N/A	$1.10	N/A
System (l/b/f) Cost ($/klm)	$11.06	$9.92	N/A	$9.77	N/A	N/A	$9.53	N/A	$9.06	N/A	$8.62	N/A
Labor Cost ($/hr)	$95.28	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	1.0	1.0	N/A	1.0	N/A	N/A	1.0	N/A	1.0	N/A	1.0	N/A
Total Installed Cost ($)	$287.32	$265.74	N/A	$257.82	N/A	N/A	$254.00	N/A	$246.64	N/A	$239.64	N/A
Annual Maintenance Cost ($)	$3.93	$19.00	N/A	$18.28	N/A	N/A	$17.67	N/A	$16.51	N/A	$15.44	N/A
Total Installed Cost ($/klm)	$22.00	$16.82	N/A	$16.32	N/A	N/A	$16.08	N/A	$15.61	N/A	$15.17	N/A
Annual Maintenance Cost ($/klm)	$0.30	$1.20	N/A	$1.16	N/A	N/A	$1.12	N/A	$1.05	N/A	$0.98	N/A

Final

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	250	400	N/A	398	N/A	N/A	388	N/A	369	N/A	351	N/A
Lamp Lumens	13500	32000	N/A	32000	N/A	N/A	32000	N/A	32000	N/A	32000	N/A
Lamp Efficacy (lm/W)	54	80	N/A	80	N/A	N/A	83	N/A	87	N/A	91	N/A
System Wattage	293	443	N/A	440	N/A	N/A	430	N/A	409	N/A	389	N/A
System Lumens	12245	32000	N/A	32000	N/A	N/A	32000	N/A	32000	N/A	32000	N/A
System Efficacy (lm/W)	42	72	N/A	73	N/A	N/A	75	N/A	78	N/A	82	N/A
Ballast Efficiency (BLE)	90%	90%	N/A	90%	N/A	N/A	90%	N/A	90%	N/A	90%	N/A
CRI	65	80	N/A	80	N/A	N/A	80	N/A	80	N/A	80	N/A
Correlated Color Temperature (CCT)	3100	4000	N/A	4000	N/A	N/A	4000	N/A	4000	N/A	4000	N/A
Average Lamp Life (1000 hrs)	10	15	N/A	15	N/A	N/A	15	N/A	16	N/A	17	N/A
Annual Operating Hours	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$17.67	$29.46	N/A	$29.63	N/A	N/A	$28.90	N/A	$27.48	N/A	$26.14	N/A
Ballast Price ($)	$48.84	$46.70	N/A	$46.00	N/A	N/A	$44.86	N/A	$42.67	N/A	$40.58	N/A
Fixture Price ($)	$94.03	$89.91	N/A	$88.56	N/A	N/A	$86.37	N/A	$82.15	N/A	$78.13	N/A
Lamp Cost ($/klm)	$1.31	$0.92	N/A	$0.93	N/A	N/A	$0.90	N/A	$0.86	N/A	$0.82	N/A
System (l/b/f) Cost ($/klm)	$12.83	$5.19	N/A	$5.13	N/A	N/A	$5.00	N/A	$4.76	N/A	$4.53	N/A
Labor Cost ($/hr)	$71.47	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	2.0	2.0	N/A	2.0	N/A	N/A	2.0	N/A	2.0	N/A	2.0	N/A
Labor Lamp Change (hr)	1.4	1.4	N/A	1.4	N/A	N/A	1.4	N/A	1.4	N/A	1.4	N/A
Total Installed Cost ($)	$300.09	$311.48	N/A	$302.18	N/A	N/A	$298.11	N/A	$290.28	N/A	$282.84	N/A
Annual Maintenance Cost ($)	$4.81	$43.12	N/A	$41.82	N/A	N/A	$40.40	N/A	$37.73	N/A	$35.25	N/A
Total Installed Cost ($/klm)	$24.51	$9.73	N/A	$9.44	N/A	N/A	$9.32	N/A	$9.07	N/A	$8.84	N/A
Annual Maintenance Cost ($/klm)	$0.39	$1.35	N/A	$1.31	N/A	N/A	$1.26	N/A	$1.18	N/A	$1.10	N/A

Performance/Cost Characteristics » Commercial Sodium Vapor High-Bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	150	250	N/A	249	N/A	N/A	242	N/A	231	N/A	219	N/A
Lamp Lumens	13500	24300	N/A	24300	N/A	N/A	24300	N/A	24300	N/A	24300	N/A
Lamp Efficacy (lm/W)	90	97	N/A	98	N/A	N/A	100	N/A	105	N/A	111	N/A
System Wattage	190	297	N/A	295	N/A	N/A	288	N/A	274	N/A	261	N/A
System Lumens	10754	24300	N/A	24300	N/A	N/A	24300	N/A	24300	N/A	24300	N/A
System Efficacy (lm/W)	57	82	N/A	82	N/A	N/A	84	N/A	89	N/A	93	N/A
Ballast Efficiency (BLE)	84%	84%	N/A	84%	N/A	N/A	84%	N/A	84%	N/A	84%	N/A
CRI	22	22	N/A	22	N/A	N/A	22	N/A	22	N/A	22	N/A
Correlated Color Temperature (CCT)	3100	2100	N/A	2100	N/A	N/A	2100	N/A	2100	N/A	2100	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$62.80	$45.28	N/A	$44.60	N/A	N/A	$43.50	N/A	$41.37	N/A	$39.35	N/A
Ballast Price ($)	$79.49	$76.00	N/A	$74.87	N/A	N/A	$73.02	N/A	$69.45	N/A	$66.05	N/A
Fixture Price ($)	$247.51	$236.65	N/A	$233.11	N/A	N/A	$227.34	N/A	$216.23	N/A	$205.66	N/A
Lamp Cost ($/klm)	$4.65	$1.86	N/A	$1.84	N/A	N/A	$1.79	N/A	$1.70	N/A	$1.62	N/A
System (l/b/f) Cost ($/klm)	$30.96	$14.73	N/A	$14.51	N/A	N/A	$14.15	N/A	$13.46	N/A	$12.80	N/A
Labor Cost ($/hr)	$241.44	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	2.0	2.0	N/A	2.0	N/A	N/A	2.0	N/A	2.0	N/A	2.0	N/A
Labor Lamp Change (hr)	1.4	1.4	N/A	1.4	N/A	N/A	1.4	N/A	1.4	N/A	1.4	N/A
Total Installed Cost ($)	$815.84	$503.35	N/A	$490.57	N/A	N/A	$481.84	N/A	$465.03	N/A	$449.04	N/A
Annual Maintenance Cost ($)	$3.93	$32.28	N/A	$31.18	N/A	N/A	$30.05	N/A	$27.92	N/A	$25.96	N/A
Total Installed Cost ($/klm)	$75.86	$20.71	N/A	$20.19	N/A	N/A	$19.83	N/A	$19.14	N/A	$18.48	N/A
Annual Maintenance Cost ($/klm)	$0.37	$1.33	N/A	$1.28	N/A	N/A	$1.24	N/A	$1.15	N/A	$1.07	N/A

Performance/Cost Characteristics » Commercial T5 4xF54 HO High-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	54	54	N/A	54	54	N/A	53	53	52	52	51	51
Lamp Lumens	4752	4850	N/A	4273	4750	N/A	4273	4750	4273	4750	4273	4750
Lamp Efficacy (lm/W)	88	90	N/A	79	88	N/A	80	89	82	91	83	92
System Wattage	240	240	N/A	240	240	N/A	238	238	233	233	228	228
System Lumens	18060	19400	N/A	17092	19000	N/A	17092	19000	17092	19000	17092	19000
System Efficacy (lm/W)	75	81	N/A	71	79	N/A	72	80	73	82	75	83
Ballast Efficiency (BLE)	92%	92%	N/A	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	85	86	N/A	86	86	N/A	86	86	86	86	86	86
Correlated Color Temperature (CCT)	4100	4100	N/A	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	24	N/A	25	25	N/A	26	26	27	27	28	28
Annual Operating Hours	4042	4042	N/A	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp Price ($)	$5.06	$7.12	N/A	$5.66	$9.48	N/A	$5.52	$9.25	$5.25	$8.79	$4.99	$8.36
Ballast Price ($)	$29.47	$28.18	N/A	$27.51	$27.51	N/A	$26.83	$26.83	$25.52	$25.52	$24.27	$24.27
Fixture Price ($)	$113.97	$108.94	N/A	$107.32	$107.32	N/A	$104.66	$104.66	$99.54	$99.54	$94.68	$94.68
Lamp Cost ($/klm)	$1.06	$1.47	N/A	$1.32	$2.00	N/A	$1.29	$1.95	$1.23	$1.85	$1.17	$1.76
System (l/b/f) Cost ($/klm)	$8.50	$8.54	N/A	$9.21	$9.09	N/A	$8.98	$8.87	$8.55	$8.43	$8.13	$8.02
Labor Cost ($/hr)	$45.81	$65.10	N/A	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.7	0.7	N/A	0.7	0.7	N/A	0.7	0.7	0.7	0.7	0.7	0.7
Labor Lamp Change (hr)	0.4	0.4	N/A	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	$184.10	$187.64	N/A	$185.95	$189.77	N/A	$182.48	$186.20	$175.78	$179.32	$169.41	$172.78
Annual Maintenance Cost ($)	$2.81	$6.93	N/A	$6.39	$7.62	N/A	$6.19	$7.36	$5.80	$6.87	$5.45	$6.41
Total Installed Cost ($/klm)	$10.19	$9.67	N/A	$10.88	$9.99	N/A	$10.68	$9.80	$10.28	$9.44	$9.91	$9.09
Annual Maintenance Cost ($/klm)	$0.16	$0.36	N/A	$0.37	$0.40	N/A	$0.36	$0.39	$0.34	$0.36	$0.32	$0.34

Performance/Cost Characteristics » Commercial LED High-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	212	189	183	101	N/A	128	107	100	77	82	70
System Lumens	548	18915	15070	18722	13640	N/A	16000	16000	16000	16000	16000	16000
System Efficacy (lm/W)	15	89	80	102	135	N/A	125	150	160	207	194	230
Ballast Efficiency (BLE) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	74	73	80	83	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	5000	5000	5000	4000	4100	N/A	4000	4000	4000	4000	4000	4000
Average Lamp Life (1000 hrs)	50	70	50	60	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp Price ($)	$215.19	$2,395.94	$398.34	$711.42	$297.76	N/A	$388.26	$388.26	$206.35	$206.35	$109.67	$109.67
Ballast Price ($) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$26.43	$38.00	$21.83	N/A	$24.27	$24.27	$12.90	$12.90	$6.85	$6.85
Labor Cost ($/hr)	$36.83	$72.71	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.99	$68.99
Labor System Installation (hr)	1.5	1.5	1.5	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$2,505.00	$501.83	$814.90	$401.25	N/A	$491.75	$491.75	$309.83	$309.83	$213.15	$213.15
Annual Maintenance Cost ($)	$0.07	$144.63	$40.56	$54.89	$32.43	N/A	$20.49	$20.49	$12.52	$12.52	$8.61	$8.61
Total Installed Cost ($/klm)	$493.50	$132.44	$33.30	$43.53	$29.42	N/A	$30.73	$30.73	$19.36	$19.36	$13.32	$13.32
Annual Maintenance Cost ($/klm)	$0.13	$7.65	$2.69	$2.93	$2.38	N/A	$1.28	$1.28	$0.78	$0.78	$0.54	$0.54

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. LED High-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Additional Technologies of Interest: Lighting

Final

- Tables were not provided for technologies of interest utilizing occupancy sensors and other controls due to lack of available data and currently small market presence.
  - Lighting controls can save energy by either reducing input wattage or limiting hours of operation.
  - The following table indicates prevalence of various lighting controls in 2010 (DOE SSL Program, 2012a).
  - Leading experts claim that controls penetration remains low, particularly for integrated/advanced controls (DOE Connected Lighting Systems Meeting, November 2015).
  - As a result, there is not enough information to determine the price and performance impacts of controls on current lighting technologies or to project improvements going forward.

Prevalence of Lighting Controls by Sector and Lamp Type

		None	Dimmer	Light Sensor	Motion Detector	Timer	EMS	Total
Residential	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%
Commercial	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%

EMS: Energy Management System
HID: High Intensity Discharge:
CFL: Compact Fluorescent Lamp

Refrigeration

Commercial Compressor Rack Systems

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,050	1,200	1,200	1,190	930	N/A	830	816	818	715	818	715
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	180	162	162	160	125	N/A	104	102	94	82	82	78
Energy Use (MWh/yr) [2]	1,618	1,497	1,497	1,484	1,160	N/A	1,033	1,016	934	816	934	816
Indexed Annual Efficiency[3]	1.00	1.08	1.08	1.09	1.40	N/A	1.57	1.59	1.73	1.98	1.73	1.98
Average Life (yrs)	15	15	15	15	15	N/A	15	15	15	15	15	15
Total Installed Cost ($1000) [4]	$630	$630	$630	$625	$488	N/A	$452	$444	$388	$339	$388	$339
Total Installed Cost ($/kBtu/hr)	$600	$525	$525	$525	$525	N/A	$545	$544	$474	$474	$474	$474
Annual Maintenance Cost ($1000)[5]	$33	$34	$34	$34	$34	N/A	$34	$34	$34	$34	$34	$34
Annual Maintenance Cost ($/kBtu/hr)	$31.14	$28.33	$28.33	$28.57	$36.56	N/A	$40.96	$41.67	$41.54	$47.55	$41.54	$47.55

[1] The total capacity represents the nominal compressor capacity required for the entire refrigeration system of a typical supermarket. This usually includes two low temperature racks and two medium temperature racks. For 2012 a 1,200 MBtu/hr total cooling capacity is based on a 100 ton estimate for total capacity – 80 tons for the medium temperature racks and 20 tons for the low temperature racks. Beyond 2012, estimates are based on data provided by a supermarket refrigeration efficiency consultant.

[2] Capacity and Annual energy consumption for 2012 and beyond are based on interviews with supermarket refrigeration consultants

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[4] The total installed cost for 2003 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. Total installed cost for 2012 and beyond is based on updated Navigant estimates. Note the decrease in cost over time as required capacity is decreased.

[5] 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%.
- 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)
- Installed cost, power draw, and capacity are all expected to decrease in the future due to the reduced load of supermarket display cases

Commercial Condensers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,680	1,680	1,680	1,666	1,302	N/A	1,121	1,102	1,004	877	1,004	877
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	25	25	24	22	18	N/A	14	14	12	10	12	10
Energy Use (MWh/yr)	138	120	115	106	86	N/A	67	66	58	51	58	48
Indexed Annual Efficiency[2]	1.00	1.15	1.20	1.30	1.60	N/A	2.06	2.10	2.38	2.72	2.38	2.87
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Total Installed Cost ($1000)	$47	$54	$54	$53	$51	N/A	$51	$51	$51	$51	$51	$51
Total Installed Cost ($/kBtu/hr)	$27.87	$32.14	$32.14	$31.81	$39.17	N/A	$45.50	$46.28	$50.80	$58.13	$50.80	$58.15
Annual Maintenance Cost[3]	$817	$954	$954	$954	$954	N/A	$956	$956	$956	$956	$956	$956
Annual Maintenance Cost ($/kBtu/hr)	$0.49	$0.57	$0.57	$0.57	$0.73	N/A	$0.85	$0.87	$0.95	$1.09	$0.95	$1.09

[1] Total capacity is the total heat rejected (THR) of condensers comprised of two low temperature condensers (THRL = 240 MBtu/hr each, suction temperature = -25°F, condensing temperature 110°F) and two medium temperature (THRM = 520 MBtu/hr each, suction temperature = 15°F, condensing temperature = 115°F) condensers; ambient temperature = 95°F. (NCI, 2009). For 2012 and beyond, capacity was estimated based on consultation with a supermarket refrigeration expert.

[2] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[3] Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks. Note a slight expected increase in maintenance costs due to the expected implementation of hybrid condenser systems.

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)
- Total installed cost is expected to decrease over time due to an expected reduction in required capacity due to more efficient display cases

Commercial Supermarket Display Cases

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	20,000	17,623	17,623	17,623	17,623	N/A	17,623	17,623	17,623	17,623	17,623	17,623
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Case Length (ft)	12	12	12	12	12	N/A	12	12	12	12	12	12
Energy Use (kWh/yr) [1,2]	21,000	13,497	13,497	12,565	11,746	N/A	11,787	11,586	10,467	9,146	9,146	8,689
Energy Use (kWh/ft)	1,750	1,125	1,125	1,047	979	N/A	982	966	872	762	762	724
Indexed Annual Efficiency[3]	1.00	1.56	1.56	1.67	1.79	N/A	1.78	1.81	2.01	2.30	2.30	2.42
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$4,371	$8,510	$8,510	$8,940	$9,601	N/A	$9,356	$9,806	$9,453	$9,550	$9,550	$9,806
Total Installed Cost	$6,452	$10,811	$10,811	$11,241	$11,902	N/A	$11,657	$12,107	$11,754	$11,851	$11,851	$12,107
Total Installed Cost ($/kBtu/hr)	323	613	613	638	675	N/A	661	687	667	672	672	687
Annual Maintenance Cost[4]	$657	$940	$940	$940	$940	N/A	$940	$940	$940	$940	$940	$940
Annual Maintenance Cost ($/kBtu/hr)	$32.85	$53.34	$53.34	$53.34	$53.34	N/A	$53.34	$53.34	$53.34	$53.34	$53.34	$53.34

[1] DOE's Federal energy conservation standards for Commercial Refrigeration Equipment (CRE) went into effect on January 1, 2012. The 2012 typical and 2015 low efficiency values are based on minimal compliance with this standard. For 2015 and beyond, energy consumption and cost values were estimated using shipments-weighted averages reported in DOE's 2014 CRE Final Rule TSD for equipment commonly used as display cases. DOE's updated conservation standard goes into effect in 2017, so units sold in 2020 are assumed to comply with this standard.

[2] **For consistency with DOE rulemaking practices, Supermarket Display Case Energy Use reported above includes energy use of the compressor racks and condensers. To avoid double counting, do not add Energy Use from the Compressor Rack or Condenser Systems tabs if calculating total energy consumption.**

[3] **Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).**

[4] 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. After 2012, these values are based on a reported maintenance and repair cost of $220 per unit for preventative maintenance plus approximately $60 per linear foot for additional repair and maintenance

Commercial Supermarket Display Cases

- DOE set Federal energy efficiency standards for Commercial Refrigeration Equipment (CRE) in 2009. 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.
- DOE updated its Energy Conservation Standards for Commercial Refrigeration Equipment in 2014, for equipment sold on or after March 27, 2017.
- The table below lists equipment used as supermarket display cases and their corresponding Energy Conservation Standard levels. The maximum allowable daily energy consumption for each equipment class is a linear function of Total Display Area (TDA)

Equipment Description	DOE Designation	Standards Equation (2012)	Standards Equation (2017)
Vertical Open Cooler	VOP.RC.M	0.82xTDA+4.07	0.64xTDA+4.07
Semi vertical Open Cooler	SVO.RC.M	0.83xTDA+3.18	0.66xTDA+3.18
Horizontal Open Cooler	HZO.RC.M	0.35xTDA+2.88	0.35xTDA+2.88
Transparent-Doored Cooler	VCT.RC.M	0.22xTDA+1.95	0.15xTDA+1.95
Deli Display Cooler	SOC.RC.M	0.51xTDA+0.11	0.44xTDA+0.11
Transparent-Doored Freezer	VCT.RC.L	0.56xTDA+2.61	0.49xTDA+2.61
Horizontal Open Freezer	HZO.RC.L	0.57xTDA+6.88	0.55xTDA+6.88

Commercial Supermarket Display Cases

- The Food Marketing Institute reported the median total supermarket size in 2003 was 44,000 sq. ft., and in 2013, the last year reported in the study, it was listed as 46,500 sq. ft.
- Unit energy consumption for 2012 and beyond is estimated using a shipments weighted average by efficiency level and equipment class, using data in DOE's 2014 CRE Final Rule TSD and Engineering Spreadsheet. The equipment classes analyzed are listed in the table on the previous slide.
- Supermarket refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks
- A typical supermarket display case contains lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- Approximately 20% of 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)
- 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, and improved insulation.
- Unit energy consumption for supermarket display cases is expected to decrease over time as a result of DOE's updated energy conservation standards
- In addition, a transition from open to transparent-doored display cases is expected to occur as supermarkets increase focus on energy efficiency.

Commercial Reach-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	3,000	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	3,800	2,340	2,665	2,033	1,394	1,394	1,448	1,340	1,259	1,150	1,221	1,117
Energy Use (kWh/yr/ft^3) [1]	79	48	54	41	28	28	30	27	26	23	25	23
Indexed Annual Efficiency[3]	1.00	1.62	1.43	1.87	2.73	2.73	2.62	2.84	3.02	3.31	3.11	3.40
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,810	$2,624	$2,728	$2,780	$3,021	$3,021	$2,947	$3,001	$3,214	$2,934	$3,280	$2,959
Total Installed Cost[4]	$2,966	$3,454	$3,591	$3,643	$3,884	$3,884	$3,810	$3,864	$4,077	$3,797	$4,143	$3,822
Total Installed Cost ($/kBtu/hr)	$989	$1,179	$1,226	$1,244	$1,326	$1,326	$1,301	$1,319	$1,392	$1,296	$1,415	$1,305
Annual Maintenance Cost[5]	$143	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185
Annual Maintenance Cost ($/kBtu/hr)	$48	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63

[1] EPACT 2005 energy standards went into effect in 2010. 2015 low efficiency cost and energy consumption values are based on minimum compliance with this standard. Unless otherwise noted, all other cases are based on shipments-weighted averages of solid and transparent doored units reported in the 2014 CRE TSD. DOE's updated Energy Conservation standards go into effect in 2017; therefore, compliance with this standard is assumed for 2020 and beyond.

[2] The Energy Star category is based on a shipments weighted average of solid and transparent-doored units that are minimally compliant with Energy Star v3, effective October 1, 2014. Units compliant with Energy Star are found to be the most efficient reach-in refrigeration equipment on the market in 2015

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based DOE's CRE Final Rule, which assumes a installation cost of $863 for self-contained equipment.

[5] Maintenance costs after 2003 are based on DOE's CRE Final Rule TSD, which reports $35 annual preventative maintenance, per unit, per year, plus approximately $40 per linear foot, per year of additional repair and maintenance costs for the units characterized

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).
- In 2014, DOE updated its energy conservation standards for Reach-in refrigerators, effective March 27, 2017. Both standards are reported in the table below.

Equipment Class	EPCA Standard Level (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.M)	0.10xV+2.04	0.05xV + 1.36
Glass Door (VCT.SC.M)	0.12xV+3.34	0.1xV+0.86

- In 2013, EPA updated its Energy Star® for Reach-in refrigerators, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit.

Reach-In Refrigerator Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.M)	0.02xV+1.60	0.09xV+0.55	0.01xV+2.95	0.06xV+0.45
Glass Door (VCT.SC.M)	0.10xV+1.07	0.15xV+0.32	0.06xV+3.02	0.08xV+2.02

Commercial Reach-In Refrigerators

- Unit energy consumption for 2012 and beyond was estimated based on shipment-weighted averages by efficiency level and equipment class for 49 ft^3 VCS.SC.M and VCT.SC.M units reported in DOE's 2014 CRE Final Rule TSD. These units were estimated to comprise approximately 85% and 15% of total reach-in refrigerator shipments, 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.
- Unit energy consumption is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to compliance with EPA SNAP
- After 2020, the high efficiency cases are based on solid doored units rather than shipment-weighted averages due to the assumption that stakeholders will increasingly value energy conservation.

Commercial Reach-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[3]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr) [1]	9,392	6,023	7,658	5,592	4,563	4,763	4,453	4,417	4,417	3,975	3,776	3,587
Energy Use (kWh/yr/ft^3)	192	123	156	114	93	97	91	90	90	81	77	69
Indexed Annual Efficiency[4]	1.00	1.56	1.23	1.68	2.06	1.97	2.11	2.13	2.13	2.36	2.49	2.62
Average Life (yrs)	8	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,498	$2,886	$3,002	$3,033	$3,186	$3,118	$3,395	$3,389	$3,230	$3,588	$3,617	$3,812
Total Installed Cost[5]	$2,654	$3,749	$3,865	$3,896	$4,049	$3,981	$4,258	$4,252	$4,093	$4,451	$4,480	$4,675
Total Installed Cost ($/kBtu/hr)	$611	$864	$890	$897	$933	$917	$981	$979	$943	$1,025	$1,032	$1,077
Annual Maintenance Cost[6]	$140	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181
Annual Maintenance Cost ($/kBtu/hr)	$32.25	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70

[1] EPACT 2005 energy standards went into effect in 2010. The 2015 low energy consumption and cost values are based on minimal compliance with this standard.

[2] A 49 ft^3 unit was characterized, as this was the representative size selected for DOE's rulemaking analysis.

[3] The Energy Star category was based on a solid doored unit that is minimally compliant with Energy Star v3, effective October 1, 2014

[4] **Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).**

[5] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $863 for self-contained equipment.

[6] Maintenance costs are calculated based on a $35 per unit annual preventative maintenance cost, plus an additional $45 per linear foot repair and maintenance cost estimated based on values reported in the in the CRE TSD

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).
- In December of 2014, DOE updated its energy conservation standards for commercial refrigeration equipment, including reach-in freezers. Both the EPCA and DOE standards are reported in the table below.

Equipment Class	EPCA (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.L)	0.4xV+1.38	0.22xV+1.38
Transparent Door (VCT.SC.L)	0.75xV+4.10	0.29xV+2.95

- In 2013, EPA updated its Energy Star standards for reach-in freezers, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit

Reach-In Freezer Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.L)	0.25xV+1.55	0.20xV+2.30	0.25xV+0.80	0.14xV+6.30
Glass Door (VCT.SC.L)	0.56xV+1.61	0.30xV+5.50	0.55xV+2.00	0.32xV+9.49

Commercial Reach-In Freezers

- The commercial reach-in freezer characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 49 cubic ft. solid two-door unit with a nominal compressor size 4,341 Btu/hr.
- 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.
- Unit energy consumption for reach-in freezers is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to EPA SNAP compliance.

Commercial Walk-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	37,820	37,820	37,820	37,820	37,820	N/A	37,820	37,820	37,820	37,820	37,820	37,820
Size (ft^2) [1]	305	305	305	305	305	N/A	305	305	305	305	305	305
Energy Use (kWh/yr) [2]	53,756	30,689	31,892	30,689	27,571	N/A	16,014	15,855	15,214	15,063	14,453	14,310
Energy Use (kWh/ft^2/yr)	176	101	105	101	90	N/A	53	52	50	49	47	47
Indexed Annual Efficiency[3]	1.00	1.75	1.69	1.75	1.95	N/A	3.36	3.39	3.53	3.57	3.72	3.76
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$19,607	$23,598	$23,583	$23,598	$23,644	N/A	$24,290	$24,473	$24,290	$24,473	$24,290	$24,473
Total Installed Cost[4]	$23,846	$27,012	$26,997	$27,012	$27,057	N/A	$27,703	$27,886	$27,703	$27,886	$27,703	$27,886
Total Installed Cost($/kBtu/hr)	$631	$714	$714	$714	$715	N/A	$733	$737	$733	$737	$733	$737
Annual Maintenance Cost[5]	$573	$716	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$15.15	$18.93	$19.59	$19.59	$19.59	N/A	$19.59	$19.59	$19.59	$19.59	$19.59	$19.59

[1] Estimated based on analysis from the 2014 WICF TSD, which reports the average size of a walk in cooler as 305 ft^2

[2] EISA 2007 includes prescriptive standards for walk-in refrigerators that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. In 2014, DOE updated energy conservation standards for walk-ins. All units 2015 and beyond use data from this rulemaking, and all units 2020 and beyond are assumed to comply with DOE's updated standards.

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $4,163 and $4,891 respectively. Installation cost for 2012 and beyond is based on DOE's Walk-In TSD

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

Commercial Walk-In Refrigerators

- The unit characterized in 2003 was a walk-in cooler with merchandising doors, which was also characterized in the ADL 1996 and NCI, 2009 reports. For 2012 and beyond, the unit characterized was walk-in storage cooler, based on DOE's WICF TSD
- 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
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.

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 the analysis for all units for 2012 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 Refrigerators

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Walk-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	22,114	22,114	22,114	22,114	22,114	N/A	22,114	22,114	22,114	22,114	22,114	22,114
Size (ft^2) [1]	172	172	172	172	172	N/A	172	172	172	172	172	172
Energy Use (kWh/yr) [2]	33,540	22,862	23,610	22,862	20,878	N/A	13,421	13,303	12,750	12,637	12,113	12,006
Energy Use (kWh/ft^2/yr)	195	133	137	133	121	N/A	78	77	74	73	70	70
Indexed Annual Efficiency[3]	1.00	1.47	1.42	1.47	1.61	N/A	2.50	2.52	2.63	2.65	2.77	2.79
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$16,333	$22,008	$21,993	$22,008	$22,054	N/A	$22,793	$23,452	$22,793	$23,452	$22,793	$23,452
Total Installed Cost[4]	$18,570	$24,058	$24,043	$24,058	$24,103	N/A	$24,843	$25,501	$24,843	$25,501	$24,843	$25,501
Total Installed Cost ($/kBtu/hr)	$840	$1,088	$1,087	$1,088	$1,090	N/A	$1,123	$1,153	$1,123	$1,153	$1,123	$1,153
Annual Maintenance Cost[5]	$573	$741	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$25.91	$33.51	$33.51	$33.51	$33.51	N/A	$33.51	$33.51	$33.51	$33.51	$33.51	$33.51

[1] Based on DOE's 2014 WICF Final Rule TSD which states the average floor area for a walk-in storage freezer as 172 ft^2

[2] EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. Units for 2015 and beyond are characterized using data from DOE’s 2014 WICF rulemaking. All units 2020 and beyond are assumed to comply with this standard

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $1,040. Installation cost for 2012 and beyond is based on DOE’s WICF TSD.

[5] 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 is a walk-in storage freezer with an area of 172 ft^2
- A typical walk-in freezer includes:
  - insulated floor, door, and wall panels
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.

Commercial Walk-In Freezers: EISA 2007

- 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 Walk-In Freezers: DOE 2014 Standards

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Ice Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[5]	Typical	High	Typical	High	Typical	High
Output (lbs/day) [1]	300	300	300	300	300	300	300	300	300	300	300	300
Cooling Capacity (Btu/hr)[2]	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963
Water Use (gal/100 lbs)	20	20	20	20	20	20	20	20	20	20	20	20
Energy Use (kWh/100 lbs)	8.4	7.7	7.7	6.7	6.1	6.7	6.1	6.0	6.0	5.7	5.7	5.7
Energy Use (kWh/yr)[3]	3,833	3,185	3,185	3,078	3,009	3,078	2,901	2,901	2,658	2,640	2,525	2,508
Normalized Annual Efficiency[4]	1.00	1.20	1.20	1.25	1.27	1.25	1.32	1.32	1.44	1.45	1.52	1.53
Average Life (yrs)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Retail Equipment Cost	$1,374	$2,146	$2,189	$2,284	$2,392	$2,284	$2,392	$2,427	$2,427	$2,786	$2,786	$2,786
Total Installed Cost (with Bin)	$1,499	$2,441	$2,484	$2,579	$2,687	$2,579	$2,687	$2,722	$2,722	$3,081	$3,081	$3,081
Total Installed Cost ($/kBtu/hr)	$763	$1,244	$1,265	$1,314	$1,369	$1,314	$1,369	$1,387	$1,387	$1,570	$1,570	$1,570
Annual Maintenance Cost[6]	$639	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826
Annual Maintenance Cost ($/kBtu/hr)	$326	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421

[1] Based on the Final Rule shipment data from DOE's Automatic Ice Maker rulemaking which states the most common equipment type is a small air cooled unit with an integrated ice making head with a representative capacity of 300 lbs/day.

[2] Defined as the average heat load to remove the latent and sensible heat required to freeze the daily output capacity of ice

[3] EPACT 2005 energy standards went into effect in 2010. The 2015 Low values are based on this standard. In 2014, DOE set new standards for commercial ice machines, with compliance required by 2018. The unit characterized for 2012 and beyond use data from this rulemaking. All units 2020 and beyond are assumed to comply with the updated standard.

[4] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[5] The Energy Star category is based on minimum compliance with the Energy Star v2.0 standard, which went into effect on February 1, 2013. According to this analysis, Energy Star certification is typical for the small air-cooled IMH unit characterized.

[6] 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 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.
- 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.
- ENERGY STAR® updated its maximum energy consumption levels, in KWh/100 lbs ice, for air cooled ice machines that went into effect on February 1, 2013. These efficiency levels are based on the harvest rate, in lbs/24 hrs. (H). Water cooled ice machines are not eligible for Energy Star certification.

ENERGY STAR Requirements for Air-Cooled Batch-Type Ice Makers			
Equipment Type	Applicable Ice Harvest Rate Range (lbs of ice/24 hrs)	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$200 \leq H \leq 1600$	$\leq 37.72 * H^{-0.298}$	≤ 20.0
RCU	$400 \leq H \leq 1600$	$\leq 22.95 * H^{-0.258} + 1.00$	≤ 20.0
	$1600 \leq H \leq 4000$	$\leq -0.00011 * H + 4.60$	≤ 20.0
SCU	$50 \leq H \leq 450$	$\leq 48.66 * H^{-0.326} + 0.08$	≤ 25.0

ENERGY STAR Requirements for Air-Cooled Continuous-Type Ice Makers		
Equipment Type	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$\leq 9.18 * H^{-0.057}$	≤ 15.0
RCU	$\leq 6.00 * H^{-0.162} + 3.50$	≤ 15.0
SCU	$\leq 59.45 * H^{-0.349} + 0.08$	≤ 15.0

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

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 Ice Machines: 2014 DOE Standards

Energy Conservation Standards for Batch Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<300	6.88 - 0.0055H	200 - 0.022H
		300 and <850	5.80 - 0.00191H	200 - 0.022H
		850 and <1,500	4.42 - 0.00028H	200 - 0.022H
		1500 and <2,500	4.0	200 - 0.022H
		2500 and <4,000	4.0	145
Ice-Making Head	Air	<300	10 - 0.01233H	Not Applicable
		300 and <800	7.05 - 0.0025H	Not Applicable
		800 and <1500	5.55 - 0.00063H	Not Applicable
		1500 and <4,000	4.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	50 and <1,000	7.97 - 0.00342H	Not Applicable
		1,000 and <4,000	4.55	Not Applicable
Remote Condensing and Remote Compressor	Air	<942	7.97 - 0.00342H	Not Applicable
		942 and <4,000	4.75	Not Applicable
Self-Contained	Water	<200	9.5 - 0.019H	191 - 0.0315H
		200 and <2,500	5.7	191 - 0.0315H
		2500 and <4,000	5.7	112
Self-Contained	Air	<110	14.79 - 0.0469H	Not Applicable
		110 and <200	12.42 - 0.02533H	Not Applicable
		200 and <4,000	7.35	Not Applicable

Energy Conservation Standards for Continuous Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<801	6.48 - 0.00267H	180 - 0.0198H
		801 and <2,500	4.34	180 - 0.0198H
		2,500 and <4,000	4.34	130.5
Ice-Making Head	Air	<310	9.19 - 0.00629H	Not Applicable
		310 and <820	8.23 - 0.0032H	Not Applicable
		820 and <4,000	5.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	<800	9.7 - 0.0058H	Not Applicable
		800 and <4,000	5.06	Not Applicable
Remote Condensing and Remote Compressor	Air	<800	9.9 - 0.0058H	Not Applicable
		800 and <4,000	5.26	Not Applicable
Self-Contained	Water	<900	7.6 - 0.00302H	153 - 0.0252H
		900 and <2,500	4.88	153 - 0.0252H
		2500 and <4,000	4.88	90
Self-Contained	Air	<200	14.22 - 0.03H	Not Applicable
		200 and <700	9.47 - 0.00624H	Not Applicable
		700 and <4,000	5.1	Not Applicable

Commercial Beverage Merchandisers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27	27
Energy Use (kWh/yr)	3,900	1,829	2,523	1,781	1,694	1,694	1,380	1,369	1,369	1,329	1,318	1,186
Energy Use ($kWh/ft^3/yr$) [1]	144	68	93	66	63	63	51	51	51	49	49	44
Indexed Annual Efficiency[3]	1.00	2.13	1.55	2.19	2.30	2.30	2.83	2.85	2.85	2.94	2.96	3.29
Average Life (yrs)	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Retail Equipment Cost	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$2,839	$2,972	$3,078	$3,232
Total Installed Cost[4]	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$2,839	$2,972	$3,078	$3,232
Total Installed Cost ($/kBtu/hr)	$311	$508	$496	$555	$560	$560	$599	$605	$605	$634	$656	$689
Annual Maintenance Cost[5]	$84	$108	$108	$98	$95	$95	$95	$95	$95	$95	$95	$95
Annual Maintenance Cost ($/kBtu/hr)	$17.91	$23.03	$23.03	$20.79	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15

[1] EPACT 2005 energy conservation standards went into effect in 2010. The 2015 Low values are based on this standard. In 2015, DOE updated its energy conservation standards for commercial refrigeration equipment, including transparent-doored refrigerators with pull-down capability. Compliance with this standard is required by 2017. Units characterized for 2012 and beyond use data reported in this rulemaking's TSD. Units 2020 and beyond are assumed to comply with this updated standard.

[2] The Energy Star category characterizes a unit that is compliant with Energy Star v3, effective October 1, 2014. This standard does not separately define units with pull-down capability

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Beverage merchandisers are shipped ready to be plugged in, so installation costs are assumed to be negligible

[5] Maintenance costs are estimated based on CRE Final Rule TSD data. Note that maintenance costs decrease slightly for more efficient units, which are assumed to include LED lighting with lower associated maintenance costs

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.
- In 2014, DOE updated its energy consumption standards for commercial refrigeration equipment, including beverage merchandisers, effective March 27, 2015. Both the DOE and EPCA standards are reported below.

Equipment Type	EPCA (2010)	DOE Standards (2017)
Beverage Merchandisers (PD.SC.M)	0.126xV + 3.51	0.11xV+0.81

- In 2013, EPA updated its Energy Star standards for glass doored commercial refrigerators, which can be used as beverage merchandisers, effective October 1, 2014. These standards are also based on the volume of the unit (V). Note that Energy Star does not have a separate equipment class for units with pull-down capability.

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

Commercial Beverage Merchandisers

- The beverage merchandiser characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a nominal compressor size of 4,689 Btu/hr.
- The efficiency of beverage merchandisers can be increased through the use of more efficient compressors, fluorescent lighting with electronic ballasts, and improved insulation.
- 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.
- Unit energy consumption of beverage merchandisers is expected to decrease as a result of DOE's updated Energy Conservation Standards, as well as a transition from R-134a to more efficient propane refrigerant due to EPA SNAP compliance
- By 2040, beverage merchandisers with vapor-compression refrigeration systems are expected to have reached the limit of possible improvements to energy efficiency.

Commercial Refrigerated Vending Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810
Can Capacity	500	470	470	470	470	470	470	470	470	470	470	470
Size (ft^3)	26	26	26	26	26	26	26	26	26	26	26	26
Energy Use (kWh/yr)[1]	3,000	1,632	1,718	1,632	1,504	1,504	1,360	1,292	1,319	1,253	1,293	1,228
Energy Use (kWh/ft^3/yr)	115	63	66	63	58	58	52	50	51	48	50	47
Indexed Annual Efficiency[3]	1.00	1.84	1.75	1.84	1.99	1.99	2.21	2.32	2.27	2.39	2.32	2.44
Average Life (yrs)	14	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Retail Equipment Cost	$1,769	$3,209	$3,187	$3,209	$3,276	$3,276	$3,551	$3,738	$3,661	$3,854	$3,736	$3,933
Total Installed Cost	$1,844	$3,320	$3,298	$3,320	$3,387	$3,387	$3,662	$3,849	$3,772	$3,965	$3,847	$4,044
Total Installed Cost ($/kBtu/hr)	$1,019	$1,834	$1,822	$1,834	$1,872	$1,872	$2,023	$2,127	$2,084	$2,191	$2,125	$2,234
Annual Maintenance Cost[4]	$209	$270	$270	$270	$250	$250	$250	$250	$250	$250	$250	$250
Annual Maintenance Cost ($/kBtu/hr)	$115	$149	$149	$149	$138	$138	$138	$138	$138	$138	$138	$138

[1] Energy use for 2012 and beyond is estimated based on DOE's 2015 BVM Final Rule

[2] The Energy Star category assumes units that are compliant with the Energy Star v3 standard, since combination units are currently not separately defined by Energy Star. This standard went into effect on March 1, 2013. Our analysis finds Energy Star certified equipment to be the most efficient currently available on the market

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[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) ≤ 0.055*V + 2.56
  - Refrigerated Vending Machines that are zone-cooled (Type B) ≤ 0.073*V + 3.16
- Energy Star® updated its maximum daily energy consumption efficiency levels, also in KWh/day, for refrigerated vending machines that went into effect on March 1, 2013. These efficiency levels are based on refrigerated volume.

Equipment Type	Maximum Daily Energy Consumption	Low Power Mode Requirement
Class A (Transparent-Front)	MDEC= 0.0523 x V + 2.432	Hard-wired controls and/or software capable of placing the machine into a low power mode during periods of extended inactivity while still connected to its power source
Class B (Solid-Front)	MDEC = 0.0657 x V + 2.844	

- DOE is currently engaged in rulemaking for refrigerated vending machines, which will separately define combination vending machines with a separate, partitioned volume for unrefrigerated products. Data for characterizing units 2012 and beyond is drawn from this NOPR TSD.

Commercial Refrigerated Vending Machines

- In December 2015, DOE updated its energy conservation standards for beverage vending machines, and defined two new product classes for combination vending machines Compliance with these standards is required by 2019. For this analysis, compliance with these updated standards is assumed for equipment sold in 2020 and beyond. The updated standards and DOE equipment definitions are listed in the table below.

Equipment Class	Maximum daily energy consumption (kilowatt hours per day)
Class A – a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.052 x V + 2.43
Class B – any refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine	MDEC = 0.052 x V + 2.20
Combination A – a combination vending machine where 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.086 x V + 2.66
Combination B – a combination vending machine that is not considered to be Combination A	MDEC = 0.111 x V + 2.04

Commercial Ventilation

Commercial Constant Air Volume

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4,5]	Typical[4,6]	High[4,7]	Energy Star	Typical[4,7]	High[4,8]	Typical[4,7,9]	High[4,8,9]	Typical[4,7,9]	High[4,8,9]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	11.80	11.56	11.56	11.56	11.56	N/A	11.56	11.56	10.98	10.98	9.83	9.83
Specific Fan Power (W/CFM)	0.787	0.771	0.771	0.771	0.771	N/A	0.771	0.771	0.732	0.732	0.655	0.655
Annual Fan Energy Use (kWh/yr)[1]	44,858	43,924	23,038	20,018	15,226	N/A	15,226	11,155	14,465	10,597	12,942	9,482
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$68,539	$68,539	$68,979	$68,979	$74,178	N/A	$74,178	$74,778	$74,178	$74,778	$74,178	$74,778
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$4,569	$4,569	$4,599	$4,599	$4,945	N/A	$4,945	$4,985	$4,945	$4,985	$4,945	$4,985
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

1 Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

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.

4 ASHRAE 90.1-2010 & 2013 Section 6.5.3.2 require minimum 2-speed fan control (no longer always constant volume).

5 Two-speed motor.

6 Two-speed VFD.

7 Modulating VFD (66-100%).

8 Modulating VFD (50-100%).

9 High aerodynamic efficiency fan.

Commercial Constant Air Volume

- Constant air volume (CAV) ventilation systems are common, inexpensive, air-side HVAC systems that operate in response to a single control zone. Historically, 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. Recent energy efficiency standard changes (ASHRAE 90.1-2013) now mandate at least two fan speed settings with the requirement of a maximum 40% power at 66% flow. Systems with variable speed fans are increasingly popular, making the term "constant air volume" somewhat of a misnomer for this system type. This analysis examines only the fan energy of the CAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for CAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the CAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- 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 $60,722 (RS Means 2016). Ductwork would cost approximately $7,817 additional ($68,539 total). A 2-speed motor (estimated $440 incremental cost) and variable frequency drive (estimated $5,639) add cost.
- 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 2012 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, motor efficiency, and speed/flow control.

Commercial Variable Air Volume

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4]	Typical[5]	High[6]	Energy Star	Typical[6]	High[6,7]	Typical[6,7]	High[6,7]	Typical[6,7]	High[6,7]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	16.72	15.99	15.99	15.99	15.99	N/A	15.99	15.19	15.19	14.39	14.39	13.59
Specific Fan Power (W/CFM)	1.115	1.066	1.066	1.066	1.066	N/A	1.066	1.013	1.013	0.959	0.959	0.906
Annual Fan Energy Use (kWh/yr)[1]	25,839	24,699	24,699	18,181	16,425	N/A	16,425	15,604	15,604	14,783	14,783	13,961
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$88,207	$88,207	$88,207	$93,846	$94,346	N/A	$94,446	$94,946	$94,446	$94,946	$94,446	$94,946
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$5,880	$5,880	$5,880	$6,256	$6,290	N/A	$6,296	$6,330	$6,296	$6,330	$6,296	$6,330
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

[1] Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[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.

[4] ASHRAE 90.1-2010 Section 6.5.3.2 minimum power-flow requirement.

[5] ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 50%-100% flow.

[6] ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 30%-100% flow.

[7] High aerodynamic efficiency fan.

Commercial Variable Air Volume

- 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 speed/flow to meet space conditioning requirements; minimum flow settings apply for DX cooling stages and gas furnace heating stages. Most hours of operation are much lower than full speed, and fan power varies with the cube of fan speed according to fan affinity laws. The 2012 ASHRAE Handbook: HVAC Systems and Equipment (p. 45.11) provided the typical flow profile used for this analysis. The unit characterized in this report is a 15,000 CFM VAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for VAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the VAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- A 15,000 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $69,100 (RS Means 2016). Ductwork and (10) VAV boxes with reheat would cost approximately $19,107 additional ($88,207 total). A 20 hp variable frequency drive (estimated $5,639) is an additional cost.
- 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 2012 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 Units

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[5]	Low[3]	Typical[5]	High[6]	Energy Star	Typical[4,6]	High[4,7]	Typical[4,7]	High[4,8]	Typical[4,8]	High[4,8,9]
System Airflow (CFM)	800	800	800	800	800	N/A	800	800	800	800	800	800
System Fan Power (kW)	0.315	0.241	0.748	0.241	0.148	N/A	0.148	0.148	0.148	0.148	0.148	0.141
Specific Fan Power (W/CFM)	0.394	0.302	0.935	0.301	0.185	N/A	0.185	0.185	0.185	0.185	0.185	0.176
Annual Fan Energy Use (kWh/yr)[1]	709	543	1,683	543	333	N/A	333	152	152	94	94	89
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$2,429	$2,429	$2,429	$2,429	$2,753	N/A	$2,753	$2,995	$2,753	$2,995	$2,753	$2,995
Annual Maintenance Cost ($)	$100	$100	$100	$100	$100	N/A	$100	$100	$100	$100	$100	$100
Total Installed Cost ($/1000 CFM)	$3,036	$3,036	$3,036	$3,036	$3,441	N/A	$3,441	$3,744	$3,441	$3,744	$3,441	$3,744
Annual Maintenance Cost ($/1000 CFM)	$125	$125	$125	$125	$125	N/A	$125	$125	$125	$125	$125	$125

[1] Based on 2250 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.

[3] Based on ASHRAE 90.1-2010 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

[4] Based on ASHRAE 90.1-2013 Section 6.5.3.5 requirement of electronically commutated or 70+% efficient fan motor.

[5] Permanent split capacitor fan motor.

[6] Electronically commutated fan motor (single speed).

[7] Electronically commutated fan motor (two-speed).

[8] Electronically commutated fan motor (variable speed).

[9] High aerodynamic efficiency fan.

Commercial Fan Coil Units

- 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.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons. This analysis examines only the fan energy of FCUs.
- 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. ASHRAE 90.1-2013 requires an electronically commutated fan motor (or minimum motor efficiency of 70%) for this system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for FCUs. Fan power can be minimized through good design practice and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including small systems such as the FCU considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- 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 2012 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, motor efficiency, and fan speed control.

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

Residential Lighting

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

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Ref. Case	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)	DOE, 2008										
Average Lamp Life (1000 hrs)	2012 EIA Ref. Case										
Annual Operating Hours (hrs/yr)	DOE, 2012(3)										
Lamp Price ($)	2012 EIA Ref. Case										
Lamp Cost ($/klm)											
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

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

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Ref. Case	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)	DOE, 2008										
Average Lamp Life (1000 hrs)	2012 EIA Ref. Case										
Annual Operating Hours (hrs/yr)	DOE, 2012(3)										
Lamp Price ($)	2012 EIA Ref. Case										
Lamp Cost ($/klm)											
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential General Service Halogen Lamps (60 watt Incandescent Equivalent)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	N/A	Product Catalogs	N/A							
Lamp Lumens	Product Catalogs										
Lamp Efficacy (lm/W)	Calculated; NCI, 2014(1)										
CRI	Product Catalogs										
Correlated Color Temperature (CCT)	DOE, 2008		DOE, 2008								
Average Lamp Life (1000 hrs)	Calculated; NCI, 2014(1)		Product Catalogs								
Annual Operating Hours (hrs/yr)	DOE, 2012(3)		DOE, 2012(3)								
Lamp Price ($)	Calculated; NCI, 2014(1)		Distributor Websites								
Lamp Cost ($/klm)			Calculated								
Labor Cost ($/hr)	N/A		N/A								
Labor Installation (hr)											
Total Installed Cost ($)	Calculated		Calculated								
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources» Residential General Service Halogen Lamps (75 watt Incandescent Equivalent)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>Calculated</td><td rowspan="15">N/A</td><td rowspan="4">Product Catalogs</td><td rowspan="15" colspan="8">N/A</td></tr>
<tr><td>Lamp Lumens</td><td>Product Catalogs</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>Calculated; NCI, 2014(1)</td></tr>
<tr><td>CRI</td><td>Product Catalogs</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE, 2008</td><td>DOE, 2008</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>Calculated; NCI, 2014(1)</td><td>Product Catalogs</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated; NCI, 2014(1)</td><td>Distributor Websites</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td></tr>
<tr><td>Labor Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4">Calculated</td><td rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Residential General Service Compact Fluorescent Lamps

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Lamp Wattage</td><td rowspan="4">2012 EIA Ref. Case</td><td colspan="3" rowspan="2">Product Catalogs</td><td rowspan="6">TCP 1ES134AMO, Lowest performing product in the Energy Star Light Bulb product database downloaded 11-10-15</td><td colspan="6" rowspan="6">NCI, 2014(1)</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="3">Product Catalogs</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>Product Catalogs</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2012 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="11">DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">2012 EIA Ref. Case</td><td colspan="3">Distributor Websites</td><td rowspan="8">N/A</td><td colspan="6" rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="4" rowspan="2">N/A</td><td colspan="6" rowspan="2">N/A</td></tr>
<tr><td>Labor Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="4" rowspan="4">Calculated</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Residential General Service LED Lamps (60 Watt Equivalent)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>Calculated</td><td colspan="3" rowspan="4">LED Lighting Facts Database (downloaded 10/31/15)</td><td rowspan="2">Energy Star Light Bulb product database (downloaded 11/4/15)</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td>Product Catalogs</td><td colspan="6">Calculated from 2015 Values</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>2012 SSL MYPP</td><td>Calculated</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Calculated</td></tr>
<tr><td>CRI</td><td rowspan="3">Product Catalogs</td><td rowspan="2">Energy Star Light Bulb product database (downloaded 11/4/15)</td><td colspan="6" rowspan="2">Assume Unchanged From 2015 Typical</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td><td rowspan="2">SSL R&D Plan Table 2.1 (DOE SSL Program, 2015)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>Retailer Websites</td><td colspan="2">Retailer Websites</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Assume Unchanged</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="11">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td>Calculated</td><td>Retailer Websites</td><td>Calculated</td><td colspan="2">Retailer Websites</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>2012 SSL MYPP</td><td>Calculated</td><td>SSL R&D Plan Table 2.1 +adjustment (DOE SSL Program, 2015)</td><td colspan="2">Calculated</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="11" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="11" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Final

Data Sources » Residential Reflector Lamps (65W BR30 Incandescent)

<table>
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<tr><td>Lamp Wattage</td><td rowspan="4">2012 EIA Ref. Case</td><td rowspan="9">N/A</td><td rowspan="6">Product Catalogs</td><td rowspan="9" colspan="2">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE, 2012(1)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2012 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated; NCI 2014(1)</td><td>Distributor Websites</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2" colspan="11">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4" colspan="11">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
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Data Sources » Residential Reflector Lamps (PAR30 Halogen)

<table>
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<tr><td>Lamp Wattage</td><td rowspan="4">2012 EIA Ref. Case</td><td rowspan="9">N/A</td><td rowspan="6">Product Catalogs</td><td rowspan="9">N/A</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE, 2012(1)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2012 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated; NCI 2014(1)</td><td>Distributor Websites</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2" colspan="11">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
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<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Residential Reflector Lamps (PAR30 Halogen Infrared Reflector (HIR)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	N/A	Product Catalogs	N/A		NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Lamp Lumens	Product Catalogs										
Lamp Efficacy (lm/W)	Calculated; NCI, 2014(1)										
CRI	Product Catalogs										
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)	Calculated; NCI, 2014(1)										
Annual Operating Hours (hrs/yr)	DOE, 2012(3)		DOE, 2012(3)			DOE, 2012(3)		DOE, 2012(3)		DOE, 2012(3)	
Lamp Price ($)	Calculated; NCI, 2014(1)		Distributor Websites			NCI, 2014(1)		NCI, 2014(1)		NCI, 2014(1)	
Lamp Cost ($/klm)			Calculated								
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Reflector Lamps (BR30 CFL)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Lamp Wattage</td><td rowspan="4">2012 EIA Ref. Case</td><td colspan="3" rowspan="6">Product Catalogs</td><td rowspan="6">EcoSmart CFL 15W BR30 158-653, Lowest performing product in the Energy Star Light Bulb product database downloaded 11-10-15</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE, 2012(1)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2012 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="4">DOE, 2012(3)</td><td rowspan="3">N/A</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">2012 EIA Ref. Case</td><td colspan="3">Distributor Websites</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="11" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="11" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
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Data Sources » Residential Reflector LED BR30

<table>
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<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>Calculated</td><td colspan="3" rowspan="4">LED Lighting Facts Database (downloaded 10/31/15)</td><td rowspan="2">Energy Star Light Bulb product database (downloaded 11/4/15)</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td rowspan="2">Adjusted based on PAR38 values</td><td colspan="6">Nominal lumen output based on historical values</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>Calculated</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2"></td></tr>
<tr><td>CRI</td><td rowspan="3">Adjusted based on PAR38 values</td><td rowspan="2">Energy Star Light Bulb product database (downloaded 11/4/15)</td><td colspan="6" rowspan="2">Assume Unchanged</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td><td rowspan="2">DOE SSL Program R&D Plan (DOE SSL Program, 2015)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>Retailer Websites</td><td colspan="2">Retailer Websites</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Assume Unchanged</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="11">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td>Calculated</td><td>Retailer Websites</td><td>Calculated</td><td colspan="2">Retailer Websites</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Adjusted based on PAR38 values</td><td>Calculated</td><td>DOE SSL Program R&D Plan (DOE SSL Program, 2015)</td><td colspan="2">Calculated</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="11" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="11" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Linear Fluorescent Lamp T12

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage											
Lamp Lumens	DOE GSFL and IRL Energy Conservation Standard, 2009										
Lamp Efficacy (lm/W)											
System Wattage											
System Lumens											
System Efficacy (lm/W)	Calculated										
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011										
CRI	DOE GSFL and IRL Energy Conservation Standard, 2009										
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013										
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009										
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					N/A					
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009										
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011										
Fixture Price ($)											
Lamp Cost ($/klm)											
System (l/b/f) Cost ($/klm)											
Labor Cost ($/hr)											
Labor System Installation (hr)											
Labor Lamp Change (hr)											
Total Installed Cost ($)											
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)	Calculated										

Data Sources » Residential Linear Fluorescent Lamp T8

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	Calculated					
Lamp Lumens						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	Calculated	Calculated				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Final Rule TSD (DOE, 2015)			Energy Star Light Bulb product database (downloaded 11-4-15)						
System Lumens											
System Efficacy (lm/W)		Calculated									
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011	GSFL IRL Final Rule TSD (DOE, 2015)			Assume same as other 2015 data	Assume Unchanged from 2015					
CRI	DOE GSFL and IRL Energy Conservation Standard, 2009				Energy Star Light Bulb product database (downloaded 11-4-15)						
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013										
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011				N/A						
Fixture Price ($)	Assume Same as Commercial Fixture				Retailer Websites						
Lamp Cost ($/klm)	Calculated	Calculated									
System (l/b/f) Cost ($/klm)											
Labor Cost ($/hr)		GSFL IRL Final Rule TSD (DOE, 2015)									
Labor System Installation (hr)											
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	Calculated					
Lamp Lumens						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage	Calculated	GSFL IRL Final Rule TSD (DOE, 2015)			Energy Star Light Bulb product database (downloaded 11-4-15)						
System Lumens											
System Efficacy (lm/W)		Calculated									
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011	GSFL IRL Final Rule TSD (DOE, 2015)			Asssume Constant	Assume Unchanged from 2015					
CRI	DOE GSFL and IRL Energy Conservation Standard, 2009				Energy Star Light Bulb product database (downloaded 11-4-15)						
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013										
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011										
Fixture Price ($)	Assume Same as Commercial Fixture				Retailer Websites						
Lamp Cost ($/klm)	Calculated	Calculated									
System (l/b/f) Cost ($/klm)											
Labor Cost ($/hr)		GSFL IRL Final Rule TSD (DOE, 2015)									
Labor System Installation (hr)	Assume same as 2015										
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Linear LED Replacement Lamp 2 Lamp System*

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)			N/A	Calculated					
Lamp Lumens						Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage	Calculated					Calculated					
System Lumens	DOE SSL Program R&D Plan (DOE SSL Program, 2015)					DOE SSL Program R&D Plan (DOE SSL Program, 2015)					
System Efficacy (lm/W)	Calculated					Calculated					
Ballast Efficiency (BLE)	N/A					N/A					
CRI	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List Downloaded 11/17/15	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)		Retailer Websites	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A					N/A					
Fixture Price ($)*											
Lamp Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*	N/A					N/A					
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor System Installation (hr)*											
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Linear LED Luminaire*

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage											
Lamp Lumens	N/A										
Lamp Efficacy (lm/W)											
System Wattage		DLC Qualified Product List (Downloaded 11/18/15)		DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
System Lumens	Calculated	Calculated	LED Lighting Facts Database (downloaded 10/31/15)	Calculated		Adjusted for 2015 Typical Lumen Output					
System Efficacy (lm/W)		DLC Qualified Product List (Downloaded 11/18/15)		DLC Qualified Product List (Downloaded 11/18/15)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Efficiency (BLE)	N/A										
CRI			LED Lighting Facts Database (downloaded 10/31/15)			Assume Unchanged					
Correlated Color Temperature (CCT)	Calculated	DLC Qualified Product List (Downloaded 11/18/15)		DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)						
Average Lifetime (1000 hrs)			DOE SSL Program R&D Plan (DOE SSL Program, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp/Luminaire Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites	Retailer Websites	Calculated					
Ballast Price ($)											
Fixture Price ($)	N/A										
Lamp Cost ($/klm)											
System (l/b/f) Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	Assume Same as T5										
Labor System Installation (hr)											
Labor Lamp Change (hr)	N/A										
Total Installed Cost ($)											
Annual Maintenance Cost ($)	Calculated										
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Security: BR30 Incandescent)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as indoor Residential Incandescent Reflector	N/A	Same as indoor Residential Incandescent Reflector	N/A		Same as indoor Residential Incandescent Reflector	N/A	Same as indoor Residential Incandescent Reflector	N/A	Same as indoor Residential Incandescent Reflector	N/A
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE, 2012(2)		DOE, 2012(2)			DOE, 2012(2)		DOE, 2012(2)		DOE, 2012(2)	
Lamp Price ($)	Same as indoor Residential Incandescent Reflector		Same as indoor Residential Incandescent Reflector			Same as indoor Residential Incandescent Reflector		Same as indoor Residential Incandescent Reflector		Same as indoor Residential Incandescent Reflector	
Lamp Cost ($/klm)											
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Security: PAR38 Halogen)

<table>
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<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="6">Interpolated from Commercial PAR38 Halogen</td><td rowspan="9">N/A</td><td rowspan="6">Same as Commercial PAR38 Halogen</td><td rowspan="9" colspan="2">N/A</td><td rowspan="6" colspan="6">Same as Commercial PAR38 Halogen</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(2)</td><td>DOE, 2012(2)</td><td colspan="6">DOE, 2012(2)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Interpolated from Commercial PAR38 Halogen</td><td rowspan="2">Same as Commercial PAR38 Halogen</td><td rowspan="2" colspan="6">Same as Commercial PAR38 Halogen</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2" colspan="11">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4" colspan="11">Calculated</td></tr>
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Data Sources » Residential Outdoor Lamps (Security: PAR38 HIR)

<table>
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<tr><td>Lamp Wattage</td><td rowspan="6">Interpolated from Commercial PAR38 HIR</td><td rowspan="9">N/A</td><td rowspan="6">Same as Commercial PAR38 HIR</td><td rowspan="9" colspan="2">N/A</td><td rowspan="6" colspan="6">Same as Commercial PAR38 HIR</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(2)</td><td>DOE, 2012(2)</td><td colspan="6">DOE, 2012(2)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Interpolated from Commercial PAR38 HIR</td><td rowspan="2">Same as Commercial PAR38 HIR</td><td rowspan="2" colspan="6">Same as Commercial PAR38 HIR</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2" colspan="11">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4" colspan="11">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Final

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<tr><td>Lamp Wattage</td><td>Calculated</td><td rowspan="9">N/A</td><td rowspan="6">Product Catalogs</td><td rowspan="9">N/A</td><td rowspan="6">Product Catalogs; Distributor Websites (Distributor websites claim ENERGY STAR certification for nearly all lamp models but no PAR38 CFLs listed on ENERGY STAR product list)</td><td colspan="6" rowspan="6">NCI, 2014(1)</td></tr>
<tr><td>Lamp Lumens</td><td>Same as outdoor halogen reflector</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>Calculated; NCI, 2014(1)</td></tr>
<tr><td>CRI</td><td rowspan="2">Product Catalogs</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>Calculated; NCI, 2014(1)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(2)</td><td>DOE, 2012(2)</td><td rowspan="3">N/A</td><td colspan="6">DOE, 2012(2)</td></tr>
<tr><td>Lamp Price ($)</td><td>Calculated</td><td>Distributor Websites</td><td colspan="6" rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Calculated; NCI, 2014(1)</td><td>Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="11" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="11" rowspan="4">Calculated</td></tr>
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</table>

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

DATA SOURCES	2009	2015*				2020*		2030*		2040*	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential General Service 75W Incandescent	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE, 2012(2)										
Lamp Price ($)	Same as Residential General Service 75W Incandescent										
Lamp Cost ($/klm)											
Labor Cost ($/hr)											
Labor Lamp Installation (hr)											
Total Installed Cost ($)											
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Porch: Halogen A-Type)

DATA SOURCES	2009	2015*				2020**		2030**		2040**	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential General Service 75W Equivalent Halogen	N/A	Same as Residential General Service 75W Equivalent Halogen	N/A							
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE, 2012(2)		DOE, 2012(2)								
Lamp Price ($)	Same as Residential General Service 75W Equivalent Halogen		Same as Residential General Service 75W Equivalent Halogen								
Lamp Cost ($/klm)											
Labor Cost ($/hr)											
Labor Lamp Installation (hr)											
Total Installed Cost ($)											
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Porch: CFL Bare Spiral)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Lamp Wattage</td><td>Calculated</td><td colspan="3" rowspan="2">Product Catalogs</td><td rowspan="6">Energy Star Light Bulb product database downloaded 11-10-15</td><td colspan="6" rowspan="6">NCI, 2014(1)</td></tr>
<tr><td>Lamp Lumens</td><td>Same as 2015 Typical</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>Calculated; NCI, 2014(1)</td><td colspan="3">Calculated</td></tr>
<tr><td>CRI</td><td rowspan="2">Product Catalogs</td><td colspan="3" rowspan="3">Product Catalogs</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>Calculated; NCI, 2014(1)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="4">DOE, 2012(2)</td><td rowspan="3">N/A</td><td colspan="6">DOE, 2012(2)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated; NCI, 2014(1)</td><td colspan="3">Distributor Websites</td><td colspan="6" rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="11" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
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<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Residential Outdoor Lamps (Porch: LED A-Type*)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star*	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated										
Lamp Lumens	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Lamp Efficacy (lm/W)	Scaled based on 60W Residential A-type Lamp										
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE SSL Program, Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates (DOE SSL Program, 2012)										
Lamp Price ($)	Calculated										
Lamp Cost ($/klm)	Scaled based on 60W Residential A-type Lamp										
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Commercial Lighting

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Reference Case		N/A									
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage												
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI												
Correlated Color Temperature (CCT)	DOE, 2008											
Average Lamp Life (1000 hrs)	2012 EIA Reference Case											
Annual Operating Hours (hrs/yr)	DOE, 2012(3)											
Lamp Price ($)	2012 EIA Reference Case; Calculated											
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	2016 RSMeans Online											
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	Calculated											
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial General Service Halogen Lamp (100W Incandescent Equivalent) in Recessed Can Fixture

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Reference Case		N/A	Product Catalogs	N/A							
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage												
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI												
Correlated Color Temperature (CCT)	DOE, 2008											
Average Lamp Life (1000 hrs)	2012 EIA Reference Case											
Annual Operating Hours (hrs/yr)	DOE, 2012(3)			DOE, 2012(3)								
Lamp Price ($)	2012 EIA Reference Case; Calculated			Distributor Websites								
Ballast Price ($)												
Fixture Price ($)				NCI, 2014(2)								
Lamp Cost ($/klm)				Calculated								
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	2016 RSMeans Online			2016 RSMeans Online								
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	Calculated			Calculated								
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Reference Case		Product Catalogs			GE FLE26HT3/2/SXE/SW, Lowest Performing product in the Energy Star Light Bulb product database downloaded 11-10-15	Calculated					
Lamp Lumens							Held Constant 2015-2040					
Lamp Efficacy (lm/W)							NCI, 2014(1)					
System Wattage							Same as lamp wattage					
System Lumens							Calculated; 2012 EIA Reference Case					
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI							2012 EIA Reference Case					
Correlated Color Temperature (CCT)	Product Catalogs						Product Catalogs					
Average Lamp Life (1000 hrs)	2012 EIA Reference Case						Calculated; Product Catalogs; NCI, 2014(1)					
Annual Operating Hours (hrs/yr)	DOE, 2012(3)					N/A	DOE, 2012(3)					
Lamp Price ($)	2012 EIA Reference Case; Calculated		Distributor Websites				Calculated; Distributor Websites; NCI, 2014(1)					
Ballast Price ($)												
Fixture Price ($)			NCI, 2014(2)									
Lamp Cost ($/klm)			Calculated									
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	2016 RSMeans Online						2016 RSMeans Online					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage		Calculated										
System Lumens*												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)			Retailer Websites	Assume Same as A19 60W equiv	Retailer Websites							
Average Lamp Life (1000 hrs)		Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	Calculated				Calculated	
System (l/b/f) Cost ($/klm)		N/A										
Labor Cost ($/hr)		Same as for CFL										
Labor System Installation (hr)**												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated										
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Halogen Reflector Lamp (PAR38) in Recessed Can Fixture

Final

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td colspan="2" rowspan="8">2012 EIA Reference Case</td><td rowspan="23">N/A</td><td rowspan="10">Product Catalogs</td><td colspan="2" rowspan="23">N/A</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td colspan="6">Held Constant 2015-2040</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="6">NCI, 2014(1)</td></tr>
<tr><td>System Wattage</td><td colspan="6">Same as lamp wattage</td></tr>
<tr><td>System Lumens</td><td colspan="6" rowspan="3">Calculated; 2012 EIA Reference Case</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td></tr>
<tr><td>CRI</td><td colspan="6">2012 EIA Reference Case</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td colspan="2">Product Catalogs</td><td colspan="6">Product Catalogs</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="2">2012 EIA Reference Case</td><td colspan="6">Calculated; Product Catalogs; NCI, 2014(1)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="2">DOE, 2012(3)</td><td>DOE, 2012(3)</td><td colspan="6">DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td colspan="2" rowspan="5">2012 EIA Reference Case; Calculated</td><td rowspan="2">Distributor Websites</td><td colspan="6" rowspan="5">Calculated; Distributor Websites; NCI, 2014(1)</td></tr>
<tr><td>Ballast Price ($)</td></tr>
<tr><td>Fixture Price ($)</td><td>NCI, 2014(2)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="2" rowspan="3">2016 RSMeans Online</td><td rowspan="3">2016 RSMeans Online</td><td colspan="6" rowspan="3">2016 RSMeans Online</td></tr>
<tr><td>Labor System Installation (hr)</td></tr>
<tr><td>Labor Lamp Change (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="2" rowspan="4">Calculated</td><td rowspan="4">Calculated</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Reference Case		N/A	Product Catalogs	N/A		Calculated					
Lamp Lumens							Held Constant 2015-2040					
Lamp Efficacy (lm/W)							NCI, 2014(1)					
System Wattage							Same as lamp wattage					
System Lumens							Calculated; 2012 EIA Reference Case					
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI							2012 EIA Reference Case					
Correlated Color Temperature (CCT)	Product Catalogs						Product Catalogs					
Average Lamp Life (1000 hrs)	2012 EIA Reference Case						Calculated; Product Catalogs; NCI, 2014(1)					
Annual Operating Hours (hrs/yr)	DOE, 2012(3)			DOE, 2012(3)			DOE, 2012(3)					
Lamp Price ($)	2012 EIA Reference Case; Calculated			Distributor Websites			Calculated; Distributor Websites; NCI, 2014(1)					
Ballast Price ($)												
Fixture Price ($)				NCI, 2014(2)								
Lamp Cost ($/klm)				Calculated								
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	2016 RSMeans Online			2016 RSMeans Online			2016 RSMeans Online					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	Calculated			Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial LED Reflector Lighting (PAR38)

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)				Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage		Calculated										
System Lumens*												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)		N/A										
CRI		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)	N/A	Calculated	Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)**		N/A										
Labor Cost ($/hr)		Same as for Halogen										
Labor System Installation (hr)**												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated										
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft T8 F32 Commodity in 2-Lamp System

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>2008 EIA Reference Case</td><td rowspan="2">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td rowspan="2" colspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td><td rowspan="23">N/A</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td>Calculated</td><td colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="3">2008 EIA Reference Case</td><td colspan="4">Calculated</td><td rowspan="4" colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>System Wattage</td><td rowspan="2">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td rowspan="2" colspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td><td colspan="5">Calculated</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="4">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td rowspan="4" colspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td><td rowspan="3" colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE Solid-State Lighting Multi-Year Program Plan, 2013</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2008 EIA Reference Case</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="5">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td colspan="6">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated</td><td rowspan="2">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td rowspan="2" colspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td><td rowspan="5" colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Ballast Price ($)</td></tr>
<tr><td>Fixture Price ($)</td><td colspan="5">Calculated</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="2" colspan="4">Calculated</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="3">Calculated</td><td rowspan="3">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td rowspan="3" colspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td><td rowspan="3" colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>Labor System Installation (hr)</td></tr>
<tr><td>Labor Lamp Change (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="4" colspan="4">Calculated</td><td rowspan="4" colspan="6">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td><td rowspan="2">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Commercial 4-ft T8 F32 High-efficiency/High-output in 2-Lamp System

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	N/A	GSFL IRL Final Rule TSD (DOE, 2015)	N/A	N/A	Calculated					
Lamp Lumens							Assume Unchanged					
Lamp Efficacy (lm/W)		Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)		Calculated		Calculated								
Ballast Efficiency (BLE)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			Assume Unchanged					
CRI												
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)							Calculated					
Fixture Price ($)		Calculated		Calculated								
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			Assume Unchanged					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated - See Chapter 8; Section 8.2.2 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)			N/A	Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)	Calculated											
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated										
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
Labor System Installation (hr)	Assume unchanged											
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

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DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)			N/A	Calculated					
Lamp Lumens							Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage		Calculated					Calculated					
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI		DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)				Assume Unchanged					
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)			Retailer Websites	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)		N/A					N/A					
Fixture Price ($)*												
Lamp Cost ($/klm)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*		N/A					N/A					
Labor Cost ($/hr)		Calculated	Assume Same as Analgous Conventional Tech				Assume Unchanged					
Labor System Installation (hr)*		N/A										
Labor Lamp Change (hr)		Calculated										
Total Installed Cost ($)		Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems*

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DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)												
Average Lifetime (1000 hrs)	Calculated						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Website	Calculated	Retailer Website		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case	Calculated									Assume Unchanged	
Labor System Installation (hr)	2008 EIA Reference Case											
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft T8 F59 Typical Efficiency in a 2-Lamp System

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>2008 EIA Reference Case</td><td rowspan="2">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="3" rowspan="2">GSFL IRL Final Rule TSD (DOE, 2015)</td><td rowspan="21">N/A</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td>Calculated</td><td colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="3">2008 EIA Reference Case</td><td colspan="4">Calculated</td><td colspan="6" rowspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>System Wattage</td><td rowspan="2">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="3" rowspan="2">GSFL IRL Final Rule TSD (DOE, 2015)</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td><td colspan="5">Calculated</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="4">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="3" rowspan="4">GSFL IRL Final Rule TSD (DOE, 2015)</td><td colspan="6" rowspan="3">Assume Unchanged from 2015</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE Solid-State Lighting Multi-Year Program Plan, 2013</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2008 EIA Reference Case</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="5">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td colspan="6">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated</td><td rowspan="2">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="3" rowspan="2">GSFL IRL Final Rule TSD (DOE, 2015)</td><td colspan="6" rowspan="5">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Ballast Price ($)</td></tr>
<tr><td>Fixture Price ($)</td><td colspan="5">Calculated</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td rowspan="2">2008 EIA Reference Case</td><td colspan="4" rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="3">Calculated</td><td rowspan="3">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="3" rowspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td><td colspan="6" rowspan="3">Assume Unchanged from 2015</td></tr>
<tr><td>Labor System Installation (hr)</td></tr>
<tr><td>Labor Lamp Change (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2">2008 EIA Reference Case</td><td colspan="4" rowspan="4">Calculated</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td><td rowspan="2">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Commercial 8-ft T8 F59 High Efficiency in a 2-Lamp System

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)			N/A	Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)	Calculated											
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated										
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft T8 F96 High-Output in a 2-Lamp System

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Calculated					
Lamp Lumens							Assume Unchanged from 2015					
Lamp Efficacy (lm/W)		Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)		Calculated										
Ballast Efficiency (BLE)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.				N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)		Calculated										
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System*

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A			LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	N/A		Calculated					
Lamp Lumens							Nominal Lumen output based on 2015 values					
Lamp Efficacy (lm/W)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage				Calculated			Calculated					
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)				N/A			Assume Unchanged from 2015					
CRI				Calculated from LED Lighting Facts Qualified Product List Downloaded 11/17/15								
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)				U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)				Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)				N/A			N/A					
Fixture Price ($)*												
Lamp Cost ($/klm)				Navigant Price Analysis			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System (l/b/f) Cost ($/klm)*				N/A			N/A					
Labor Cost ($/hr)				Assume Same as Analgous Conventional Tech			Assume Unchanged from 2015					
Labor System Installation (hr)*												
Labor Lamp Change (hr)												
Total Installed Cost ($)				Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td colspan="3" rowspan="23">N/A</td><td rowspan="3">Calculated</td><td colspan="2" rowspan="23">N/A</td><td colspan="6" rowspan="3">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Wattage</td><td rowspan="3">Retailer Websites</td><td colspan="6">Calculated</td></tr>
<tr><td>System Lumens</td><td colspan="4" rowspan="2">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Assume Unchanged</td></tr>
<tr><td>System Efficacy (lm/W)</td><td colspan="2">Calculated</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td>N/A</td><td colspan="6">N/A</td></tr>
<tr><td>CRI</td><td rowspan="3">Retailer Websites</td><td colspan="6" rowspan="2">Assume Unchanged from 2015</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lifetime (1000 hrs)</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td colspan="6">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp/Luminaire Price ($)</td><td>Calculated</td><td colspan="6">Calculated</td></tr>
<tr><td>Ballast Price ($)</td><td rowspan="3">N/A</td><td colspan="6" rowspan="3">N/A</td></tr>
<tr><td>Fixture Price ($)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td><td>Navigant Price analysis</td><td colspan="4" rowspan="3">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2">Assume Same as Analgous Conventional Tech</td><td colspan="2" rowspan="2">Assume Unchanged</td></tr>
<tr><td>Labor System Installation (hr)</td></tr>
<tr><td>Labor Lamp Change (hr)</td><td>N/A</td><td colspan="6">N/A</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4">Calculated</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Commercial Mercury Vapor Low-bay

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A		Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage												
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case						Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated		Calculated								
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule			GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Metal Halide Low-bay

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A	N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Sodium Vapor Low-bay

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A		Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A						N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	Retailer Websites	N/A	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case		Assume Same as Analgous Conventional Tech								Assume Unchanged	
Labor System Installation (hr)												
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Final

Data Sources » Commercial Mercury Vapor High-Bay

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>2008 EIA Reference Case</td><td rowspan="10">HID Final Determination TSD (DOE, 2015)</td><td rowspan="23">N/A</td><td rowspan="10">HID Final Determination TSD (DOE, 2015)</td><td rowspan="23" colspan="2">N/A</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td>Calculated</td><td colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="3">2008 EIA Reference Case</td><td rowspan="4" colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>System Wattage</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td><td>Calculated</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="3" colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE Solid-State Lighting Multi-Year Program Plan, 2013</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2008 EIA Reference Case</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td>U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td>U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td colspan="6">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="3">2008 EIA Reference Case</td><td rowspan="3">HID Final Determination TSD (DOE, 2015)</td><td rowspan="3">HID Final Determination TSD (DOE, 2015)</td><td rowspan="5" colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Ballast Price ($)</td></tr>
<tr><td>Fixture Price ($)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="2">Calculated</td><td rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td>Calculated</td><td>HID Final Determination TSD (DOE, 2015)</td><td>HID Final Determination TSD (DOE, 2015)</td><td rowspan="3" colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>Labor System Installation (hr)</td><td rowspan="2" colspan="2">GSFL Rule</td><td rowspan="2">GSFL Rule</td></tr>
<tr><td>Labor Lamp Change (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="4">Calculated</td><td rowspan="4">Calculated</td><td rowspan="4" colspan="6">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td><td rowspan="2">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Commercial Metal Halide High-Bay

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A		Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial T5 4xF54 HO High-bay

Final

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>2008 EIA Reference Case</td><td rowspan="3">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td rowspan="23">N/A</td><td colspan="2" rowspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td><td rowspan="23">N/A</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td>Calculated</td><td colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="3">2008 EIA Reference Case</td><td colspan="6" rowspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>System Wattage</td><td>Calculated</td><td colspan="2">Calculated</td></tr>
<tr><td>System Lumens</td><td>GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="2">GSFL IRL Final Rule TSD (DOE, 2015)</td></tr>
<tr><td>System Efficacy (lm/W)</td><td>Calculated</td><td>Calculated</td><td colspan="2">Calculated</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="4">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="2" rowspan="4">GSFL IRL Final Rule TSD (DOE, 2015)</td><td colspan="6" rowspan="3">Assume Unchanged from 2015</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE Solid-State Lighting Multi-Year Program Plan, 2013</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2008 EIA Reference Case</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td>U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td colspan="2">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td colspan="6">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="3">2008 EIA Reference Case</td><td rowspan="2">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="2" rowspan="2">GSFL IRL Final Rule TSD (DOE, 2015)</td><td colspan="6" rowspan="5">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Ballast Price ($)</td></tr>
<tr><td>Fixture Price ($)</td><td rowspan="3">Calculated</td><td colspan="2" rowspan="3">Calculated</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td rowspan="2">2008 EIA Reference Case</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td>Calculated</td><td rowspan="3">GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td><td colspan="2" rowspan="3">GSFL IRL Final Rule TSD (DOE, 2015)</td><td colspan="6" rowspan="3">Assume Unchanged from 2015</td></tr>
<tr><td>Labor System Installation (hr)</td><td rowspan="2">GSFL Rule</td></tr>
<tr><td>Labor Lamp Change (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2">2008 EIA Reference Case</td><td rowspan="4">Calculated</td><td colspan="2" rowspan="4">Calculated</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td><td rowspan="2">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Commercial LED High-bay Luminaire *

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites							
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case	Assume Same as Analgous Conventional Tech									Assume Unchanged	
Labor System Installation (hr)	Assume Same as Analgous Conventional Tech											
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Refrigeration

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	Copeland, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	ADL, 1996 / NCI Analysis, 2015	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Normalized Annual Efficiency	Calculated											
Average Life (yrs)	Kysor-Warren, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI, 2009 / NCI Analysis, 2012	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost ($1000)	ADL, 1996 / NCI Analysis, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	NCI Analysis, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ADL, 1996 / NCI Analysis, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007	Interviews with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	EIA, 2012										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Supermarket Display Cases

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2007 / NCI Analysis, 2008	Navigant Analysis, 2015										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis										
Case Length	DOE, 2014: CRE TSD											
Energy Use (kWh/yr)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Energy Use (kWh/ft)	Calculated											
Normalized Annual Efficiency	Calculated											
Average Life (yrs)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE TSD										
Retail Equipment Cost	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Total Installed Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cst ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Reach-In Refrigerators

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Engineering Spreadsheet										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Energy Use ($kWh/yr/ft^3$)	NCI Analysis, 2012	Calculated										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use (kWh/yr/ft^3)	NCI Analysis, 2012	Calculated										
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	Fricke, et al, 2012, Navigant Analysis, 2015											
Size (ft^2)	Navigant Analysis, 2015											
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^2/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / FMI, 2005 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Walk-In Freezers

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical		High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	Fricke, et al, 2012, Navigant Analysis, 2015										
Size (ft^2)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^2/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: WICF TSD / Navigant Analysis, 2014											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Output (lbs/day)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Water Use (gal/100 lbs)	ADL, 1996 / Distributor Web Sites	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/100 lbs)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/yr)	ACEEE, 2002 / NCI Analysis, 2012	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Total Installed Cost (with Bin)	NCI Analysis, 2008	DOE, 2014: ACIM TSD / Distributor Websites / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2014: CRE TSD											
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^3/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2015: CRE TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	DOE, 2014: CRE TSD, Navigant Analysis											
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: CRE TSD, Navigant Analysis, 2015											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Refrigerated Vending Machines

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2008 / NCI Analysis, 2008	DOE, 2015: BVM TSD / Navigant Analysis, 2015										
Can Capacity	CEC, 2005 / NREL, 2003 / FEMP, 2004	DOE, 2015: BVM TSD										
Size (ft³)	DOE, 2015: BVM TSD / Navigant Analysis, 2015											
Energy Use (kWh/yr)	ADL, 1996 / CEC, 2008 / NREL, 2003	DOE, 2015: BVM TSD										
Energy Use (kWh/ft³/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	DOE, 2008	DOE, 2015: BVM TSD										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM TSD										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM TSD										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2008	DOE, 2015: BVM TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Commercial Ventilation

Data Sources » Commercial Constant Air Volume Ventilation

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	CBECS 2003 & BED 2007											
System Fan Power (kW)	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Data Sources » Commercial Variable Air Volume Ventilation

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	CBECS 2003 & BED 2007											
System Fan Power (kW)	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	Product Literature											
System Fan Power (kW)	Product Literature	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Appendix B
References

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APPENDIX D

Final

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

Presented to:

U.S. Energy Information Administration

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August 2016

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Final

The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment in an "Advanced Case" that assumes accelerated adoption of energy-saving technologies due to increased R&D funding and market incentives.

- 2003/2012 (commercial) and 2009 (residential) baselines, as well as today's (2015)
  - 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.

- The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (for commercial products) 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.
  - Installed Base: the installed and “in use” equipment for that year. Represents the installed stock of equipment, but does NOT represent sales.
  - Current Standard: the minimum efficiency (or maximum energy use) required (allowed) by current DOE standards, when applicable.
  - ENERGY STAR: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable. Presented performance data represents certified products just meeting current ENERGY STAR specifications.
  - Low: The minimum available efficiency product or product mix available on the market. This typically reflects minimal compliance with DOE standards.
  - Typical: the average, or “typical,” product being sold in the particular timeframe.
  - High: the product with the highest efficiency available in the particular timeframe.
  - Lumens: All reported lumens are initial lumens.
  - Correlated Color Temperature (CCT): a specification of the color appearance of the light emitted by a lamp.
  - Color Rendering Index (CRI): a scale from 0 to 100 percent indicating how accurate a "given" light source is at rendering color when compared to a "reference" light source. The higher the CRI, the better the color rendering ability.

- The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric
  - **Lighting**
    - **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))
  - **Commercial Refrigeration**
    - **Nominal Capacity over Average Input (Btu in / Btu out)** = (Cooling or Heat Rejection Capacity)*24*365/(Annual Energy Consumption * 3412)
    - **Total Installed Cost** = Retail Equipment Cost + Labor Installation Cost
    - **Total Installed Cost ($/kBtu/hr)** = Total Installed Cost*1000 / (Cooling or Heat Rejection Capacity)
    - **Annual Maintenance Cost ($/kBtu/hr)** = Annual Maintenance Cost * 1000 / (Cooling or Heat Rejection Capacity)
  - **Ventilation**
    - **CFM out / Btu in / hr** = System Airflow / (System Fan Power * 3412)
    - **Total Installed Cost ($/1000 CFM)** = Total Installed Cost * 1000 / System Airflow
    - **Annual Maintenance Cost ($/1000 CFM)** = Annual Maintenance Cost * 1000 / System Fan Power

The market for the reviewed products has changed since the analysis was performed in 2012. These changes are noted and reflected in the efficiency and cost characteristics.

- DOE issued Federal minimum efficiency standards that have or will soon go into effect for General Service Fluorescent Lamps (effective 2012), Incandescent Reflector Lamps (July 2012), Fluorescent Lamp Ballasts (2014), Refrigerated Beverage Vending Machines (2012), Automatic Commercial Ice Makers (2018), Walk-In Coolers and Freezers (2017) and Commercial Refrigeration Equipment (2017). DOE published a Final Rule updating energy conservation standards for Refrigerated Beverage Vending Machines at the end of 2015, effective in 2018.

Residential Lighting

Note: More aggressive R&D investment and effort in the lighting industry will only change future projections of LED technologies as it is unlikely that additional funding/effort will be applied to traditional technologies that have been exceeded in performance by their LED counterparts. Therefore, the inputs for all non-LED technologies remain unchanged from the Reference Case and are therefore not included in this report.

The residential general service lamps characterized in this report are a 60 watt and a 75 watt medium screw based A-type incandescent lamp and their halogen, CFL, and LED equivalents. A standard 60 watt incandescent lamp produces approximately 800 lumens. A standard 75 watt incandescent lamp produces approximately 1100 lumens (ENERGY STAR Program).

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the <u>annual operating hours of 652 hours/year</u> for residential general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60 watt general service lamps effective in 2014 and 75 watt lamps effective in 2013. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- 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. California's Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies 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, halogen, and CFL technologies.
- 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. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- Beginning in 2017, California's Title 24 will require all light sources to be high efficacy. All general service lamps with medium screw bases must meet the following requirements: initial efficacy ≥45 lm/W, power factor ≥0.90, CCT ≤3000K, CRI ≥90, rated life ≥15,000 hours.
- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	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.

Performance/Cost Characteristics » Residential General Service LED Lamps (60 Watt Equivalent)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	7	4	5	4	4	4
Lamp Lumens	800	850	837	865	800	840	840	840	840	840	840
Lamp Efficacy (lm/W)	44	64	93	104	59	123	197	171	230	219	230
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	652	652	652	652	652	652	652	652	652	652	652
Lamp Price ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$4.07	$4.07	$1.33	$1.33	$1.00	$1.00
Lamp Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$4.07	$4.07	$1.33	$1.33	$1.00	$1.00
Annual Maintenance Cost ($)	$2.22	$0.63	$0.20	$0.13	$0.31	$0.05	$0.05	$0.02	$0.02	$0.01	$0.01
Total Installed Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Annual Maintenance Cost ($/klm)	$2.77	$0.74	$0.23	$0.15	$0.39	$0.06	$0.06	$0.02	$0.02	$0.02	$0.02

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

The residential reflector lamps characterized in this report are directional lamps that emit between approximately 550-750 lumens. Multiple baseline reflector lamps were analyzed, including: 65W Incandescent BR30, Halogen PAR30, Halogen Infrared Reflector (HIR) PAR30, CFL BR30, LED BR30, LED PAR38.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 642 hours/year for residential reflector lamps(DOE SSL Program, 2012a).

Legislation:

- 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. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for omnidirectional lamps with CRI ≥ 90 and 70 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).

Performance/Cost Characteristics » Residential Reflector Lamps

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, 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.

Performance/Cost Characteristics » Residential Reflector LED BR30

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	18	11	10	8	12	6	4	5	3	4	3
Lamp Lumens	600	670	794	699	605	700	700	700	700	700	700
Lamp Efficacy (lm/W)	33	59	78	89	50	109	197	153	230	196	230
CRI	80	95	84	82	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	5000	2700	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$3.39	$3.39	$1.11	$1.11	$1.00	$1.00
Lamp Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$4.84	$4.84	$1.58	$1.58	$1.43	$1.43
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$3.39	$3.39	$1.11	$1.11	$1.00	$1.00
Annual Maintenance Cost ($)	$3.16	$0.33	$0.38	$0.54	$1.91	$0.04	$0.04	$0.01	$0.01	$0.01	$0.01
Total Installed Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$4.84	$4.84	$1.58	$1.58	$1.43	$1.43
Annual Maintenance Cost ($/klm)	$5.26	$0.50	$0.48	$0.77	$3.16	$0.06	$0.06	$0.02	$0.02	$0.02	$0.02

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential Reflector LED PAR38

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	28	18	16	17	20	13	7	9	6	7	6
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	109	197	153	230	196	230
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Annual Maintenance Cost ($)	$5.26	$0.66	$0.64	$0.94	$0.88	$0.09	$0.09	$0.03	$0.03	$0.02	$0.02
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Annual Maintenance Cost ($/klm)	$5.26	$0.56	$0.48	$0.48	$0.84	$0.06	$0.06	$0.02	$0.02	$0.02	$0.02

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- 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.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. The LED luminaire is more efficient and cost effective for new installations or fixture retrofits.
- Labor costs for lamp changes are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore annual maintenance costs are the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 684 hours/year for residential linear systems(DOE SSL Program, 2012a).

Legislation:

- 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 (ENERGY STAR, 2012).

Performance/Cost Characteristics » Residential 4-foot Linear 2-Lamp Lighting Systems

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T12	0%	0%	-0.5%	Limited as the technology is mature.
T8	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Residential Linear LED Replacement Lamp 2 Lamp System

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	19	18	18	N/A	14	12	11	10	9	9
Lamp Lumens	1355	1743	2151	2309	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	75	92	116	132	N/A	151	173	199	203	230	230
System Wattage	36	38	37	35	N/A	28	24	21	21	18	18
System Lumens	2304	3103	3829	4110	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	64	82	104	117	N/A	142	162	191	194	221	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	70	80	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	4000	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	35	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$135.83	$22.19	$34.42	$38.30	N/A	$15.21	$15.21	$4.97	$4.97	$2.10	$2.10
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[3]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$100.25	$12.73	$16.00	$16.59	N/A	$7.24	$7.24	$2.36	$2.36	$1.00	$1.00
System (l/b/f) Cost ($/klm)[3]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor System Installation (hr)[3]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($)	$271.67	$44.38	$68.84	$76.60	N/A	$30.43	$30.43	$9.93	$9.93	$4.20	$4.20
Annual Maintenance Cost ($)	$5.31	$0.61	$1.05	$1.05	N/A	$0.42	$0.42	$0.14	$0.14	$0.06	$0.06
Total Installed Cost ($/klm)	$200.49	$25.46	$32.00	$33.17	N/A	$14.49	$14.49	$4.73	$4.73	$2.00	$2.00
Annual Maintenance Cost ($/klm)	$3.92	$0.35	$0.49	$0.45	N/A	$0.20	$0.20	$0.06	$0.06	$0.03	$0.03

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.
4. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential Linear LED Luminaire

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	46	48	57	40	55	30	25	22	22	22	22
System Lumens	3395	4044	5697	4918	4000	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	67	84	100	122	73	164	197	230	230	230	230
Ballast Efficiency (BLE) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	87	83	83	83	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
Average Lamp Life (1000 hrs)	50	60	56	50	36	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$731.04	$439.00	$176.61	$513.45	$139.00	$93.02	$93.02	$45.29	$45.29	$22.06	$22.06
Ballast Price ($) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)[5]	$215.34	$108.56	$31.00	$104.41	$34.75	$18.60	$18.60	$9.06	$9.06	$4.41	$4.41
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$765.14	$473.10	$210.71	$547.55	$173.10	$127.12	$127.12	$79.39	$79.39	$56.16	$56.16
Annual Maintenance Cost ($)	$10.46	$5.39	$2.57	$7.49	$3.29	$0.90	$0.90	$0.54	$0.54	$0.38	$0.38
Total Installed Cost ($/klm)	$225.38	$116.99	$36.99	$111.35	$43.28	$25.42	$25.42	$15.88	$15.88	$11.23	$11.23
Annual Maintenance Cost ($/klm)	$3.08	$1.33	$0.45	$1.52	$0.82	$0.18	$0.18	$0.11	$0.11	$0.08	$0.08

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Residential Outdoor Lamps

- The residential outdoor lamps characterized in this report include reflector and general service lamps used for security and/or porch lighting that can be switched on from inside the home (i.e. parking lot/garage and outdoor common area lighting at multifamily buildings are excluded) with lumen outputs of approximately 1000 lumens. Multiple baseline lamps were analyzed according to estimates of installed base average lumens by lamp type, including:

Security (Reflector Lamps)	Porch (General Service Lamps)
Incandescent BR30	Incandescent A-Type
Halogen PAR38	Halogen A-Type
Halogen Infrared Reflector (HIR) PAR38	CFL Bare Spiral
CFL PAR38	LED A-Type Lamp
LED PAR38	

- In 2010, it was estimated that over 96% of residential outdoor lamps were incandescent, halogen, or CFL technologies. Approximately, 51% of residential outdoor lamps were general service and 24% were reflector lamps. The remaining share was made up of primarily decorative and miscellaneous lamp types (DOE, 2012(3)).

Performance:

- 65W BR30 is the only viable incandescent reflector lamp due to exemption from EISA 2007. The lumen output of this lamp type is well below other reflector lamp technologies characterized for residential outdoor spaces, thus its use is limited for this application.
- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 1059 hours/year for residential reflector lamps (DOE SSL Program, 2012b).

Legislation:

- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014).
- Additionally, the lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent Omnidirectional	0%	+0.5%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Incandescent	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, 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.

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	18	16	17	20	13	7	9	6	7	6
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	109	197	153	230	196	230
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Annual Maintenance Cost ($)	$8.68	$1.09	$1.05	$1.55	$1.46	$0.15	$0.15	$0.05	$0.05	$0.04	$0.04
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Annual Maintenance Cost ($/klm)	$8.68	$0.93	$0.79	$0.79	$1.39	$0.10	$0.10	$0.03	$0.03	$0.03	$0.03

Data based on an indoor 100W Equivalent LED A-type lamp, scaled to lumen output reported for the building exterior low-output technologies in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: LED A-Type)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	8	5	6	4	4	4
Lamp Lumens	964	964	964	964	964	964	964	964	964	964	964
Lamp Efficacy (lm/W)	44	64	93	104	71	123	197	171	230	219	230
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$5.02	$5.02	$1.64	$1.64	$1.04	$1.04
Lamp Cost ($/klm)	$85.00	$24.90	$9.00	$5.18	$12.43	$4.84	$4.84	$1.58	$1.58	$1.00	$1.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$5.02	$5.02	$1.64	$1.64	$1.04	$1.04
Annual Maintenance Cost ($)	$3.60	$1.02	$0.37	$0.21	$0.51	$0.11	$0.11	$0.03	$0.03	$0.02	$0.02
Total Installed Cost ($/klm)	$70.54	$24.90	$9.00	$5.18	$12.43	$5.21	$5.21	$1.70	$1.70	$1.08	$1.08
Annual Maintenance Cost ($/klm)	$3.73	$1.05	$0.38	$0.22	$0.53	$0.11	$0.11	$0.04	$0.04	$0.02	$0.02

Data based on an indoor 100W Equivalent LED A-type lamp, scaled to lumen output reported for the building exterior low-output technologies in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)

Commercial Lighting

Note: More aggressive R&D investment and effort in the lighting industry will only change future projections of LED technologies as it is unlikely that additional funding/effort will be applied to traditional technologies that have been exceeded in performance by their LED counterparts. Therefore, the inputs for all non-LED technologies remain unchanged from the Reference Case and are therefore not included in this report.

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Performance/Cost Characteristics » Commercial General Service Lamps in Recessed Can Fixtures

This section characterizes commercial omnidirectional incandescent, halogen, CFL, and LED screw based general service lamps emitting approximately 1600 lumens (equivalent to a 100W incandescent lamp) used in recessed can fixtures. A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, an omnidirectional lamp is not well suited for use in such fixtures, as light that emits upwards and out of the sides must be reflected downwards and out of the fixture and some light is absorbed in the process. A fixture efficiency of 61% is used to characterize these lumen losses for all omnidirectional lamps. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3868 hours/year for commercial general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- 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. California's Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies 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, halogen, and CFL technologies.
- 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. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- For ENERGY STAR qualification, general service, omnidirectional lamps, must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	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.

Performance/Cost Characteristics » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

Final

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	27	17	15	16	23	11	10	8	7	7	7
Lamp Lumens	N/A	1600	1580	1646	1710	1600	1600	1600	1600	1600	1600	1600
Lamp Efficacy (lm/W)	N/A	60	92	108	110	71	150	161	209	220	230	230
System Wattage	N/A	27	17	15	16	23	11	10	8	7	7	7
System Lumens	N/A	976	964	1004	1043	976	976	976	976	976	976	976
System Efficacy (lm/W)	N/A	36.6	56.4	66.2	67.3	43.4	91.6	98.1	127.4	133.9	140.3	140.3
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	80	84	83	81	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	3000	3000	2700	2700	3000	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	N/A	22	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868
Lamp Price ($)	N/A	$40.00	$14.71	$15.30	$15.99	$22.99	$7.74	$7.74	$2.53	$2.53	$1.60	$1.60
Ballast Price ($) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$25.00	$9.31	$9.30	$9.35	$14.37	$4.84	$4.84	$1.58	$1.58	$1.00	$1.00
System (l/b/f) Cost ($/klm) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Labor Lamp Change (hr)	N/A	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost ($)	N/A	$117.05	$96.66	$97.25	$97.94	$104.94	$89.69	$89.69	$84.48	$84.48	$83.55	$83.55
Annual Maintenance Cost ($)	N/A	$7.71	$2.91	$3.00	$3.11	$4.19	$0.95	$0.93	$0.51	$0.51	$0.44	$0.44
Total Installed Cost ($/klm)	N/A	$73.16	$61.18	$59.10	$57.27	$65.59	$56.06	$56.06	$52.80	$52.80	$52.22	$52.22
Annual Maintenance Cost ($/klm)	N/A	$4.82	$1.84	$1.82	$1.82	$2.62	$0.60	$0.58	$0.32	$0.32	$0.28	$0.28

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For installations where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

Performance/Cost Characteristics » Commercial Reflector Lamps in Recessed Can Fixtures

This section characterizes commercial halogen, HIR, and LED screw based reflector lamps emitting approximately 1400 lumens used in recessed can fixtures.

- 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.
- A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, a reflector lamp, which employs reflective coating to direct light out in only one direction, is well suited for use in such fixtures. However, some light is not able to escape the fixture, and a fixture efficiency of 93% is used to characterize these minimal lumen losses. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3860 hours/year for commercial reflector lamps (DOE SSL Program, 2012a).

Legislation:

- 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. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for omnidirectional lamps with CRI ≥ 90 and 70 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
HIR	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	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.

Performance/Cost Characteristics » Commercial LED Reflector Lighting (PAR38)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	17	18	16	17	20	12	11	9	8	7	6
Lamp Lumens	N/A	1045	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	N/A	61	64	83	116	53	116	124	162	170	209	216
System Wattage	N/A	17	18	16	17	20	12	11	9	8	7	6
System Lumens*	N/A	972	1090	1235	1821	977	1302	1302	1302	1302	1302	1302
System Efficacy (lm/W)	N/A	57	59	78	108	49	108	115	151	158	194	201
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	83	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	N/A	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	N/A	22	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860
Lamp Price ($)	N/A	$52.25	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.40	$1.40
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$50.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.00	$1.00
System (l/b/f) Cost ($/klm)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)[5]	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Labor Lamp Change (hr)	N/A	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total Installed Cost ($)	N/A	$56.99	$30.72	$32.93	$41.63	$39.51	$11.82	$11.82	$7.25	$7.25	$6.44	$6.44
Annual Maintenance Cost ($)	N/A	$10.00	$4.74	$4.54	$6.43	$6.10	$0.93	$0.93	$0.56	$0.56	$0.50	$0.50
Total Installed Cost ($/klm)	N/A	$54.53	$26.22	$24.79	$21.26	$37.63	$8.44	$8.44	$5.18	$5.18	$4.60	$4.60
Annual Maintenance Cost ($/klm)	N/A	$9.57	$4.05	$3.42	$3.28	$5.81	$0.66	$0.66	$0.40	$0.40	$0.36	$0.36

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For installations where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

Performance/Cost Characteristics » Commercial 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. 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.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4055 hours/year for commercial 4ft linear systems (DOE SSL Program, 2012a).

Legislation:

- 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.
- 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 does not cover commercial linear luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F32 Commodity	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F32 High Efficiency/High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5 F28	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	21	19	18	18	N/A	14	12	11	10	9	9
Lamp Lumens	N/A	2091	1743	2151	2303	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	N/A	101	92	116	132	N/A	151	173	199	221	230	230
System Wattage	N/A	42	38	37	35	N/A	28	24	21	19	18	18
System Lumens	N/A	3555	3102	3829	4099	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	N/A	85	82	104	117	N/A	142	162	191	212	221	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	86	80	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	4100	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lifetime (1000 hrs)	N/A	50	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp/Luminaire Price ($)	N/A	$234.66	$22.19	$34.42	$38.30	N/A	$15.21	$15.21	$4.97	$4.97	$2.10	$2.10
Ballast Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$112.20	$12.73	$16.00	$16.63	N/A	$7.24	$7.24	$2.36	$2.36	$1.00	$1.00
System (l/b/f) Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.40	0.40	0.40	0.40	N/A	0.40	0.40	0.40	0.40	0.40	0.40
Total Installed Cost ($)	N/A	$495.15	$71.43	$95.90	$103.65	N/A	$42.27	$42.27	$32.02	$32.02	$29.15	$29.15
Annual Maintenance Cost ($)	N/A	$40.16	$5.79	$8.64	$8.41	N/A	$3.50	$3.50	$2.60	$2.60	$2.36	$2.36
Total Installed Cost ($/klm)	N/A	$236.76	$40.98	$44.57	$45.01	N/A	$20.13	$20.13	$15.25	$15.25	$13.88	$13.88
Annual Maintenance Cost ($/klm)	N/A	$19.20	$3.32	$4.02	$3.65	N/A	$1.67	$1.67	$1.24	$1.24	$1.13	$1.13

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

Performance/Cost Characteristics » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36.4	51	48	57	40	N/A	30	25	22	22	22	22
System Lumens	548	4818	4044	5697	4918	N/A	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	15	94	84	100	122	N/A	164	197	230	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	84	83	83	83	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	N/A	3500	3500	3500	3500	3500	3500
Average Lifetime (1000 hrs)	50	67	60	56	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp/Luminaire Price ($)	$215.19	$610.32	$439.00	$176.61	$513.45	N/A	$93.02	$93.02	$45.29	$45.29	$22.06	$22.06
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$108.56	$31.00	$104.41	N/A	$18.60	$18.60	$9.06	$9.06	$4.41	$4.41
Labor Cost ($/hr)	$110.50	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.50	0.50	0.50	0.50	N/A	0.50	0.50	0.50	0.50	0.50	0.50
Labor Lamp Change (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$642.87	$473.10	$210.71	$547.55	N/A	$127.12	$127.12	$79.39	$79.39	$56.16	$56.16
Annual Maintenance Cost ($)	$0.07	$38.91	$31.98	$15.26	$44.41	N/A	$5.31	$5.31	$3.22	$3.22	$2.28	$2.28
Total Installed Cost ($/klm)	$493.50	$133.43	$116.99	$36.99	$111.35	N/A	$25.42	$25.42	$15.88	$15.88	$11.23	$11.23
Annual Maintenance Cost ($/klm)	$0.13	$8.08	$7.91	$2.68	$9.03	N/A	$1.06	$1.06	$0.64	$0.64	$0.46	$0.46

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components

Performance/Cost Characteristics » Commercial 8-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 8ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. 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.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4147 hours/year for commercial 8ft linear systems (DOE SSL Program, 2012a).

Legislation:

- 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.
- 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 does not cover commercial linear luminaires (ENERGY STAR, 2012).

Performance/Cost Characteristics » Commercial 8-foot Linear 2-Lamp Lighting Systems

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F59 Typical Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F59 High Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F96 High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical[1]	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	36	N/A	N/A	39	34	30	27	25	25
Lamp Lumens	N/A	N/A	N/A	3975	N/A	N/A	5650	5650	5650	5650	5650	5650
Lamp Efficacy (lm/W)	N/A	N/A	N/A	111	N/A	N/A	144	165	190	211	230	230
System Wattage	N/A	N/A	N/A	71	N/A	N/A	79	69	59	54	49	49
System Lumens	N/A	N/A	N/A	7076	N/A	N/A	10622	10622	10848	10848	10848	10848
System Efficacy (lm/W)	N/A	N/A	N/A	99	N/A	N/A	135	155	182	203	221	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	80	N/A	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	N/A	N/A	N/A	5000	N/A	N/A	5000	5000	5000	5000	5000	5000
Average Lifetime (1000 hrs)	N/A	N/A	N/A	50	N/A	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp/Luminaire Price ($)	N/A	N/A	N/A	$75.53	N/A	N/A	$48.60	$48.60	$15.87	$15.87	$5.65	$5.65
Ballast Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	N/A	N/A	$19.00	N/A	N/A	$8.60	$8.60	$2.81	$2.81	$1.00	$1.00
System (l/b/f) Cost ($/klm)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	N/A	N/A	0.4	N/A	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	N/A	N/A	$176.63	N/A	N/A	$74.18	$74.18	$41.44	$41.44	$32.70	$32.70
Annual Maintenance Cost ($)	N/A	N/A	N/A	$14.65	N/A	N/A	$6.28	$6.28	$3.44	$3.44	$2.71	$2.71
Total Installed Cost ($/klm)	N/A	N/A	N/A	$44.43	N/A	N/A	$13.13	$13.13	$7.33	$7.33	$5.79	$5.79
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$3.69	N/A	N/A	$1.11	$1.11	$0.61	$0.61	$0.48	$0.48

1. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
2. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

Performance/Cost Characteristics » Commercial 8-ft Linear LED Luminaire Replacement for a 2-Lamp System

Final

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical[1]	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	N/A	N/A	N/A	73	N/A	N/A	46	41	35	35	35	35
System Lumens	N/A	N/A	N/A	8000	N/A	N/A	8000	8000	8000	8000	8000	8000
System Efficacy (lm/W)	N/A	N/A	N/A	110	N/A	N/A	173	197	230	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	90	N/A	N/A	90	90	90	90	90	90
Correlated Color Temperature (CCT)	N/A	N/A	N/A	4000	N/A	N/A	4000	4000	4000	4000	4000	4000
Average Lifetime (1000 hrs)	N/A	N/A	N/A	75	N/A	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp/Luminaire Price ($)	N/A	N/A	N/A	$640.00	N/A	N/A	$384.08	$384.08	$187.02	$187.02	$91.07	$91.07
Ballast Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	N/A	N/A	N/A	$80.00	N/A	N/A	$48.01	$48.01	$23.38	$23.38	$11.38	$11.38
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	N/A	N/A	N/A	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	N/A	N/A	N/A	$708.20	N/A	N/A	$452.28	$452.28	$255.22	$255.22	$159.27	$159.27
Annual Maintenance Cost ($)	N/A	N/A	N/A	$39.16	N/A	N/A	$19.34	$19.34	$10.58	$10.58	$6.60	$6.60
Total Installed Cost ($/klm)	N/A	N/A	N/A	$88.53	N/A	N/A	$56.53	$56.53	$31.90	$31.90	$19.91	$19.91
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$4.89	N/A	N/A	$2.42	$2.42	$1.32	$1.32	$0.83	$0.83

1. Based on the CREE CS18-80LHE found on Grainger online of 11/20/15
2. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Commercial Low-Bay Lighting Systems

The commercial low bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits between 6,000 and 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). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Performance/Cost Characteristics » Commercial Low-Bay Lighting Systems

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
T5 4xF54 HO Linear System	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial LED Low-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	68	104	71	46	N/A	47	36	34	30	30	30
System Lumens	548	4877	8410	7042	6294	N/A	7000	7000	7000	7000	7000	7000
System Efficacy (lm/W)	15	72	81	100	136	N/A	150	197	207	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	85	75	81	84	N/A	81	81	81	81	81	81
Correlated Color Temperature (CCT)	4000	4000	5000	4000	4000	N/A	4000	4000	4000	4000	4000	4000
Average Lifetime (1000 hrs)	50	50	100	60	100	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp/Luminaire Price ($)	$215.19	$761.95	$447.31	$267.59	$332.80	N/A	$159.63	$159.63	$77.73	$77.73	$37.85	$37.85
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$156.23	$53.19	$38.00	$52.88	N/A	$22.80	$22.80	$11.10	$11.10	$5.41	$5.41
Labor Cost ($/hr)	$36.83	$68.99	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.20	$68.20
Labor System Installation (hr)	1.5	1.5	1.5	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$865.44	$550.80	$371.08	$436.29	N/A	$263.12	$263.12	$181.22	$181.22	$140.15	$140.15
Annual Maintenance Cost ($)	$0.07	$69.95	$22.26	$25.00	$17.63	N/A	$10.96	$10.96	$7.32	$7.32	$5.66	$5.66
Total Installed Cost ($/klm)	$493.50	$177.44	$65.49	$52.70	$69.32	N/A	$37.59	$37.59	$25.89	$25.89	$20.02	$20.02
Annual Maintenance Cost ($/klm)	$0.13	$14.34	$2.65	$3.55	$2.80	N/A	$1.57	$1.57	$1.05	$1.05	$0.81	$0.81

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18//15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. LED Low-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Commercial High-Bay Lighting Systems

The commercial high-bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits greater than 10,000 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). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
T5 4xF54 HO Linear System	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial LED High-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	212	189	183	101	N/A	100	76	72	65	65	65
System Lumens	548	18915	15070	18722	13640	N/A	15000	15000	15000	15000	15000	15000
System Efficacy (lm/W)	15	89	80	102	135	N/A	150	197	207	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	74	73	80	83	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	5000	5000	5000	4000	4100	N/A	4000	4000	4000	4000	4000	4000
Average Lifetime (1000 hrs)	50	70	50	60	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp/Luminaire Price ($)	$215.19	$2,395.94	$398.34	$711.42	$297.76	N/A	$342.07	$342.07	$166.57	$166.57	$81.11	$81.11
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$26.43	$38.00	$21.83	N/A	$22.80	$22.80	$11.10	$11.10	$5.41	$5.41
Labor Cost ($/hr)	$36.83	$72.71	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.99	$68.99
Labor System Installation (hr)	2	2	2	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$2,505.00	$501.83	$814.90	$401.25	N/A	$445.55	$445.55	$270.05	$270.05	$184.59	$184.59
Annual Maintenance Cost ($)	$0.07	$144.63	$40.56	$54.89	$32.43	N/A	$18.56	$18.56	$10.91	$10.91	$7.46	$7.46
Total Installed Cost ($/klm)	$493.50	$132.44	$33.30	$43.53	$29.42	N/A	$29.70	$29.70	$18.00	$18.00	$12.31	$12.31
Annual Maintenance Cost ($/klm)	$0.13	$7.65	$2.69	$2.93	$2.38	N/A	$1.24	$1.24	$0.73	$0.73	$0.50	$0.50

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. LED High-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Additional Technologies of Interest: Lighting

Final

- Tables were not provided for technologies of interest utilizing occupancy sensors and other controls due to lack of available data and currently small market presence.
  - Lighting controls can save energy by either reducing input wattage or limiting hours of operation.
  - The following table indicates prevalence of various lighting controls in 2010 (DOE SSL Program, 2012a).
  - Leading experts claim that controls penetration remains low, particularly for integrated/advanced controls (DOE Connected Lighting Systems Meeting, November 2015).
  - As a result, there is not enough information to determine the price and performance impacts of controls on current lighting technologies or to project improvements going forward.

Prevalence of Lighting Controls by Sector and Lamp Type

		None	Dimmer	Light Sensor	Motion Detector	Timer	EMS	Total
Residential	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%
Commercial	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%

EMS: Energy Management System
HID: High Intensity Discharge:
CFL: Compact Fluorescent Lamp

Refrigeration
Advanced Case

Commercial Compressor Rack Systems

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,050	1,200	1,200	1,190	930	N/A	830	775	777	679	777	679
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	180	162	162	160	125	N/A	104	102	85	74	74	70
Energy Use (MWh/yr) [2]	1,618	1,497	1,497	1,484	1,160	N/A	1033	914	841	735	841	735
Indexed Annual Efficiency [3]	1.00	1.08	1.08	1.09	1.40	N/A	1.57	1.77	1.92	2.20	1.92	2.20
Average Life (yrs)	15	15	15	15	15	N/A	15	15	15	15	15	15
Total Installed Cost ($1000) [4]	$630	$630	$630	$625	$488	N/A	$452	$422	$408	$356	$408	$356
Total Installed Cost ($/kBtu/hr)	$600	$525	$525	$525	$525	N/A	$545	$545	$524	$524	$524	$524
Annual Maintenance Cost ($1000) [5]	$33	$34	$34	$34	$34	N/A	$34	$34	$34	$34	$34	$34
Annual Maintenance Cost ($/kBtu/hr)	$31.14	$28	$28	$29	$37	N/A	$41	$44	$44	$50	$44	$50

[1] The total capacity represents the nominal compressor capacity required for the entire refrigeration system of a typical supermarket. This usually includes two low temperature racks and two medium temperature racks. For 2012 a 1,200 MBtu/hr total cooling capacity is based on a 100 ton estimate for total capacity – 80 tons for the medium temperature racks and 20 tons for the low temperature racks. Beyond 2012, estimates are based on data provided by a supermarket refrigeration efficiency consultant.

[2] Capacity and Annual energy consumption for 2012 and beyond are based on interviews with supermarket refrigeration consultants

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[4] The total installed cost for 2003 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. Total installed cost for 2012 and beyond is based on updated Navigant estimates. Note the decrease in cost over time as required capacity is decreased.

[5] 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%.
- 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)
- Installed cost, power draw, and capacity are all expected to decrease in the future due to the reduced load of supermarket display cases
- **For this advanced case, a 10% reduction in energy consumption and a 5% reduction in required capacity is assumed to occur over the reference case for 2020 and beyond due to VIP adoption by display cases and a relaxation in charge size limits for more efficient, low GWP, but toxic/flammable refrigerants such as ammonia and propane due to improved safety technology such as leak detection**.

Commercial Condensers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,680	1,680	1,680	1,666	1,302	N/A	1,121	1,065	904	833	904	833
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	25	25	24	22	18	N/A	14	13	11	9	11	9
Energy Use (MWh/yr)	138	120	115	106	86	N/A	67	64	52	46	52	43
Indexed Annual Efficiency [2]	1.00	1.15	1.20	1.30	1.60	N/A	2.06	2.17	2.64	3.03	2.64	3.18
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Total Installed Cost ($1000)	$47	$54	$54	$53	$51	N/A	$51	$50	$50	$50	$50	$50
Total Installed Cost ($/kBtu/hr)	$27.87	$32	$32	$32	$39	N/A	$45	$47	$55	$60	$55	$60
Annual Maintenance Cost [3]	$817	$954	$954	$954	$954	N/A	$956	$956	$956	$956	$956	$956
Annual Maintenance Cost ($/kBtu/hr)	$0.49	$0.57	$0.57	$0.57	$0.73	N/A	$0.85	$0.90	$1.06	$1.15	$1.06	$1.15

[1] Total capacity is the total heat rejected (THR) of condensers comprised of two low temperature condensers (THRL = 240 MBtu/hr each, suction temperature = -25°F, condensing temperature 110°F) and two medium temperature (THRM = 520 MBtu/hr each, suction temperature = 15°F, condensing temperature = 115°F) condensers; ambient temperature = 95°F. (NCI, 2009). For 2012 and beyond, capacity was estimated based on consultation with a supermarket refrigeration expert.

[2] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[3] Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks. Note a slight expected increase in maintenance costs due to the expected implementation of hybrid condenser systems.

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)
- Total installed cost is expected to decrease over time due to an expected reduction in required capacity due to more efficient display cases
- **For this advanced case, a 10% reduction in energy consumption and a 5% reduction in required capacity is assumed to occur over the reference case for 2020 and beyond due to VIP adoption by display cases and a relaxation in charge size limits for more efficient, low GWP, but toxic/flammable refrigerants such as ammonia and propane due to improved safety technology such as leak detection**.

Commercial Supermarket Display Cases

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	20,000	17623	17623	17623	17623	N/A	17623	17623	17623	17623	17623	17623
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Case Length (ft)	12	12	10	10	10	N/A	10	10	10	10	10	10
Energy Use (kWh/yr) [1,2]	21,000	13,497	13,497	12,565	11,746	N/A	11,787	10,467	9,420	8,938	7,823	7,667
Energy Use (kWh/ft)	1,750	1,125	1,350	1,257	1,175	N/A	1,179	1,047	942	894	782	767
Indexed Annual Efficiency[3]	1.00	1.56	1.56	1.67	1.79	N/A	1.78	2.01	2.23	2.35	2.68	2.74
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$4,371	$8,510	$8,510	$8,940	$9,601	N/A	$9,356	$9,454	$9,926	$10,868	$10,096	$10,302
Total Installed Cost	$6,452	$10,811	$10,811	$11,241	$11,902	N/A	$11,657	$11,755	$12,227	$13,169	$12,397	$12,603
Total Installed Cost ($/kBtu/hr)	323	613	613	638	675	N/A	661	667	694	747	703	715
Annual Maintenance Cost[4]	$657	$940	$940	$940	$940	N/A	$940	$940	$940	$940	$940	$940
Annual Maintenance Cost ($/kBtu/hr)	$32.85	$53.34	$53.34	$53.34	$53.34	N/A	$53.34	$53.34	$53.34	$53.34	$53.34	$53.34

[1] DOE's Federal energy conservation standards for Commercial Refrigeration Equipment (CRE) went into effect on January 1, 2012. The 2012 typical and 2015 low efficiency values are based on minimal compliance with this standard. For 2015 and beyond, energy consumption and cost values were estimated using shipments-weighted averages reported in DOE's 2014 CRE Final Rule TSD for equipment commonly used as display cases. DOE's updated conservation standard goes into effect in 2017, so units sold in 2020 are assumed to comply with this standard.

[2] For consistency with DOE rulemaking practices, Supermarket Display Case Energy Use reported above includes energy use of the compressor racks and condensers. To avoid double counting, do not add Energy Use from the Compressor Rack or Condenser Systems tabs if calculating total energy consumption.

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[4] 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. After 2012, these values are based on a reported maintenance and repair cost of $220 per unit for preventative maintenance plus approximately $60 per linear foot for additional repair and maintenance

Commercial Supermarket Display Cases

- DOE set Federal energy efficiency standards for Commercial Refrigeration Equipment (CRE) in 2009. 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.
- DOE updated its Energy Conservation Standards for Commercial Refrigeration Equipment in 2014, for equipment sold on or after March 27, 2017.
- The table below lists equipment used as supermarket display cases and their corresponding Energy Conservation Standard levels. The maximum allowable daily energy consumption for each equipment class is a linear function of Total Display Area (TDA)

Equipment Description	DOE Designation	Standards Equation (2012)	Standards Equation (2017)
Vertical Open Cooler	VOP.RC.M	0.82xTDA+4.07	0.64xTDA+4.07
Semi vertical Open Cooler	SVO.RC.M	0.83xTDA+3.18	0.66xTDA+3.18
Horizontal Open Cooler	HZO.RC.M	0.35xTDA+2.88	0.35xTDA+2.88
Transparent-Doored Cooler	VCT.RC.M	0.22xTDA+1.95	0.15xTDA+1.95
Deli Display Cooler	SOC.RC.M	0.51xTDA+0.11	0.44xTDA+0.11
Transparent-Doored Freezer	VCT.RC.L	0.56xTDA+2.61	0.49xTDA+2.61
Horizontal Open Freezer	HZO.RC.L	0.57xTDA+6.88	0.55xTDA+6.88

Commercial Supermarket Display Cases

- The Food Marketing Institute reported the median total supermarket size in 2003 was 44,000 sq. ft., and in 2013, the last year reported in the study, it was listed as 46,500 sq. ft.
- Unit energy consumption for 2012 and beyond is estimated using a shipments weighted average by efficiency level and equipment class, using data in DOE's 2014 CRE Final Rule TSD and Engineering Spreadsheet. The equipment classes analyzed are listed in the table on the previous slide.
- Supermarket refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks
- A typical supermarket display case contains lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- Approximately 20% of 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)
- 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, and improved insulation.
- Unit energy consumption for supermarket display cases is expected to decrease over time as a result of DOE's updated energy conservation standards
- In addition, a transition from open to transparent-doored display cases is expected to occur as supermarkets increase focus on energy efficiency.
- **For this advanced scenario, the typical display case in 2020 is assumed to minimally comply DOE's updated ECS.**
- **For 2020 and beyond, accelerated adoption of energy savings technologies is assumed to take place over the reference case, including accelerated shipments migration to doored over open units, where applicable, as well as vacuum insulated panels.**
- **The incremental cost of VIPs is assumed to decrease from its present value due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This advanced case assumes a transition from HFC to more efficient propane and ammonia refrigerants by 2040**

Commercial Reach-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	3,000	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	3,800	2,340	2,665	2,033	1,394	1,394	1,448	1,303	1,099	1,047	1,047	1,026
Energy Use (kWh/yr/ft^3) [1]	79	48	54	41	28	28	30	27	22	21	21	21
Indexed Annual Efficiency[3]	1.00	1.62	1.43	1.87	2.73	2.73	2.62	2.92	3.46	3.63	3.63	3.70
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,810	$2,624	$2,728	$2,780	$3,021	$3,021	$2,947	$3,242	$3,632	$3,335	$3,115	$3,271
Total Installed Cost[4]	$2,966	$3,454	$3,591	$3,643	$3,884	$3,884	$3,810	$4,105	$4,495	$4,198	$3,978	$4,134
Total Installed Cost ($/kBtu/hr)	$989	$1,227	$1,226	$1,244	$1,326	$1,326	$1,301	$1,402	$1,535	$1,434	$1,358	$1,411
Annual Maintenance Cost[5]	$143	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185
Annual Maintenance Cost ($/kBtu/hr)	$48	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63

[1] EPACT 2005 energy standards went into effect in 2010. 2015 low efficiency cost and energy consumption values are based on minimum compliance with this standard. Unless otherwise noted, all other cases are based on shipments-weighted averages of solid and transparent doored units reported in the 2014 CRE TSD. DOE's updated Energy Conservation standards go into effect in 2017; therefore, compliance with this standard is assumed for 2020 and beyond.

[2] The Energy Star category is based on a shipments weighted average of solid and transparent-doored units that are minimally compliant with Energy Star v3, effective October 1, 2014. Units compliant with Energy Star are found to be the most efficient reach-in refrigeration equipment on the market in 2015

[3] Annual efficiency normalized to the typical efficiency of the 2003 installed base. Normalized Annual Efficiency = (Typical 2003 Energy Use) / (Energy Use)[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based DOE's CRE Final Rule, which assumes a installation cost of $863 for self-contained equipment.

[4] Maintenance costs after 2003 are based on DOE's CRE Final Rule TSD, which reports $35 annual preventative maintenance, per unit, per year, plus approximately $40 per linear foot, per year of additional repair and maintenance costs for the units characterized

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).
- In 2014, DOE updated its energy conservation standards for Reach-in refrigerators, effective March 27, 2017. Both standards are reported in the table below.

Equipment Class	EPCA Standard Level (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.M)	0.10xV+2.04	0.05xV + 1.36
Glass Door (VCT.SC.M)	0.12xV+3.34	0.1xV+0.86

- In 2013, EPA updated its Energy Star® for Reach-in refrigerators, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit.

Reach-In Refrigerator Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.M)	0.02xV+1.60	0.09xV+0.55	0.01xV+2.95	0.06xV+0.45
Glass Door (VCT.SC.M)	0.10xV+1.07	0.15xV+0.32	0.06xV+3.02	0.08xV+2.02

Commercial Reach-In Refrigerators

- Unit energy consumption for 2012 and beyond was estimated based on shipment-weighted averages by efficiency level and equipment class for 49 ft^3 VCS.SC.M and VCT.SC.M units reported in DOE's 2014 CRE Final Rule TSD. These units were estimated to comprise approximately 85% and 15% of total reach-in refrigerator shipments, 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.
- Unit energy consumption is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to compliance with EPA SNAP
- **For this advanced scenario, the typical unit in 2020 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration**
- **A shipments migration from transparent to solid-doored units is assumed for the advanced case**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Reach-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[3]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr) [1]	9,392	6,023	7,658	5,592	4,563	4,763	4,453	4,008	3,656	3,473	3,473	3,369
Energy Use (kWh/yr/ft^3)	192	123	156	114	93	97	93	93	93	93	93	93
Indexed Annual Efficiency[4]	1.00	1.56	1.23	1.68	2.06	1.97	2.11	2.34	2.57	2.70	2.70	2.79
Average Life (yrs)	8	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,498	$2,886	$3,002	$3,033	$3,186	$3,118	$3,395	$3,490	$4,099	$4,304	$3,674	$3,777
Total Installed Cost[5]	$2,654	$3,749	$3,865	$3,896	$4,049	$3,981	$4,258	$4,353	$4,962	$5,167	$4,537	$4,640
Total Installed Cost ($/kBtu/hr)	$611	$864	$890	$897	$933	$917	$981	$1,003	$1,143	$1,190	$1,045	$1,069
Annual Maintenance Cost[6]	$140	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181
Annual Maintenance Cost ($/kBtu/hr)	$32.25	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70

1 EPACT 2005 energy standards went into effect in 2010. The 2015 low energy consumption and cost values are based on minimal compliance with this standard.

2 A 49 ft^3 unit was characterized, as this was the representative size selected for DOE's rulemaking analysis.

3 The Energy Star category was based on a solid doored unit that is minimally compliant with Energy Star v3, effective October 1, 2014

4 **Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).**

5 Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $863 for self-contained equipment.

6 Maintenance costs are calculated based on a $35 per unit annual preventative maintenance cost, plus an additional $45 per linear foot repair and maintenance cost estimated based on values reported in the in the CRE TSD

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).
- In December of 2014, DOE updated its energy conservation standards for commercial refrigeration equipment, including reach-in freezers. Both the EPCA and DOE standards are reported in the table below.

Equipment Class	EPCA (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.L)	0.4xV+1.38	0.22xV+1.38
Transparent Door (VCT.SC.L)	0.75xV+4.10	0.29xV+2.95

- In 2013, EPA updated its Energy Star standards for reach-in freezers, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit

Reach-In Freezer Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.L)	0.25xV+1.55	0.20xV+2.30	0.25xV+0.80	0.14xV+6.30
Glass Door (VCT.SC.L)	0.56xV+1.61	0.30xV+5.50	0.55xV+2.00	0.32xV+9.49

Commercial Reach-In Freezers

- The commercial reach-in freezer characterized in this report, which is the typical unit according to DOE’s 2014 CRE rulemaking, is a 49 cubic ft. solid two-door unit with a nominal compressor size 4,341 Btu/hr.
- 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.
- Unit energy consumption for reach-in freezers is expected to decrease as a result of DOE’s updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to EPA SNAP compliance.
- **For this advanced scenario, the typical unit in 2020 is assumed to comply with DOE’s updated energy conservation standards for commercial refrigeration**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Walk-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	37,820	37,820	37,820	37,820	37,820	N/A	37,820	37,820	37,820	37,820	37,820	37,820
Size (ft2)[1]	305	305	305	305	305	N/A	305	305	305	305	305	305
Energy Use (kWh/yr)[2]	53,756	30,689	31,892	30,689	27,571	N/A	16,014	14,413	14,453	14,310	14,019	13,880
Energy Use (kWh/ft2/yr)	176	101	105	101	90	N/A	53	47	47	47	46	46
Indexed Annual Efficiency[3]	1.00	1.38	1.69	1.75	1.95	N/A	3.36	3.73	3.72	3.76	3.83	3.87
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$19,607	$23,598	$23,583	$23,598	$23,644	N/A	$24,290	$25,696	$25,504	$25,696	$25,504	$25,696
Total Installed Cost[4]	$23,846	$27,012	$26,997	$27,012	$27,057	N/A	$27,703	$29,280	$29,088	$29,280	$29,088	$29,280
Total Installed Cost($/kBtu/hr)	$631	$714	$714	$714	$715	N/A	$733	$774	$769	$774	$769	$774
Annual Maintenance Cost[5]	$573	$716	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$15.15	$18.93	$19.59	$19.59	$19.59	N/A	$19.59	$19.59	$19.59	$19.59	$19.59	$19.59

1 Size is estimated based on analysis from the 2014 WICF TSD, which lists the average size of a walk in cooler as 305 ft^2

2 EISA 2007 includes prescriptive standards for walk-in refrigerators that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. In 2014, DOE updated energy conservation standards for walk-ins. All units 2015 and beyond use data from this rulemaking, and all units 2020 and beyond are assumed to comply with DOE's updated standards.

3 Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

4 Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $4,163 and $4,891 respectively. Installation cost for 2012 and beyond is based on DOE's Walk-In TSD

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

Commercial Walk-In Refrigerators

- The unit characterized in this report is a walk-in storage cooler with an area of 305 ft^2, the average floor area reported by DOE's 2014 Final Rule TSD for this equipment type.
- 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
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- **This advanced scenario assumes a projected 10% decrease in energy consumption over the reference case due to adoption of more efficient refrigerants.**

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 the analysis for all units for 2012 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 Refrigerators

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Walk-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	22,114	22,114	22,114	22,114	22,114	N/A	22,114	22,114	22,114	22,114	22,114	22,114
Size (ft^2) [1]	172	172	172	172	172	N/A	172	172	172	172	172	172
Energy Use (kWh/yr) [2]	33,540	22,862	23,610	22,862	20,878	N/A	13,421	12,079	12,113	12,006	11,749	11,645
Energy Use (kWh/ft^2/yr)	195	133	137	133	121	N/A	78	70	70	70	68	68
Indexed Annual Efficiency[3]	1.00	1.47	1.42	1.47	1.61	N/A	2.50	2.78	2.77	2.79	2.85	2.88
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$16,333	$22,008	$21,993	$22,008	$22,054	N/A	$22,793	$25,856	$25,130	$25,856	$25,130	$25,856
Total Installed Cost[4]	$18,570	$24,058	$24,043	$24,058	$24,103	N/A	$24,843	$28,115	$27,389	$28,115	$27,389	$28,115
Total Installed Cost ($/kBtu/hr)	$840	$1,088	$1,087	$1,088	$1,090	N/A	$1,123	$1,271	$1,239	$1,271	$1,239	$1,271
Annual Maintenance Cost[5]	$573	$741	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$25.91	$33.51	$33.51	$33.51	$33.51	N/A	$33.51	$33.51	$33.51	$33.51	$33.51	$33.51

[1] Based on DOE's 2014 WICF Final Rule TSD which states the average floor area for a walk-in storage freezer as 172 ft^2

[2] EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. Units for 2015 and beyond are characterized using data from DOE’s 2014 WICF rulemaking. All units 2020 and beyond are assumed to comply with this standard

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $1,040. Installation cost for 2012 and beyond is based on DOE’s WICF TSD.

[5] 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 is a walk-in storage freezer with an area of 172 ft^2 , the average size reported by DOE's WICF TSD

- A typical walk-in freezer includes:
  - insulated floor, door, and wall panels
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- **This advanced scenario assumes a projected 10% decrease in energy consumption over the reference case due to adoption of more efficient refrigerants.**

Commercial Walk-In Freezers: EISA 2007

- 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 Walk-In Freezers: DOE 2014 Standards

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Ice Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[5]	Typical	High	Typical	High	Typical	High
Output (lbs/day)[1]	300	300	300	300	300	300	300	300	300	300	300	300
Cooling Capacity (Btu/hr)[2]	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963
Water Use (gal/100 lbs)	20	20	20	20	20	20	20	20	20	20	20	20
Energy Use (kWh/100 lbs)	8.4	7.7	7.7	6.7	6.1	6.7	6.1	5.4	5.7	5.4	5.4	5.4
Energy Use (kWh/yr)[3]	3,833	3,185	3,185	3,078	3,009	3,078	2901.0	2,611	2,525	2,508	2,399	2,383
Normalized Annual Efficiency[4]	1.00	1.20	1.20	1.25	1.27	1.25	1.32	1.47	1.52	1.53	1.60	1.61
Average Life (yrs)	8.0	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost	$1,374	$2,146	$2,189	$2,284	$2,392	$2,284	$2,392	$2,548	$2,548	$2,925	$2,925	$2,925
Total Installed Cost (with Bin)	$1,499	$2,484	$2,484	$2,579	$2,687	$2,579	$2,699	$2,855	$2,855	$3,232	$3,232	$3,232
Total Installed Cost ($/kBtu/hr)	$763	$1,265	$1,265	$1,314	$1,369	$1,314	$1,375	$1,455	$1,455	$1,647	$1,647	$1,647
Annual Maintenance Cost[6]	$639	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826
Annual Maintenance Cost ($/kBtu/hr)	$326	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421

[1] Based on the Final Rule shipment data from DOE's Automatic Ice Maker rulemaking which states the most common equipment type is a small air cooled unit with an integrated ice making head with a representative capacity of 300 lbs/day.

[2] Defined as the average heat load to remove the latent and sensible heat required to freeze the daily output capacity of ice

[3] EPACT 2005 energy standards went into effect in 2010. The 2015 Low values are based on this standard. In 2014, DOE set new standards for commercial ice machines, with compliance required by 2018. The unit characterized for 2012 and beyond use data from this rulemaking. All units 2020 and beyond are assumed to comply with the updated standard.

[4] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[5] The Energy Star category is based on minimum compliance with the Energy Star v2.0 standard, which went into effect on February 1, 2013. According to this analysis, Energy Star certification is typical for the small air-cooled IMH unit characterized.

[6] 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

- **For this advanced case, a 10% reduction in energy consumption is projected over the reference case due to the adoption of more efficient refrigerants such as propane, which, while not currently required by EPA SNAP, are a source of possible efficiency improvements**
- The commercial ice machine characterized in this report 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.
- 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.
- ENERGY STAR® updated its maximum energy consumption levels, in KWh/100 lbs ice, for air cooled ice machines that went into effect on February 1, 2013. These efficiency levels are based on the harvest rate, in lbs/24 hrs. (H). Water cooled ice machines are not eligible for Energy Star certification.

ENERGY STAR Requirements for Air-Cooled Batch-Type Ice Makers			
Equipment Type	Applicable Ice Harvest Rate Range (lbs of ice/24 hrs)	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$200 \leq H \leq 1600$	$\leq 37.72 * H^{-0.298}$	≤ 20.0
RCU	$400 \leq H \leq 1600$	$\leq 22.95 * H^{-0.258} + 1.00$	≤ 20.0
	$1600 \leq H \leq 4000$	$\leq -0.00011 * H + 4.60$	≤ 20.0
SCU	$50 \leq H \leq 450$	$\leq 48.66 * H^{-0.326} + 0.08$	≤ 25.0

ENERGY STAR Requirements for Air-Cooled Continuous-Type Ice Makers		
Equipment Type	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$\leq 9.18 * H^{-0.057}$	≤ 15.0
RCU	$\leq 6.00 * H^{-0.162} + 3.50$	≤ 15.0
SCU	$\leq 59.45 * H^{-0.349} + 0.08$	≤ 15.0

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

Commercial Ice Machines: 2014 DOE Standards

Energy Conservation Standards for Batch Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<300	6.88 - 0.0055H	200 - 0.022H
		300 and <850	5.80 - 0.00191H	200 - 0.022H
		850 and <1,500	4.42 - 0.00028H	200 - 0.022H
		1500 and <2,500	4.0	200 - 0.022H
		2500 and <4,000	4.0	145
Ice-Making Head	Air	<300	10 - 0.01233H	Not Applicable
		300 and <800	7.05 - 0.0025H	Not Applicable
		800 and <1500	5.55 - 0.00063H	Not Applicable
		1500 and <4,000	4.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	50 and <1,000	7.97 - 0.00342H	Not Applicable
		1,000 and <4,000	4.55	Not Applicable
Remote Condensing and Remote Compressor	Air	<942	7.97 - 0.00342H	Not Applicable
		942 and <4,000	4.75	Not Applicable
Self-Contained	Water	<200	9.5 - 0.019H	191 - 0.0315H
		200 and <2,500	5.7	191 - 0.0315H
		2500 and <4,000	5.7	112
Self-Contained	Air	<110	14.79 - 0.0469H	Not Applicable
		110 and <200	12.42 - 0.02533H	Not Applicable
		200 and <4,000	7.35	Not Applicable

Energy Conservation Standards for Continuous Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<801	6.48 - 0.00267H	180 - 0.0198H
		801 and <2,500	4.34	180 - 0.0198H
		2,500 and <4,000	4.34	130.5
Ice-Making Head	Air	<310	9.19 - 0.00629H	Not Applicable
		310 and <820	8.23 - 0.0032H	Not Applicable
		820 and <4,000	5.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	<800	9.7 - 0.0058H	Not Applicable
		800 and <4,000	5.06	Not Applicable
Remote Condensing and Remote Compressor	Air	<800	9.9 - 0.0058H	Not Applicable
		800 and <4,000	5.26	Not Applicable
Self-Contained	Water	<900	7.6 - 0.00302H	153 - 0.0252H
		900 and <2,500	4.88	153 - 0.0252H
		2500 and <4,000	4.88	90
Self-Contained	Air	<200	14.22 - 0.03H	Not Applicable
		200 and <700	9.47 - 0.00624H	Not Applicable
		700 and <4,000	5.1	Not Applicable

Commercial Beverage Merchandisers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27	27
Energy Use (kWh/yr)	3,900	1,829	2,523	1,781	1,694	1,694	1,380	1,242	1,119	1,063	1,063	1,041
Energy Use ($kWh/ft^3/yr$) [1]	144	68	93	66	63	63	51	46	41	39	39	39
Indexed Annual Efficiency[3]	1.00	2.13	1.55	2.19	2.30	2.30	2.83	3.14	3.49	3.67	3.67	3.75
Average Life (yrs)	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Retail Equipment Cost	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$3,398	$3,432	$3,034	$3,064
Total Installed Cost[4]	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$3,398	$3,432	$3,034	$3,064
Total Installed Cost ($/kBtu/hr)	$311	$508	$496	$555	$560	$560	$599	$605	$725	$732	$647	$654
Annual Maintenance Cost[5]	$84	$108	$108	$98	$95	$95	$95	$95	$95	$95	$95	$95
Annual Maintenance Cost ($/kBtu/hr)	$17.91	$23.03	$23.03	$20.79	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15

[1] EPACT 2005 energy conservation standards went into effect in 2010. The 2015 Low values are based on this standard. In 2015, DOE updated its energy conservation standards for commercial refrigeration equipment, including transparent-doored refrigerators with pull-down capability. Compliance with this standard is required by 2017. Units characterized for 2012 and beyond use data reported in this rulemaking's TSD. Units 2020 and beyond are assumed to comply with this updated standard.
[2] The Energy Star category characterizes a unit that is compliant with Energy Star v3, effective October 1, 2014. This standard does not separately define units with pull-down capability
[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)
[4] Beverage merchandisers are shipped ready to be plugged in, so installation costs are assumed to be negligible
[5] Maintenance costs are estimated based on CRE Final Rule TSD data. Note that maintenance costs decrease slightly for more efficient units, which are assumed to include LED lighting with lower associated maintenance costs

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.
- In 2014, DOE updated its energy consumption standards for commercial refrigeration equipment, including beverage merchandisers, effective March 27, 2015. Both the DOE and EPCA standards are reported below.

Equipment Type	EPCA (2010)	DOE Standards (2017)
Beverage Merchandisers (PD.SC.M)	0.126xV + 3.51	0.11xV+0.81

- In 2013, EPA updated its Energy Star standards for glass doored commercial refrigerators, which can be used as beverage merchandisers, effective October 1, 2014. These standards are also based on the volume of the unit (V). Note that Energy Star does not have a separate equipment class for units with pull-down capability.

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

Commercial Beverage Merchandisers

- The beverage merchandiser characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a nominal compressor size of 4,689 Btu/hr..
- The efficiency of beverage merchandisers can be increased through the use of more efficient compressors, fluorescent lighting with electronic ballasts, and improved insulation.
- 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.
- Unit energy consumption of beverage merchandisers is expected to decrease as a result of DOE's updated Energy Conservation Standards, as well as a transition from R-134a to more efficient propane refrigerant due to EPA SNAP compliance
- **For this advanced scenario, the typical unit in 2020 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Refrigerated Vending Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810
Can Capacity	500	470	470	470	470	470	470	470	470	470	470	470
Size (ft^3)	26	26	26	26	26	26	26	26	26	26	26	26
Energy Use (kWh/yr) [1]	3,000	1,632	1,718	1,632	1,504	1,504	1,360	1,224	803	701	701	687
Energy Use (kWh/ft^3/yr)	115	63	66	63	58	58	52	47	31	27	27	26
Indexed Annual Efficiency[3]	1.00	1.84	1.75	1.84	1.99	1.99	2.21	2.45	3.74	4.28	4.28	4.37
Average Life (yrs)	14	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Retail Equipment Cost	$1,769	$3,209	$3,187	$3,209	$3,276	$3,276	$3,551	$3,626	$4,479	$4,612	$4,343	$4,434
Total Installed Cost	$1,844	$3,320	$3,298	$3,320	$3,387	$3,387	$3,662	$3,737	$4,590	$4,723	$4,454	$4,545
Total Installed Cost ($/kBtu/hr)	$1,019	$1,834	$1,822	$1,834	$1,872	$1,872	$2,023	$2,065	$2,536	$2,609	$2,461	$2,511
Annual Maintenance Cost[4]	$209	$270	$270	$270	$250	$250	$250	$250	$250	$250	$250	$250
Annual Maintenance Cost ($/kBtu/hr)	$115	$149.17	$149.17	$149.17	$138.12	$138.12	$138.12	$138.12	$138.12	$138.12	$138.12	$138.12

[1] Energy use for 2012 and beyond is estimated based on DOE's 2015 BVM Final Rule

[2] The Energy Star category assumes units that are compliant with the Energy Star v3 standard, since combination units are currently not separately defined by Energy Star. This standard went into effect on March 1, 2013. Our analysis finds Energy Star certified equipment to be the most efficient currently available on the market

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[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 in 2009. 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) ≤ 0.055*V + 2.56
  - Refrigerated Vending Machines that are zone-cooled (Type B) ≤ 0.073*V + 3.16
- Energy Star® updated its maximum daily energy consumption efficiency levels, also in KWh/day, for refrigerated vending machines, which went into effect on March 1, 2013. These efficiency levels are based on refrigerated volume.

Equipment Type	Maximum Daily Energy Consumption	Low Power Mode Requirement
Class A (Transparent-Front)	MDEC= 0.0523 x V + 2.432	Hard-wired controls and/or software capable of placing the machine into a low power mode during periods of extended inactivity while still connected to its power source
Class B (Solid-Front)	MDEC = 0.0657 x V + 2.844	

- **Currently, stakeholders such as Coca Cola have indicated a preference for CO_2 refrigerant, which is less efficient. However, this advanced case scenario assumes a shift to more efficient propane for cost and energy consumption projections due to the superior efficiency of propane refrigerant.**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Refrigerated Vending Machines

- In December 2015, DOE updated its energy conservation standards for beverage vending machines, and defined two new product classes for combination vending machines Compliance with these standards is required by 2019. For this analysis, compliance with these updated standards is assumed for equipment sold in 2020 and beyond. The updated standards and DOE equipment definitions are listed in the table below.

Equipment Class	Maximum daily energy consumption (kilowatt hours per day)
Class A – a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.052 x V + 2.43
Class B – any refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine	MDEC = 0.052 x V + 2.20
Combination A – a combination vending machine where 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.086 x V + 2.66
Combination B – a combination vending machine that is not considered to be Combination A	MDEC = 0.111 x V + 2.04

Commercial Ventilation
Advanced Case

Commercial Constant Air Volume

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4,5]	Typical[4,6]	Best[4,7]	Energy Star	Typical[4,7]	Best[4,8]	Typical[4,8,9]	Best[4,8,9]	Typical[4,8,9]	Best[4,8,9]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	11.80	11.56	11.56	11.56	11.56	N/A	11.56	11.56	11.56	11.56	11.56	11.56
Specific Fan Power (W/CFM)	0.787	0.771	0.771	0.771	0.771	N/A	0.771	0.771	0.771	0.771	0.771	0.771
Annual Fan Energy Use (kWh/yr)[1]	44,858	43,924	23,038	20,018	15,226	N/A	15,226	11,155	10,597	9,482	9,482	8,366
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$68,539	$68,539	$68,979	$68,979	$74,178	N/A	$74,178	$74,778	$75,378	$75,978	$75,978	$76,578
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$4,569	$4,569	$4,599	$4,599	$4,945	N/A	$4,945	$4,985	$5,025	$5,065	$5,065	$5,105
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

[1] Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[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.

[4] ASHRAE 90.1-2010 & 2013 Section 6.5.3.2 require minimum 2-speed fan control (no longer always constant volume).

[5] Two-speed motor.

[6] Two-speed VFD.

[7] Modulating VFD (66-100%).

[8] Modulating VFD (50-100%).

[9] High aerodynamic efficiency fan.

Commercial Constant Air Volume

- Constant air volume (CAV) ventilation systems are common, inexpensive, air-side HVAC systems that operate in response to a single control zone. Historically, 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. Recent energy efficiency standard changes (ASHRAE 90.1-2013) now mandate at least two fan speed settings with the requirement of a maximum 40% power at 66% flow. This analysis examines only the fan energy of the CAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for CAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the CAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- 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 $60,722 (RS Means 2016). Ductwork would cost approximately $7,817 additional ($68,539 total). A 2-speed motor (estimated $440 incremental cost) and variable frequency drive (estimated $5,639) add cost.
- 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 2012 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, motor efficiency, and speed/flow control.

Commercial Variable Air Volume

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4]	Typical[5]	Best[6]	Energy Star	Typical[8]	Best[6,7]	Typical[6,7]	Best[6,7]	Typical[6,7]	Best[6,7]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	16.72	15.99	15.99	15.99	15.99	N/A	15.99	15.99	15.99	15.99	15.99	15.99
Specific Fan Power (W/CFM)	1.115	1.066	1.066	1.066	1.066	N/A	1.066	1.066	1.066	1.066	1.066	1.066
Annual Fan Energy Use (kWh/yr)[1]	25,839	24,699	24,699	18,181	16,425	N/A	15,604	15,604	14,783	14,783	13,961	13,140
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$88,207	$88,207	$88,207	$93,846	$94,346	N/A	$94,446	$94,946	$94,446	$94,946	$94,446	$94,946
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$5,880	$5,880	$5,880	$6,256	$6,290	N/A	$6,296	$6,330	$6,296	$6,330	$6,296	$6,330
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

1 Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

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.

4 ASHRAE 90.1-2010 Section 6.5.3.2 minimum power-flow requirement.

5 ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 50%-100% flow.

6 ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 30%-100% flow.

7 High aerodynamic efficiency fan.

Commercial Variable Air Volume

- 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 speed/flow to meet space conditioning requirements; minimum flow settings apply for DX cooling stages and gas furnace heating stages. Most hours of operation are much lower than full speed, and fan power varies with the cube of fan speed according to fan affinity laws. The 2012 ASHRAE Handbook: HVAC Systems and Equipment (p. 45.11) provided the typical flow profile used for this analysis. The unit characterized in this report is a 15,000 CFM VAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for VAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the VAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- A 15,000 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $69,100 (RS Means 2016). Ductwork and (10) VAV boxes with reheat would cost approximately $19,107 additional ($88,207 total). A 20 hp variable frequency drive (estimated $5,639) is an additional cost.
- 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 2012 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 Units

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[5]	Low[3]	Typical[6]	Best[6]	Energy Star	Typical[4,7]	Best[4,8]	Typical[4,8]	Best[4,8,9]	Typical[4,8,9]	Best[4,8,9]
System Airflow (CFM)	800	800	800	800	800	N/A	800	800	800	800	800	800
System Fan Power (kW)	0.315	0.241	0.748	0.241	0.148	N/A	0.148	0.148	0.148	0.141	0.141	0.133
Specific Fan Power (W/CFM)	0.394	0.302	0.935	0.301	0.185	N/A	0.185	0.185	0.185	0.176	0.176	0.166
Annual Fan Energy Use (kWh/yr)[1]	709	543	1,683	543	333	N/A	152	94	94	89	89	84
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$2,429	$2,429	$2,429	$2,429	$2,753	N/A	$2,753	$2,995	$2,753	$2,995	$2,995	$3,044
Annual Maintenance Cost ($)	$100	$100	$100	$100	$100	N/A	$100	$100	$100	$100	$100	$100
Total Installed Cost ($/1000 CFM)	$3,036	$3,036	$3,036	$3,036	$3,441	N/A	$3,441	$3,744	$3,441	$3,744	$3,744	$3,805
Annual Maintenance Cost ($/1000 CFM)	$125	$125	$125	$125	$125	N/A	$125	$125	$125	$125	$125	$125

[1] Based on 2250 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.

[3] Based on ASHRAE 90.1-2010 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

[4] Based on ASHRAE 90.1-2013 Section 6.5.3.5 requirement of electronically commutated or 70+% efficient fan motor.

[5] Permanent split capacitor fan motor.

[6] Electronically commutated fan motor (single speed).

[7] Electronically commutated fan motor (two-speed).

[8] Electronically commutated fan motor (variable speed).

[9] High aerodynamic efficiency fan.

Commercial Fan Coil Units

- 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.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons. This analysis examines only the fan energy of FCUs.
- 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. ASHRAE 90.1-2013 requires an electronically commutated fan motor (or minimum motor efficiency of 70%) for this system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for FCUs. Fan power can be minimized through good design practice and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including small systems such as the FCU considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- 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 2012 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, motor efficiency, and fan speed control.

Appendix A
Data Sources

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

And

Leidos
8301 Greensboro Drive
McLean, VA 22102

Residential Lighting

Data Sources » Residential General Service LED Lamps (60 Watt Equivalent)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Calculated from 2015 Values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged From 2015 Typical					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	SSL R&D Plan Table 2.1 (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	SSL R&D Plan Table 2.1 +adjustment (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Reflector LED BR30

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Adjusted based on PAR38 values					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)					Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
CRI	Adjusted based on PAR38 values				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Lamp Cost ($/klm)	Adjusted based on PAR38 values	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Reflector LED PAR38

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td>Calculated</td><td colspan="3" rowspan="4">LED Lighting Facts Database (downloaded 10/31/15)</td><td rowspan="2">Energy Star Light Bulb product database (downloaded 11/4/15)</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td>Product Catalogs</td><td colspan="6">Nominal lumen output based on historical values</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>2012 SSL MYPP</td><td>Calculated</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Calculated</td></tr>
<tr><td>CRI</td><td rowspan="3">Product Catalogs</td><td rowspan="3">Energy Star Light Bulb product database (downloaded 11/4/15)</td><td colspan="6" rowspan="2">Assume Unchanged</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td><td rowspan="2">DOE SSL Program R&D Plan (DOE SSL Program, 2015)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>Retailer Websites</td><td>Retailer Websites</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td><td colspan="2">Assume Unchanged</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="11">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td>Calculated</td><td>Retailer Websites</td><td>Calculated</td><td colspan="2">Retailer Websites</td><td colspan="4">Calculated</td><td colspan="2" rowspan="2">Calculated</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>2012 SSL MYPP</td><td>Calculated</td><td>DOE SSL Program R&D Plan (DOE SSL Program, 2015)</td><td colspan="2">Calculated</td><td colspan="4">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="11" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="11" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Residential Linear LED Replacement Lamp 2 Lamp System*

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)			N/A	Calculated					
Lamp Lumens						Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage	Calculated					Calculated					
System Lumens	DOE SSL Program R&D Plan (DOE SSL Program, 2015)					DOE SSL Program R&D Plan (DOE SSL Program, 2015)					
System Efficacy (lm/W)	Calculated					Calculated					
Ballast Efficiency (BLE)	N/A					N/A					
CRI	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List Downloaded 11/17/15	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		Assume Unchanged					
Correlated Color Temperature (CCT)			DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A					N/A					
Fixture Price ($)*											
Lamp Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*	N/A					N/A					
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor System Installation (hr)*											
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage											
Lamp Lumens	N/A										
Lamp Efficacy (lm/W)											
System Wattage		DLC Qualified Product List (Downloaded 11/18/15)		DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
System Lumens		Calculated		Calculated		Adjusted for 2015 Typical Lumen Output					
System Efficacy (lm/W)	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 10/31/15)	DLC Qualified Product List (Downloaded 11/18/15)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Efficiency (BLE)	N/A										
CRI			LED Lighting Facts Database (downloaded 10/31/15)			Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lifetime (1000 hrs)	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp/Luminaire Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites	Retailer Websites	Calculated					
Ballast Price ($)											
Fixture Price ($)	N/A										
Lamp Cost ($/klm)											
System (l/b/f) Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)											
Labor System Installation (hr)	Assume Same as T5										
Labor Lamp Change (hr)	N/A										
Total Installed Cost ($)											
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)	Calculated										
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Security: LED PAR38)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Porch: LED A-Type*)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star*	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated										
Lamp Lumens	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Lamp Efficacy (lm/W)	Scaled based on 60W Residential A-type Lamp										
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE SSL Program, Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates (DOE SSL Program, 2012)										
Lamp Price ($)	Calculated										
Lamp Cost ($/klm)	Scaled based on 60W Residential A-type Lamp										
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Commercial Lighting

Data Sources » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A	DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage		Calculated										
System Lumens*												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)			Retailer Websites	Assume Same as A19 60W equiv	Retailer Websites							
Average Lamp Life (1000 hrs)		Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	Calculated				Calculated	
System (l/b/f) Cost ($/klm)		N/A										
Labor Cost ($/hr)		Same as for CFL										
Labor System Installation (hr)**												
Labor Lamp Change (hr)		Calculated										
Total Installed Cost ($)												
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)				Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage		Calculated										
System Lumens*												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)		N/A										
CRI		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)		Calculated	Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)**		N/A										
Labor Cost ($/hr)		Same as for Halogen										
Labor System Installation (hr)**												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated										
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage		DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)				Calculated					
Lamp Lumens							Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage		Calculated					Calculated					
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI		DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)				Assume Unchanged					
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)			Retailer Websites	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)		N/A					N/A					
Fixture Price ($)*	N/A					N/A						
Lamp Cost ($/klm)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*		N/A					N/A					
Labor Cost ($/hr)		Calculated	Assume Same as Analgous Conventional Tech				Assume Unchanged					
Labor System Installation (hr)*		N/A										
Labor Lamp Change (hr)		Calculated										
Total Installed Cost ($)		Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems*

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)												
Average Lifetime (1000 hrs)	Calculated						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Website	Calculated	Retailer Website		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case	Calculated									Assume Unchanged	
Labor System Installation (hr)	2008 EIA Reference Case											
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System*

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage				LED Lighting Facts Qualified Product List (Downloaded 11/17/15)			Calculated					
Lamp Lumens							Nominal Lumen output based on 2015 values					
Lamp Efficacy (lm/W)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage				Calculated			Calculated					
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)				N/A			Assume Unchanged from 2015					
CRI				Calculated from LED Lighting Facts Qualified Product List Downloaded 11/17/15								
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)				Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)				N/A			N/A					
Fixture Price ($)*												
Lamp Cost ($/klm)				Navigant Price Analysis			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System (l/b/f) Cost ($/klm)*				N/A			N/A					
Labor Cost ($/hr)				Assume Same as Analgous Conventional Tech			Assume Unchanged from 2015					
Labor System Installation (hr)*												
Labor Lamp Change (hr)												
Total Installed Cost ($)				Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

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DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage												
Lamp Lumens				Calculated			N/A					
Lamp Efficacy (lm/W)												
System Wattage				Retailer Websites			Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)				N/A			N/A					
CRI				Retailer Websites			Assume Unchanged from 2015					
Correlated Color Temperature (CCT)												
Average Lifetime (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)				Calculated			Calculated					
Ballast Price ($)				N/A			N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)				Navigant Price analysis			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)				Assume Same as Analgous Conventional Tech							Assume Unchanged	
Labor System Installation (hr)												
Labor Lamp Change (hr)				N/A			N/A					
Total Installed Cost ($)				Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case		Assume Same as Analgous Conventional Tech								Assume Unchanged	
Labor System Installation (hr)												
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial LED High-bay Luminaire *

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DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage												
Lamp Lumens	N/A						N/A					
Lamp Efficacy (lm/W)												
System Wattage							Calculated					
System Lumens											Assume Unchanged	
System Efficacy (lm/W)	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI		DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)							
Correlated Color Temperature (CCT)	2008 EIA Reference Case			DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites		Assume Unchanged from 2015					
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)												
Fixture Price ($)							N/A					
Lamp Cost ($/klm)	N/A											
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case	Assume Same as Analgous Conventional Tech										
Labor System Installation (hr)	Assume Same as Analgous Conventional Tech										Assume Unchanged	
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)												
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated						Calculated					
Annual Maintenance Cost ($/klm)												

Refrigeration

Data Sources » Commercial Compressor Rack Systems

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	Copeland, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	ADL, 1996 / NCI Analysis, 2015	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	Kysor-Warren, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI, 2009 / NCI Analysis, 2012	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost ($1000)	ADL, 1996 / NCI Analysis, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	NCI Analysis, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Indexed Annual Efficiency	#REF!											
Average Life (yrs)	ADL, 1996 / NCI Analysis, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007	Interviews with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	EIA, 2012										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Supermarket Display Cases

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2007 / NCI Analysis, 2008	Navigant Analysis, 2015										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis										
Case Length	DOE, 2014: CRE TSD											
Energy Use (kWh/yr)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Energy Use (kWh/ft)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE TSD										
Retail Equipment Cost	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Total Installed Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cst ($/kBtu/hr)	Navigant Analysis, 2015											
Annual Maintenance Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Engineering Spreadsheet										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Energy Use ($kWh/yr/ft^3$)	NCI Analysis, 2012	Calculated										
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Reach-In Freezers

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use ($kWh/yr/ft^3$)	NCI Analysis, 2012	Calculated										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Walk-In Refrigerators

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Size (ft^2)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use ($kWh/ft^2/yr$)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / FMI, 2005 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

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DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Size (ft^2)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^2/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: WICF TSD / Navigant Analysis, 2014											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Output (lbs/day)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Water Use (gal/100 lbs)	ADL, 1996 / Distributor Web Sites	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/100 lbs)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/yr)	ACEEE, 2002 / NCI Analysis, 2012	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Average Life (yrs)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Total Installed Cost (with Bin)	NCI Analysis, 2008	DOE, 2014: ACIM TSD / Distributor Websites / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

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DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2014: CRE TSD											
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use ($kWh/ft^3/yr$)	Calculated											
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2015: CRE TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	DOE, 2014: CRE TSD, Navigant Analysis											
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: CRE TSD, Navigant Analysis, 2015											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2008 / NCI Analysis, 2008	DOE, 2015: BVM Engineering Spreadsheet										
Can Capacity	CEC, 2005 / NREL, 2003 / FEMP, 2004	DOE, 2015: BVM FR TSD / Navigant Analysis, 2015										
Size (ft^3)	DOE, 2015: BVM Engineering Spreadsheet											
Energy Use (kWh/yr)	ADL, 1996 / CEC, 2008 / NREL, 2003	DOE, 2015: BVM Engineering Spreadsheet										
Energy Use (kWh/ft^3/yr)	Calculated											
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ADL,1996	DOE, 2015: BVM FR TSD										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM Engineering Spreadsheet										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM FR TSD										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2008	DOE, 2014: BVM FR TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Commercial Ventilation

Commercial Constant Air Volume

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	CBECS 2003 & BED 2007											
System Fan Power (kW)	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Commercial Variable Air Volume

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	CBECS 2003 & BED 2007											
System Fan Power (kW)	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Commercial Fan Coil Units

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	Product Literature											
System Fan Power (kW)	Product Literature	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Appendix B
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