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Updated Buildings Sector Appliance and Equipment Costs and Efficiency

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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.

EIA conducts surveys of the building sectors, the Residential Energy Consumption Survey (RECS) and Commercial Buildings Energy Consumption Survey (CBECS), which 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 "menus" that represent competing options for most of the largest end uses. Multiple classes and types are represented in the equipment 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. These equipment menus interact with other NEMS modules to determine market shares, equipment efficiency levels, cost estimates, and equipment interactions[1], and are used to translate service demand to 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 was used in developing Reference case projections, while Appendix B was used in developing advanced technology cases.[2] These assumptions were developed and implemented during the *AEO2012* 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 was used in developing the Reference case, while Appendix D was used in developing advanced technology cases. These assumptions were developed and implemented during the *AEO2013* cycle.

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

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[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.

APPENDIX A

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

Presented to:

U.S. Energy Information Administration

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DISCLAIMER

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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.

- 2005 and 2007 baselines, as well as today's (2010)
  - 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 2035
  - 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 real, 2010 dollars.

Definitions

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2005 and 2007, to the highest efficiency equipment that is expected to be commercially available by 2035, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- 2005/2007 Installed Base: the currently installed and "in use" equipment for that year. Represents the installed stock of equipment, does not represent sales.
- 2010 Current Standard: the minimum efficiency required by current standards, or typical where no standard exists.
- 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 2007 and is reflected in the efficiency and cost characteristics.

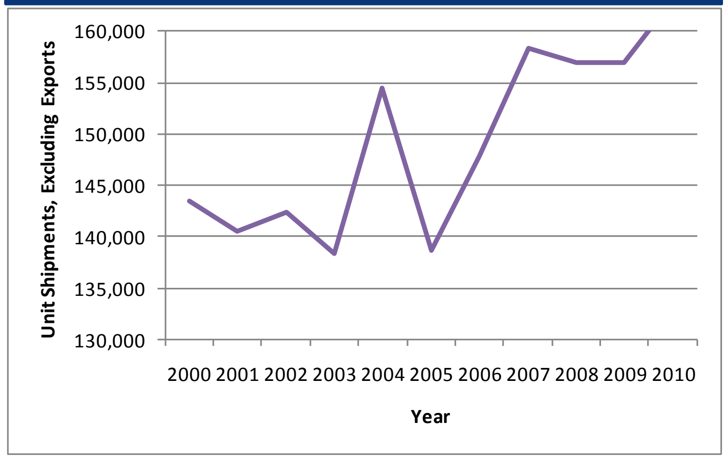
- Over the past three years, the Environmental Protection Agency (EPA) established ENERGY STAR specifications for a number of new products, including residential water heaters.
- Typical air conditioners have improved efficiencies as a result of increased Federal standards or otherwise. In 2007, the typical Energy Efficiency Ratio (EER) for a residential room air conditioner was 10.0, today it is 10.8; the typical EER for a commercial rooftop air conditioner was 10.1, today it is 11.2.
- Overall, there has been an increased market acceptance of energy efficient products driven by initiatives such as LEED and other green building programs.

Final

Historical Shipment Data

Due to the severe recession and dramatic contraction in the housing market, over the past few years there has been a trend of decreased appliance shipments, except in commercial appliances where a specific trend is not evident. In 2010, shipments have increased across all appliance types.

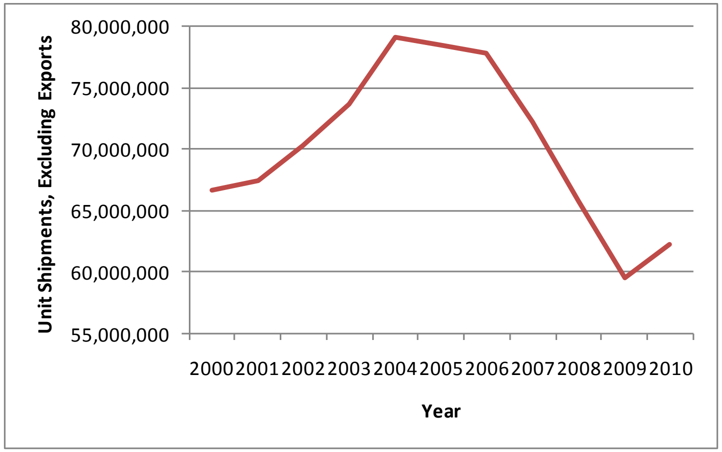
Commercial Appliances



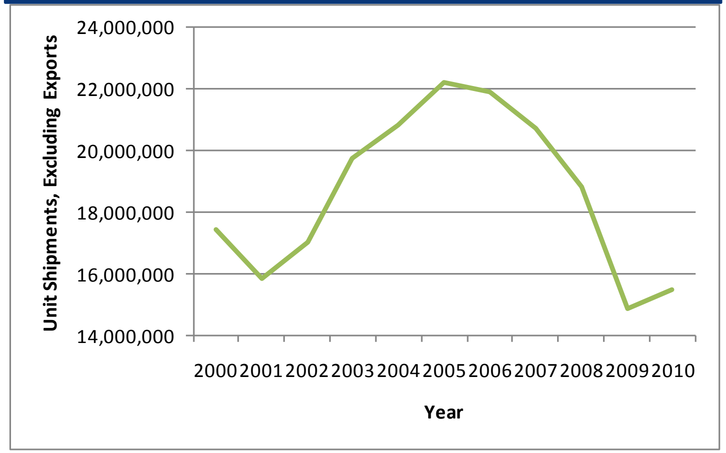
Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Throughout the presentation, shipment trends for specific products are depicted. Overall, the recession and contraction of the housing market has significantly affected each product.

Major Appliances



Comfort Conditioning



Performance / Cost Characteristics » Residential Gas-Fired Water Heaters

DATA	2005	2010	2010			2020		2030		2035	
	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	0.85	0.62	0.85	0.62	0.85	0.62	0.85
Average Life (yrs)	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15
Retail Equipment Cost ($)	470-510	470-510	480-510	780-810	1500-3000	450-500	1380-2880	450-500	1250-2750	450-500	1200-2700
Total Installed Cost ($)	920-960	920-960	930-960	1230-1260	1950-3450	900-950	1830-3330	900-950	1700-3200	900-950	1650-3150
Annual Maintenance Cost ($)	-	-	13	17	17	13	17	13	17	13	17

- 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.

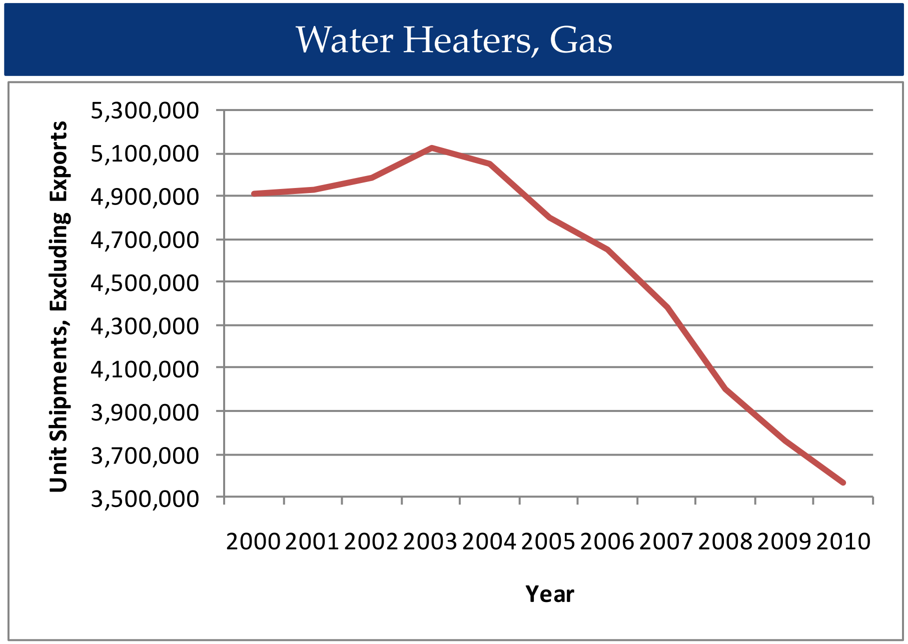
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

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

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

- Per discussions with National Labs, there is a potential trend towards a capacity of 50 gallons after 2020.
- 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.

Since the last analysis was performed in 2007, there has been a decrease in residential gas-fired water heater shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Oil Water Heaters

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	30	30	30	30	30	30	30	30	30	30	30
Energy Factor	0.5	0.53	0.54	0.62	0.68	0.62	0.68	0.62	0.68	0.62	0.68
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9
Retail Equipment Cost ($)	1200-1300	1300-1400	1350-1450	1450-1550	1600-1700	1440-1540	1600-1700	1420-1520	1600-1700	1420-1520	1600-1700
Total Installed Cost ($)	1800-1900	1900-2000	1950-2050	2050-2150	2200-2300	2040-2140	2200-2300	2020-2120	2200-2300	2020-2120	2200-2300
Annual Maintenance Cost ($)*	-	-	157	157	157	157	157	157	157	157	157

- 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, hence the range of efficiencies tops out at near-condensing efficiency levels.
- The max-tech model on the market is achieved using a proprietary "turbo flue" design.

Performance / Cost Characteristics » Residential Electric Resistance Water Heaters

DATA	2005	2010	2010		2020		2030		2035	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50
Energy Factor	0.9	0.9	0.92	0.95	0.95	0.96	0.95	0.96	0.95	0.96
Average Life (yrs)	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15
Retail Equipment Cost ($)	250-300	250-300	275-325	350-375	350-375	400-450	350-375	400-450	350-375	400-450
Total Installed Cost ($)	550-600	550-600	575-625	650-675	650-675	700-750	650-675	700-750	650-675	700-750
Annual Maintenance Cost ($)*	-	-	6	6	6	6	6	6	6	6

* Annual Maintenance Cost is negligible

- 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.

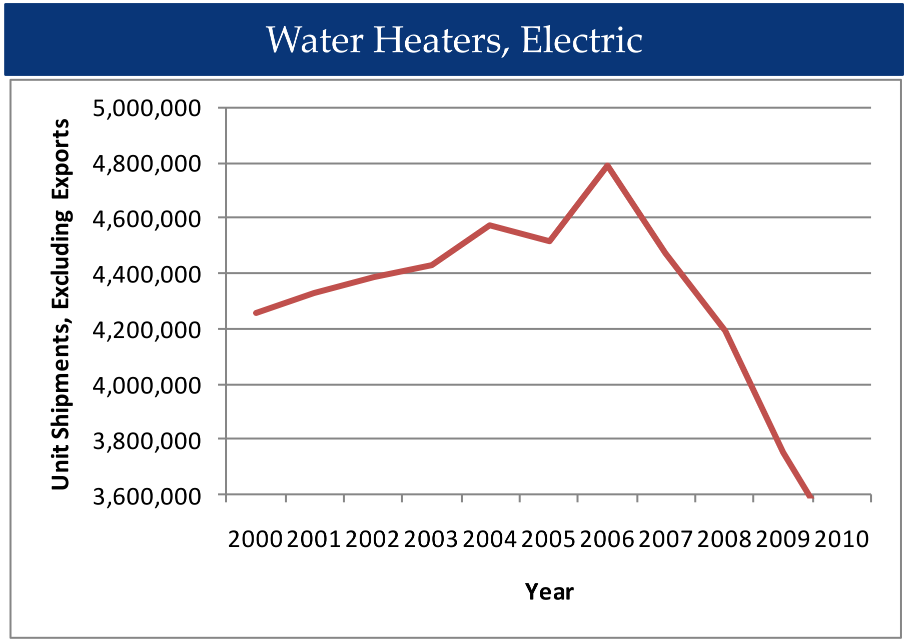
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

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

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

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

Since the last analysis was performed in 2007, there has been a decrease in residential electric resistance water heater shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Heat Pump Water Heaters

DATA	2005	2010		2020		2030		2035	
	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	2.35	2	2.35	2	2.35	2	2.35
Average Life (yrs)	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15
Retail Equipment Cost ($)	1400-1700	1400-1700	1500-2000	1300-1600	1500-2000	1300-1600	1500-2000	1250-1550	1500-2000
Total Installed Cost ($)	1500-2200	1500-2200	1600-2500	1400-2100	1600-2500	1400-2100	1600-2500	1350-2050	1600-2500
Annual Maintenance Cost ($)	15	15	15	15	15	15	15	15	15

- There is not a unique Federal standard for heat pump water heaters (HPWH). Because integrated HPWHs are in the same product class as electric resistance water heaters under DOE's classifications, the Federal standard that applies to electric resistance water heaters applies here as well.
- Since 1990, significant R&D efforts have gone into developing HPWHs. Improvements have advanced efficiency and reliability; however, the high first cost still precludes high-volume market penetration.
- Although there is an installed base listed for 2005, the market penetration of HPWHs was quite low at that time.
- Three major domestic storage water heater manufacturers (Rheem , AO Smith, and GE) have an integrated HPWH model on the market; however, new and established competitors offer integrated or retrofit units (for existing electric or indirect storage water heaters).
- Stiebel Eltron has an 80 gallon, 2.5 energy factor high efficiency HPWH. This unit was not included in the analysis presented on the previous slide because it has a significantly larger capacity than the units included, making for a difficult comparison.
- Sales are estimated to be limited and driven in part by rebates and tax credits at the utility, local, state, and Federal level. Hence, it is not surprising that all HPWH products on the market meet ENERGY STAR minimums and that no HPWH products are being offered below the ENERGY STAR efficiency level.
- While resistive heating elements are virtually 100% efficient at transferring heat to the water inside a water heater, there is a jump in efficiency when heat pump technology is adopted since the COP of heat pump systems is usually between 2 and 3, at least on a seasonal basis.
- Due to the typically slow rate at which heat pumps raise the water temperature in a storage water heater, it is not unusual for heat pump systems to use resistive heat for some proportion of the water heating process to meet consumer expectations. All HPWH systems examined by DOE allow the consumer to adjust the HPWH behavior.

Performance / Cost Characteristics » Residential Instantaneous Water Heaters

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (BTU/h)	185	185	185	185	185	185	185	185	185	185	185
Energy Factor	0.82	0.82	0.82	0.82	0.98	0.82	0.98	0.82	0.98	0.82	0.98
Average Life (yrs)	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20
Retail Equipment Cost ($)	1050-1150	1050-1150	1050-1150	1050-1150	2150-2250	1050-1150	2150-2250	1050-1150	2150-2250	1050-1150	2150-2250
Total Installed Cost ($)	1550-1650	1550-1650	1550-1650	1550-1650	2650-2750	1550-1650	2650-2750	1550-1650	2650-2750	1550-1650	2650-2750
Annual Maintenance Cost ($)	85	85	85	85	85	85	85	85	85	85	85

- Most instantaneous hot water heaters sold in 2010 are gas-fired and have an efficiency of 0.80 EF or above, which is also the qualifying criteria for ENERGY STAR
- Navien manufactures the highest efficiency gas-fired model currently available on the market, which has 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, all of which are imported and private-labeled.
- 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 3/4 inch from the typical ½ inch and change the venting.

DATA	2005 Installed Base	2010 Current Standard	2010 Typical / ENERGY STAR[2]	2020 Typical[2]	2030 Typical[2]	2035 Typical[2]
Typical Capacity (sq. ft.)	42-63	NA	42-63	42-63	42-63	42-63
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[1] ($)	3300-5200	NA	3300-5200	3000-4700	2600-4100	2600-4100
Total Installed Cost[1] ($)	7600-10000	NA	7600-10,000	7300-9500	6900-8900	6900-8900
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.

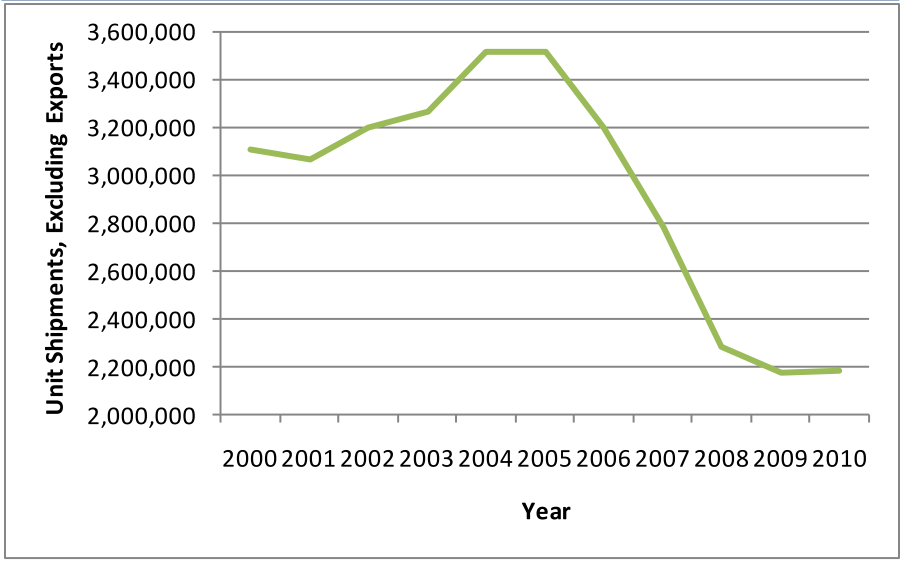
Performance / Cost Characteristics » Residential Gas-Fired Furnaces

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	75	75	75	75	75	75	75	75	75	75	75
AFUE (%)	78	78	80	90	98	90	98	90	98	90	98
Electric Consumption (kWh/yr)	780	780	430	371	340	371	340	371	340	371	340
Average Life (yrs)	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25
Retail Equipment Cost ($)	700-800	700-800	700-800	1200-2200	2200-3200	1200-2200	1700-1800	1200-2200	1700-1800	1200-2200	1700-1800
Total Installed Cost ($)	2000-3000	2000-3000	2000-3000	2500-3000	3500-4000	2500-3000	3000-3500	2500-3000	3000-3500	2500-3000	3000-3500
Annual Maintenance Cost ($)	50	50	50	50	50	50	50	50	50	50	50

- The current standard for residential gas-fired furnaces is 78% AFUE; however, virtually all furnaces on the market have an AFUE of 80% or better.
- The minimum criteria for an ENERGY STAR qualified gas-fired furnace is 90% AFUE.
- York and Lennox manufacture the highest efficiency models currently available on the market, which have an efficiency of 98%.
- 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 percent.
- 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 will breach the appliance or vent over time and hence allow flue gases into the structure.
- High-efficiency condensing furnaces typically have aluminized steel heat exchangers and low NO_x emissions, flexible installation, direct vent, and sealed combustion systems. The furnace does not use room air for combustion, but instead draws the 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 PSC or electronically commutated motors (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.

Since the last analysis was performed in 2007, there has been a decrease in gas-fired furnace shipments.

Furnaces, Warm Air, Gas



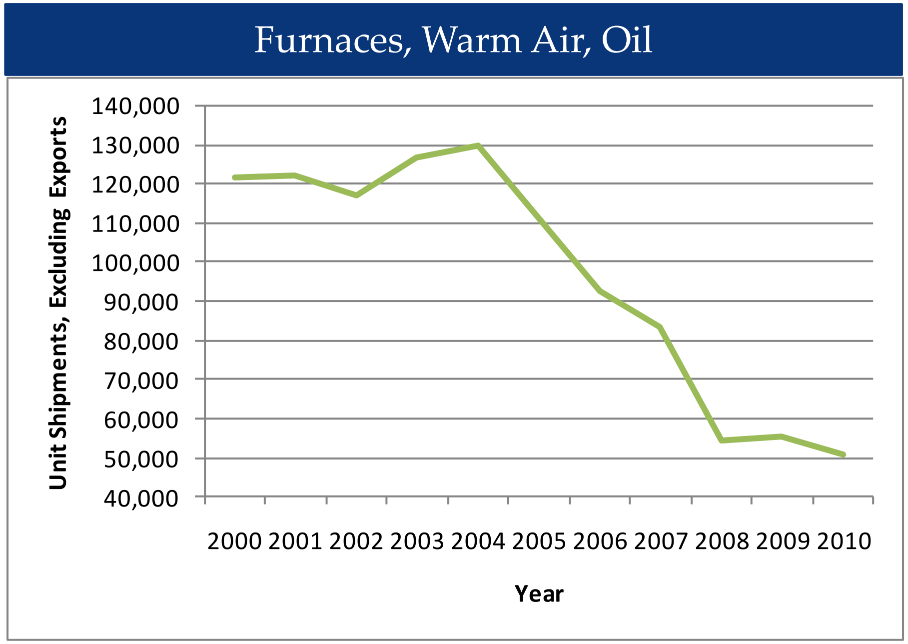
Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Oil-Fired Furnaces

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	78	80	85	98	82	98	82	98	82	98
Electric Consumption (kWh/yr)	1001	1001	1001	944	900	950	900	950	900	950	900
Average Life (yrs)	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25
Retail Equipment Cost ($)	2000-2200	2000-2200	2000-2200	2200-2800	3200-3800	1900-2100	3200-3800	1800-2000	3200-3800	1775-1975	3200-3800
Total Installed Cost ($)	3000-3500	3000-3500	3000-3500	3500-4000	4500-5000	2900-3100	4500-5000	2800-3000	4500-5000	2775-2975	4500-5000
Annual Maintenance Cost ($)	120	120	120	120	120	120	120	120	120	120	120

- The current NAECA Standard for oil-fired, forced air furnaces is 78% AFUE.
- The ENERGY STAR criteria for oil-fired furnaces is 85% 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.
- There are condensing residential oil-fired furnaces on the market that operate at about 95% AFUE. They have a 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.

Since the last analysis was performed in 2007, there was initially a decrease with a recent slight increase in oil-fired furnace shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Final

Performance / Cost Characteristics » Residential Hydronic Heating Systems (Boilers)

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	78	80	82	85	98	82	98	82	98	82	98
Average Life (yrs)	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30
Retail Equipment Cost ($)	1000-1100	1000-1800	1200-2000	2100-2500	2500-3500	1200-2000	2500-3500	1200-2000	2500-3500	1200-2000	2500-3500
Total Installed Cost ($)	2800-2900	2800-3800	3000-4000	4000-4500	4500-5500	3000-4000	4500-5500	3000-4000	4500-5500	3000-4000	4500-5500
Annual Maintenance Cost ($)	130	130	130	130	130	130	130	130	130	130	130

- The NAECA standard for hot-water residential gas boilers is 80% AFUE, while the ENERGY STAR standard for boilers is 85% AFUE. The highest available efficiency is 98% AFUE.
- Hydronic systems represent about 6% of all U.S. residential heating systems.
- The bulk of U.S. boiler sales is for non-condensing boilers, primarily manufactured in North America. These are typically high-mass systems whose heat exchangers are made of iron or steel and which have simple on/off burners.
- 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).

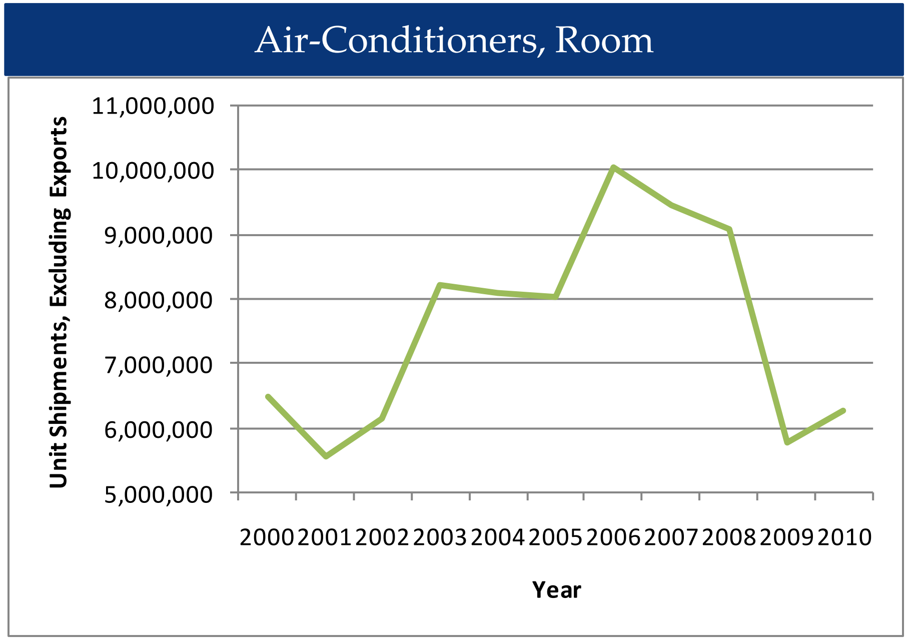
Performance / Cost Characteristics » Residential Room Air Conditioners

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
EER	8.7	9.8	9.8	10.8	11.5	11.0	11.5	11	13	11.2	13
Average Life (yrs)	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13
Retail Equipment Cost ($)	190-265	230-300	230-300	250-320	400-470	250-320	400-470	250-320	480-550	250-320	480-550
Total Installed Cost ($)	190-265	230-300	230-300	250-320	400-470	250-320	400-470	250-320	480-550	250-320	480-550
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- The residential room air conditioners analyzed in this study are window room air conditioners.
- The ENERGY STAR criteria requires an EER of 10.8, which also represents the most common efficiency on the market.
- According to the AHAM Directory of Certified Products, the most efficient product on the market has an EER of 11.5. Based on the DOE Building Technologies Program (BTP) R&D, it is anticipated that units may reach an EER of 13.0 by 2030.
- A wider range of costs reflects a variation in the marketplace
- It is assumed that the homeowners will install their own room air conditioner.
- 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.
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards will be updated in 2014 from 9.8 to 11.0

Since the last analysis was performed in 2007, there has been a decrease in room air conditioner shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Central Air Conditioners

DATA	2005	2010	2010			2020		2030		2035	
	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	10.2	13	13.7	14.5	24	14	24	14.5	24	15	24
Average Life (yrs)	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19
Retail Equipment Cost ($)	1000-1500	2000-2500	2050-3750	2500-4200	6500-13500	2500-4200	6500-13500	2500-4200	6500-13500	2750-4250	6500-13500
Total Installed Cost ($)	2500-2700	2500-3500	2550-4750	3000-5200	7000-14500	3000-5200	7000-14500	3000-5200	7000-14500	3250-5250	7000-14500
Annual Maintenance Cost ($)	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120

- The current NAECA minimum SEER is 13.0.
- The ENERGY STAR criteria is 14.5 SEER and 12 EER for split systems, which is close to the efficiency of the typical product on the market.
- Energy efficiency is driven by several factors:
  - Heat exchanger (surface area, number of tube rows, tube & fin vs. micro-channel)
  - Compressor choices (i.e., type of compressor 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, TXV, or EEV expansion devices)

  As an example, above 16 SEER, units typically have very large heat exchangers, an ECM evaporator fan motor and a two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, but does not affect the EER. Manufacturers have used the SEER boost to develop high-SEER condensing units with smaller enclosures.
- Efficiency levels beyond 21 SEER are made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and EEVs.

Performance / Cost Characteristics » Residential Air Source Heat Pumps

DATA	2005	2010	2010			2020		2030		2035	
	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
HSPF (Heating)	6.8	8	8	8.2	10.7	8.1	10.8	8.3	10.9	8.5	11
SEER (Cooling)	10	14	14	14.5	22	14.2	23	15	24	15.3	25
Average Life (yrs)	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16
Retail Equipment Cost ($)	3500-4000	4000-4500	4000-4500	5500-6000	7000-7500	4700-5200	7100-7600	6000-6500	7200-7700	6200-6700	7300-7800
Total Installed Cost ($)	4500-5500	4400-5500	4400-5500	5900-7000	7400-8500	5100-6200	7500-8600	6400-7500	7800-8700	6600-7700	7700-8800
Annual Maintenance Cost ($)	120	120	120	120	120	120	120	120	120	120	120

- The NAECA minimum HSPF is 7.7 and the minimum SEER is 13.
- The ENERGY STAR criteria states a minimum HSPF of 8.2 and a minimum SEER of 14.5.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, resistance heat is supplemented; however, when the 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.
- High efficiency cooling does not necessarily lead to high efficiency heating. The range of SEER/HSPF combinations is very broad.

Final

Performance / Cost Characteristics » Residential Ground Source Heat Pumps

DATA	2005	2010	2010			2020		2030		2035	
	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	3.1	3.5	4.3	3.1	5	3.1	5	3.1	5
EER (Cooling)	12	13.4	13.4	16.1	23	13.4	30	13.4	30	13.4	30
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	4000-6000	4000-6000	4000-6000	5000-7000	7000-9000	4000-6000	7000-9000	4000-6000	7000-9000	4000-6000	7000-9000
Total Installed Cost ($)	9000-11000	9000-11000	9000-11000	10000-12000	12000-14000	9000-11000	12000-14000	9000-11000	12000-14000	9000-11000	12000-14000
Annual Maintenance Cost ($)	70	70	70	70	70	70	70	70	70	70	70

- There are currently 19 ground source heat pump manufacturers in the US.
- Heating COP does not correlate with cooling EER (coefficient of determination, R^2 = 0.62). The highest efficiency GSHP is the Envision by WaterFurnace International, Inc. (30 EER & 5.0 COP).
- 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.
- Electronically commutated motors (ECMs) improve performance on high end models.

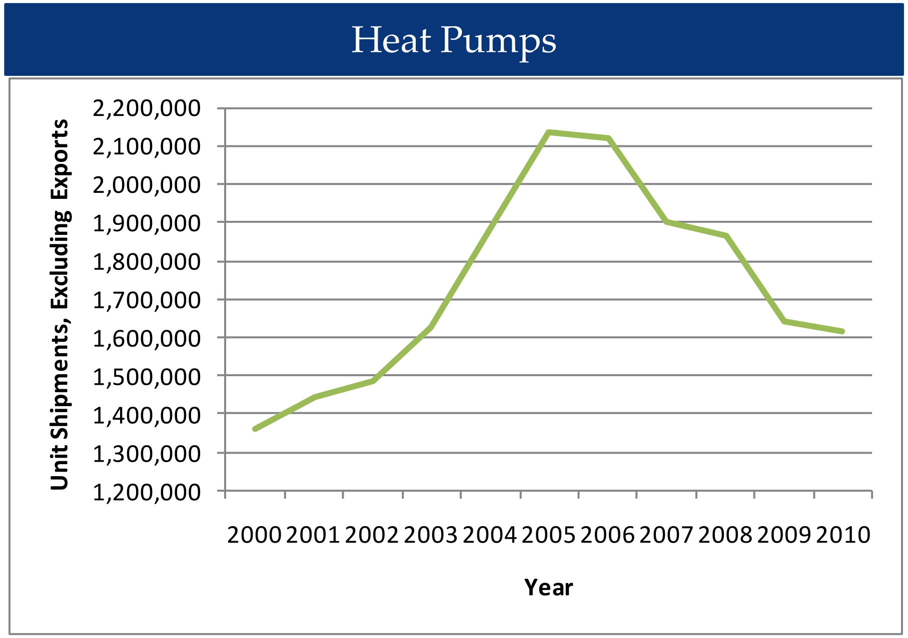
Performance / Cost Characteristics » Residential Gas Heat Pumps

DATA	2005	2010	2010	2020	2030	2035
	Installed Base	Current Standard[1]	Typical	Typical	Typical	Typical
Typical Capacity (kBTU/h)	60	60	60	60	60	60
Heating (GCOP)	1.3	NA	1.3	1.3	1.3	1.3
Cooling (GCOP)	0.6	NA	0.6	0.7	0.7	0.7
Annual Electric Use (kWh/yr)	2000	2000	2000	1500	1500	1500
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($)	6500-7500	6500-7500	6500-7500	6500-7500	6500-7500	6500-7500
Total Installed Cost ($)	8500-9500	8500-9500	8500-9500	8500-9500	8500-9500	8500-9500
Annual Maintenance Cost ($)	150	150	150	150	150	150

[1]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 are not currently covered by NAECA. CEC Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for gas heat pumps, and two residential size units are listed there; Robur and Yazaki. Both units are 5-ton cooling capacity, a size typically associated with larger homes. The Yazaki unit offers cooling only and appears to be available only in Europe at the moment. 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.
- Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market.

Since the last analysis was performed in 2007, there has been a decrease in both air source and ground source heat pump shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Final

Performance / Cost Characteristics » Residential Refrigerator / Freezer

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Capacity (cu. ft.)*	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6
Energy Consumption (kWh/yr)	840	453	475	408	285	475	285	475	285	475	285
Average Life (yrs)	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19
Retail Equipment Cost ($)	200-400	400-500	400-500	425-525	800-1200	400-500	800-1200	400-500	800-1200	400-500	800-1200
Total Installed Cost ($)	200-500	400-600	400-600	425-625	800-1300	400-600	800-1300	400-600	800-1300	400-600	800-1300
Annual Maintenance Cost ($)**	6	6	6	6	6	6	6	6	6	6	6

* Capacity is the nominal volume (not adjusted volume)
**Annual Maintenance Cost is negligible

- The current NAECA standard for a typical top-mount refrigerator/freezers is 453 kWh/yr while the typical top-mount refrigerator/freezer currently consumes approximately 475 kWh/yr. The best available top-mount refrigerator/freezer uses 285 kWh/yr.
- According to NAECA standards, for a refrigerator/freezer to qualify as ENERGY STAR, it must be at least 20% more energy efficient than the minimum Federal government standard. This equates to an annual energy use of approximately 408 kWh/yr.
- EISA 2007 requires that DOE publish a final rule no later than December 31, 2010 to determine whether to amend the standards in effect for products manufactured on or after January 1, 2014.
- A wider range of costs reflects a variation in the marketplace
- Improvement opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan 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)
- All manufacturers are using at least some of these technologies in an attempt to reach ENERGY STAR qualification.
- According to the ACEEE – AHAM Consensus Agreement, the Joint Stakeholders agree to jointly petition DOE to initiate a rulemaking by January 1, 2012 to be completed by December 31, 2012 to revise the test procedure for refrigerators/freezers to incorporate measured ice maker energy use. Additionally, the Federal standards will be revised in 2014. For top-mount units without ice makers, the standard is represented by 7.35 AV+ 207.0 and for units with ice makers, the standard is represented by 7.65 AV+ 267.0, where AV is the adjusted volume.[1]

[1]Adjusted Volume (AV) for refrigerators is calculated as follows: AV = (Fresh Volume) + 1.63 x (Freezer Volume). When the new rulemaking is published, the formula for AV will become: AV = (Fresh Volume) + 1.76 x (Freezer Volume).

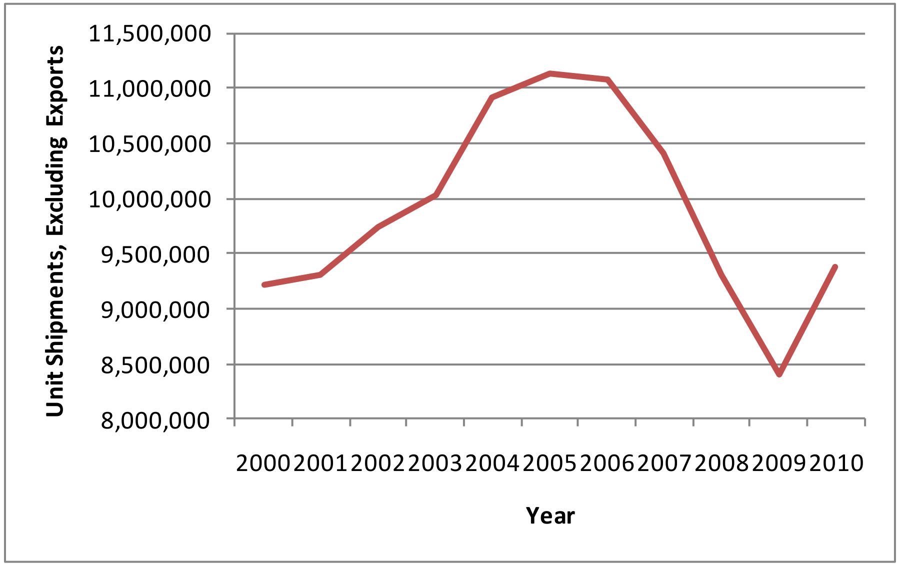
- This analysis focuses on top-mount refrigerator-freezers because they have the largest market share of all refrigerator-freezer product classes at 50.6%*. The market share for bottom- and side-mount refrigerator-freezers are as follows:
  - Bottom-mount: 12.5%*
  - Side-mount: 26.9%*
- When looking at all product classes, the energy consumption ranges from approximately 790 kWh/yr** to 230 kWh/yr, with the typical energy consumption at the current standard level.
- There are also significant differences in average equipment cost across the product classes:
  - Top-mount: $400-$1500
  - Bottom-mount: $800-$2800
  - Side-mount: $1000-$1800

* 2008 data from Technical Support Document
** A product operating at this level is less efficient than the current Federal standard

Sources: CEC, AHAM, Technical Support Document

Since the last analysis was performed in 2007, there has been a decrease in standard residential refrigerator / freezer shipments.

Refrigerators, Standard



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

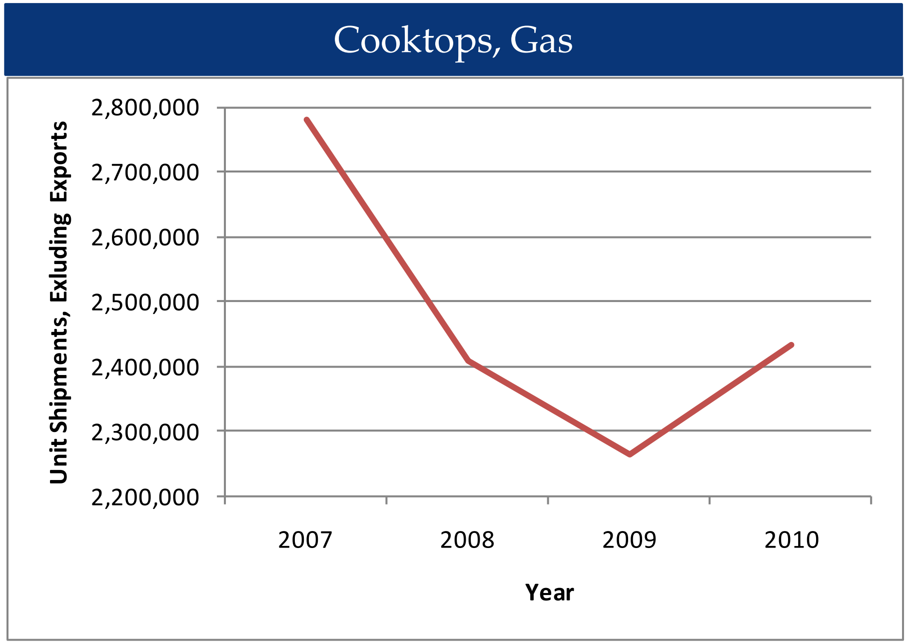
Performance / Cost Characteristics » Residential Natural Gas Cooktops

DATA	2005	2010		2020		2030		2035	
	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12
Cooking Efficiency (%)	38	39.9	42	39.9	42	39.9	42	39.9	42
Average Life (yrs)	17-18	17-18	17-18	17-18	17-18	17-18	17-18	17-18	17-18
Retail Equipment Cost ($)	225-300	250-350	375-450	250-350	375-450	250-350	375-450	250-350	375-450
Total Installed Cost ($)	275-350	300-400	425-500	300-400	425-500	300-400	425-500	300-400	425-500
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- Efficiency levels vary little for cooktops on the market.
- The typical model on the market has a cooking efficiency of 39.9% and the highest efficiency model on the market has a cooking efficiency of 42%.

Since the last analysis was performed in 2007, there has been a decrease in residential natural gas cooktop shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Data is unavailable for dates prior to 2007.

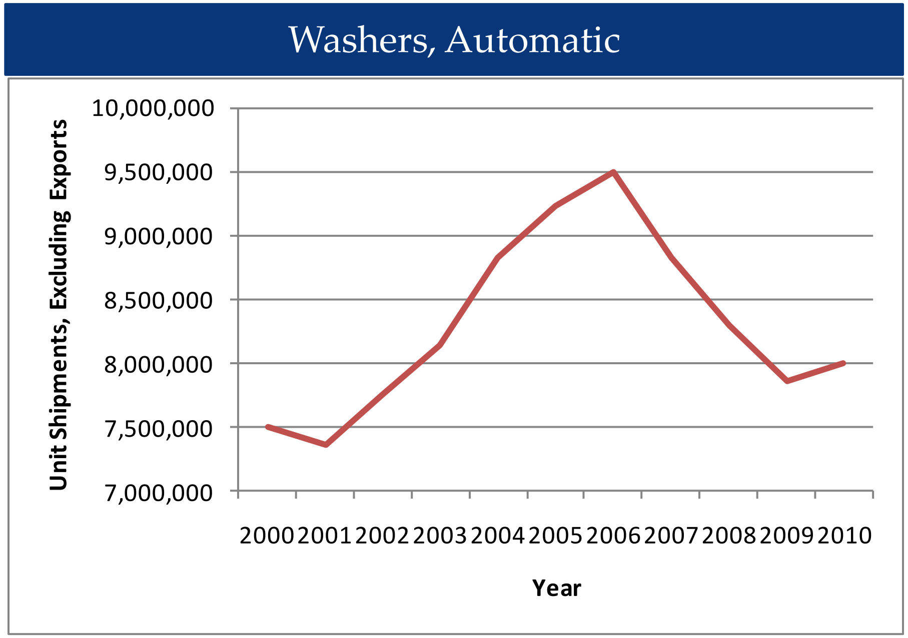
Performance / Cost Characteristics » Residential Clothes Washers

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft3)	3	3.2	3	2.7	3.5	2.7	3.5	2.7	3.5	2.7	3.5
Modified Energy Factor (ft3/kWh/cycle)	2	1.26	2	2	3.88	2.2	3.88	2.2	3.88	2.2	3.88
Average Life (yrs)	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15
Water Consumption (gal/cycle)	14	30	11	20	13	11	13	11	13	11	13
Hot Water Energy (kWh/cycle)	0.4	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Machine Energy (kWh/cycle)	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dryer Energy (kWh/cycle)	0.7	1.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Retail Equipment Cost ($)	550-700	360-440	550-700	550-700	800-900	550-700	850-950	550-700	850-950	550-700	850-950
Total Installed Cost ($)	650-800	460-540	650-800	650-800	900-1000	650-800	950-1050	650-800	950-1050	650-800	950-1050
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- This analysis examined front-loading residential clothes washers. It should be noted that there are high efficiency top-loading residential clothes washers on the market as well, though front-loaders are inherently more efficient than top-loaders.
- The current standard for standard-size front-loading and top-loading clothes washers is a modified energy factor (MEF) of 1.26. The ENERGY STAR criteria is 2 MEF; however, the most common front-loading models on the market exceed the ENERGY STAR criteria and have a MEF of 2.2.
- Only clothes washers with capacities of greater than 1.6 ft^3 are eligible to earn ENERGY STAR.
- Energy efficiency improvement opportunities include:
  - Higher efficiency motors and higher spin speeds
  - Better load sensing (soiling and size and type of load)
  - Better controls / greater number of wash programs
- The annual maintenance cost for residential clothes washers is negligible.
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards front-loading residential clothes washers will be updated in 2015 (and will remain current through the 2018 standard updates) to a MEF of 2.2 and a water factor (WF) of 4.5

Since the last analysis was performed in 2007, there has been a decrease in automatic residential clothes washer shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Clothes Dryers

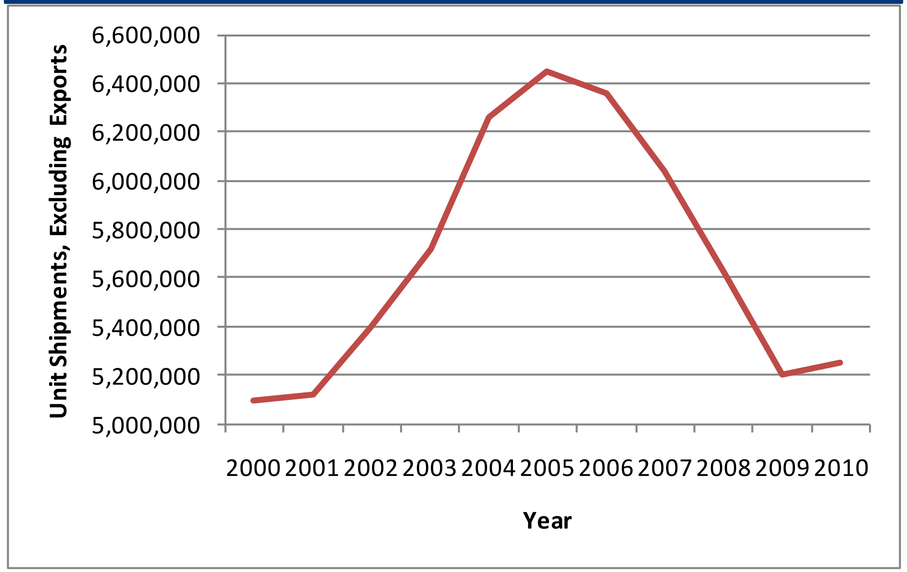
DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7
EF (lb/kWh)	electric: 3.01 gas: 2.67	electric: 3.01 gas: 2.67	electric: 3.1 gas: 2.75	gas: 2.85	electric: 3.16 gas: 3.02	electric: 3.17 gas: 2.81	electric: 4.51 gas: 3.02	electric: 3.17 gas: 2.81	electric: 4.51 gas: 3.02	electric: 3.17 gas: 2.81	electric: 4.51 gas: 3.02
Average Life (yrs)	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19
Retail Equipment Cost ($)	electric: 400-500 gas: 450-550	electric: 400-500 gas: 450-550	electric: 450-550 gas: 550-600	gas: 650-750	electric: 550-650 gas: 850-950	electric: 450-550 gas: 550-600	electric: 650-750 gas: 850-950	electric: 450-550 gas: 550-600	electric: 650-750 gas: 850-950	electric: 450-550 gas: 550-600	electric: 650-750 gas: 850-950
Total Installed Cost ($)	electric: 500-600 gas: 600-700	electric: 500-600 gas: 600-700	electric: 675-775 gas: 700-800	gas: 800-900	electric: 700-800 gas: 950-1050	electric: 675-775 gas: 700-800	electric: 900-1000 gas: 950-1050	electric: 675-775 gas: 700-800	electric: 900-1000 gas: 950-1050	electric: 675-775 gas: 700-800	electric: 900-1000 gas: 950-1050
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

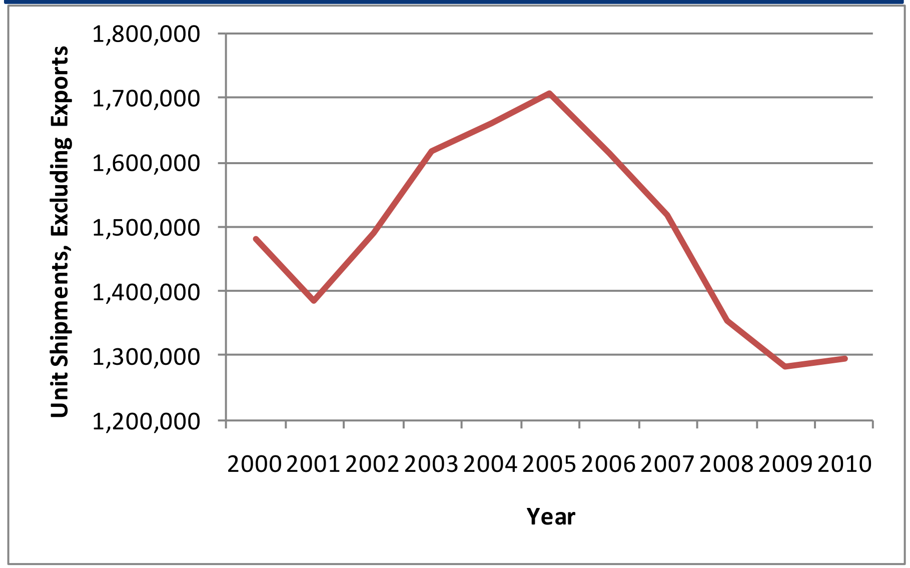
- The test procedure for residential clothes dryers was recently amended to include a new efficiency metric, combined energy factor (CEF), which adds a measure of standby/off-mode power. Although EF and CEF are both expressed in lbs/kWh of energy use, they can not be compared side-by-side since they are calculated differently.
- There are both gas and electric models of clothes dryers on the market:
  - For gas clothes dryers, the standard efficiency is 2.67 lb/kWh (CEF = 3.14 lb/kWh)
  - For electric clothes dryers, the standard efficiency is 3.01 lb/kWh (CEF = 3.55 lb/kWh)
- Improvement opportunities include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Heat pump (for electric clothes dryers): heat pump residential clothes dryers are currently available in Europe and are anticipated to make it to the US market by 2020.
  - Better control systems for cycle termination (not reflected per the current test procedure, however)
- No ENERGY STAR incentives currently exist to motivate manufacturers to adapt to existing energy efficiency opportunities. This is an especially important factor for heat pumps due to the high initial cost and the potential reliability issues.
- The high electric clothes dryer EF value of 4.51 represents a product with heat pump technology, which is planned to enter the market around 2020.
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards will be revised in 2015.
  - For gas clothes dryers, the standard efficiency will be 2.81 lb/kWh (CEF = 3.30 lb/kWh)
  - For electric clothes dryers, the standard efficiency will be 3.17 lb/kWh (CEF = 3.73 lb/kWh)

Since the last analysis was performed in 2007, there has been a decrease in residential clothes dryer shipments.

Dryers, Electric



Dryers, Gas



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Final

Performance / Cost Characteristics » Residential Dishwashers

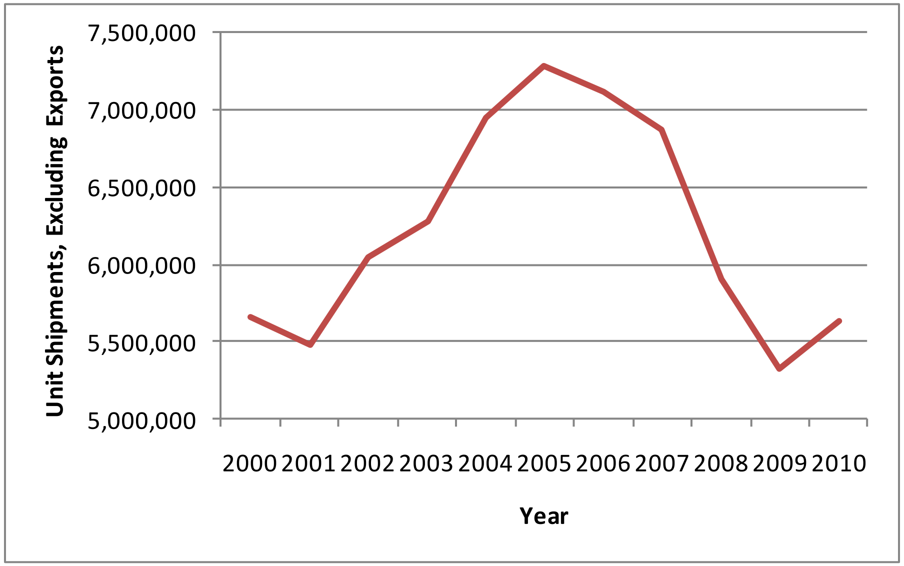
DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Annual Use (kWh/yr)	720	355	355	324	190	307	190	307	190	307	190
Efficiency (cycle/kWh)	0.30	0.61	0.61	0.66	1.13	0.70	1.13	0.70	1.13	0.70	1.13
Annual Hot Water Energy Use (kWh/yr)	286	261	261	185	100	180	100	180	100	180	100
Average Life (yrs)	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13
Retail Equipment Cost ($)	200-300	200-300	200-300	300-1200	900	200-300	900	200-300	900	200-300	900
Total Installed Cost ($)	300-400	300-400	300-400	400-1300	1200	300-400	1200	300-400	1200	300-400	1200
Annual Maintenance Cost ($)	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- The current standard was established by the EISA 2007 amendments to EPCA and stipulates a maximum of 355 kWh/yr of energy use and 6.5 gal/cycle of water use for standard sized dishwashers, which typically handle eight place settings plus six serving pieces.
- The current ENERGY STAR qualifying criteria require a maximum of 324 kWh/yr of energy use and 5.8 gal/cycle of water use for standard sized dishwashers.
- We are assuming that a typical residential dishwasher completes 215 cycles/year
- The most efficient dishwasher has an annual energy use of 190 kWh/yr, but at a high retail price and very small market share. Typical high efficiency units have an EF closer to the current standard.
- Dishwasher annual energy use is based on the U.S. DOE test procedure. This procedure is based on total energy use - including motor, dryer, booster heater (if present), and for hot water required from the water heater. The previous U.S. DOE test procedure was based on a usage estimate of 322 cycles per year, but as of September 2003 a new test procedure of 215 cycles per year was implemented.
- 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
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards will be revised in 2013. The updated standard stipulates a maximum of 307 kwh/year and 5.0 gal/cycle of water use.

Since the last analysis was performed in 2007, there has been a decrease in residential dishwasher shipments.

Dishwashers, Built-In



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Commercial Gas-Fired Furnaces

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	400	400	400	400	400	400	400	400	400	400	400
Combustion Efficiency (%)**	76	77	80	80	82	80	90	80	91	80	93
Average Life (yrs)	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20
Retail Equipment Cost ($)	1800-2000	2000-2400	2700-2900	2700-2900	2900-3200	2700-2900	3360-3660	2700-2900	3830-4130	2700-2900	4060-4360
Total Installed Cost ($)	2800-3000	3000-3500	3050-3275	3050-3275	3275-3625	3050-3275	3735-4035	3050-3275	4205-4505	3050-3275	4435-4735
Annual Maintenance Cost ($)	300	300	300	300	300	300	300	300	300	300	300

*Capacity is *input*
** Gas furnaces less than 225,000 Btu/hr are rated by AFUE. Furnaces larger than 225,000 Btu/hr must been an 80% combustion efficiency.

- EPACT standard for a gas-fired furnace is 80% combustion efficiency at maximum rated capacity.
- According to the U.S. DOE, combustion efficiency is a measure of how effectively the heat content of a fuel is transferred into usable heat.
- 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 is based on two cleanings per year.

Performance / Cost Characteristics » Commercial Oil-Fired Furnaces

DATA	2003	2007	2010	2010	2020	2030	2035
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (kBTU/h)*	400	400	400	400	400	400	400
Thermal Efficiency (%)	81	81	81	82	82	82	82
Average Life (yrs)	17-20	17-20	17-20	17-20	17-20	17-20	17-20
Retail Equipment Cost ($)	3000-3600	3000-3600	3000-3600	3600-3700	3600-3700	3600-3700	3600-3700
Total Installed Cost ($)	3575-4125	3575-4125	3575-4125	4125-4225	4125-4225	4125-4225	4125-4225
Annual Maintenance Cost ($)	300	300	300	300	300	300	300

* Capacity is *input*

- Commercial oil-fired furnaces with a capacity of 225,000 BTU/h or more must meet a thermal efficiency standard of 81% as stipulated in ASHRAE Standard 90.1-2007. The ASHRAE standard also mandates that furnaces that are not within the conditioned space must not have jacket losses that exceed 0.75% of the input rating.
- According to the U.S. DOE, thermal efficiency is interpreted as what is commonly known as "combustion efficiency" in other contexts, *i.e., 100 percent minus percent* flue loss
- The maintenance cost is based on two cleanings per year.

Performance / Cost Characteristics » Commercial Electric Boilers

DATA	2003	2007	2010	2020	2030	2035
	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 ($)	6000-7000	6000-7000	6000-7000	6000-7000	6000-7000	6000-7000
Total Installed Cost ($)	7500-9000	7500-9000	7500-9000	7500-9000	7500-9000	7500-9000
Annual Maintenance Cost ($)	100-150	100-150	100-150	100-150	100-150	100-150

* 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).

Performance / Cost Characteristics » Commercial Gas-Fired Boilers

DATA	2003	2007	2010	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	800	800	800	800	800	800	800	800	800	800	800	800
Combustion Efficiency (%)	76	77	80	80	90	98	80	98	82	98	82	98
Average Life (yrs)	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30
Retail Equipment Cost ($)	5000-6000	7000-9000	9000-11000	9000-11000	13500-16500	22500-27500	13500-16500	22500-27500	13500-16500	22500-27500	13500-16500	22500-27500
Total Installed Cost ($)	12000-13000	14000-16000	16000-18000	16000-18000	20500-23500	29500-34500	20500-23500	29500-34500	20500-23500	29500-34500	20500-23500	29500-34500
Annual Maintenance Cost ($)	450	450	450	450	450	450	450	450	450	450	450	450

* Capacity is *output*

- The current requirement for gas-fired boilers is a minimum combustion efficiency of 80% at the maximum rated capacity.
- 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.
- Since the last ASHRAE standard was published, ASHRAE has changed the metric for stating the efficiency of most classes of commercial boilers, excluding large oil hot water and large gas hot water boilers. Federal standards express efficiency in terms of combustion efficiency while efficiency levels in ASHRAE 90.1-2007 are expressed in terms of thermal efficiency. The thermal efficiency descriptor, as used in Standard 90.1-2007, accounts for jacket losses as well as flue losses, while combustion efficiency only accounts for flue losses.
- Small, gas-fired, hot water, commercial packaged boilers (input capacity between 300,000 and 2,500,000 Btu/hr) are the largest commercial packaged boiler equipment class in the market.

Performance / Cost Characteristics » Commercial Oil-Fired Boilers

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Thermal Efficiency (%)	79	80	83	83.5	98	83.5	98	83.5	98	83.5	98
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	11000-12000	11000-12000	12300-13400	12300-13400	24000-26000	12300-13400	24000-26000	12300-13400	24000-26000	12300-13400	24000-26000
Total Installed Cost ($)	15000-16000	15000-16000	16600-17700	16600-17700	30000-35000	16600-17700	30000-35000	16600-17700	30000-35000	16600-17700	30000-35000
Annual Maintenance Cost ($)	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155

* Capacity is *output*

- Commercial oil-fired boilers must meet a thermal efficiency standard of 83%.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.
- Since the last ASHRAE standard was published, ASHRAE has changed the metric for stating the efficiency of commercial boilers. Federal standards expresses efficiency in terms of combustion efficiency while efficiency levels in ASHRAE 90.1-2007 are expressed in terms of thermal efficiency. The thermal efficiency descriptor, as used in Standard 90.1-2007, accounts for jacket losses as well as flue losses, while combustion efficiency only accounts for flue losses.

Performance / Cost Characteristics » Commercial Gas-Fired Chillers[1]

DATA	2003		2007		2010		2020		2030		2035	
	Installed Base: Absorp-tion	Installed Base: Engine - Driven	Installed Base: Absorp-tion	Installed Base: Engine - Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven
Typical Capacity (tons)*	150-1500	400	150-1500	400	150-1500	400	150-1500	400	150-1500	400	150-1500	400
COP	1.0	1.5	1.0	1.5	1.1	1.8	1.2	1.8	1.3	1.8	1.3	1.8
Average Life (yrs)	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost ($/ton)	600-750	700-800	600-750	700-800	600-750	700-800	600-750	700-800	600-750	700-800	600-750	700-800
Total Installed Cost ($/ton)	750-900	850-950	750-900	850-950	750-900	850-950	750-900	850-950	750-900	850-950	750-900	850-950
Annual Maintenance Cost ($/ton)	15-30	35-45	15-30	35-45	15-30	35-45	15-30	35-45	15-30	35-45	15-30	35-45

* Capacity is *output*

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

- 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 another 50% beyond that of a double effect chiller. Prototype direct-fired triple effect absorption chillers have been tested by York and Trane, but are not commercially available. 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 on site for useful purposes.

Performance / Cost Characteristics » Commercial Centrifugal Chillers

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	350	350	350	350	350	350	350	350	350	350	350
Efficiency [full-load/IPLV] (kW/ton[1])	0.70 / 0.67	0.70 / 0.67	0.58 / 0.55	0.56 / 0.45	0.48 / 0.39	0.56 / 0.45	0.46 / 0.36	0.56 / 0.45	0.46 / 0.36	0.56 / 0.45	0.46 / 0.36
COP [full-load/IPLV] [1]	5.0 / 5.2	5.0 / 5.2	6.1 / 6.4	6.3 / 7.8	7.3 / 9.0	6.3 / 7.8	7.6 / 9.7	6.3 / 7.8	7.6 / 9.7	6.3 / 7.8	7.6 / 9.7
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($/ton)	250-350	250-350	250-350	300-400	400-500	300-400	400-500	300-400	400-500	300-400	400-500
Total Installed Cost ($/ton)	300-450	300-450	300-450	350-500	450-600	350-500	450-600	350-500	450-600	350-500	450-600
Annual Maintenance Cost ($/ton)	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30

* 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]2010 typical efficiency based on ASHRAE 90.1-2007.
[3]2010 mid efficiency based on FEMP recommendations.

- 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.
- The ASHRAE 90.1-2007 minimum efficiency requirements for centrifugal chillers greater than 300 tons capacity are the same as for 90.1-2004 (COP=6.10 full-load; COP=6.40 IPLV).
- The Federal Energy Management Program (FEMP) recommends a full -load efficiency of 0.56 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.45 kW/ton for chillers with seasonally variable loads.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed compressors
  - 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.

Performance / Cost Characteristics » Commercial Reciprocating Chillers

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200
Efficiency [full-load/IPLV] (kW/ton[1])	1.26 / 1.15	1.26 / 1.15	1.26 / 1.15	1.23 / 0.90	1.00 / 0.80	1.23 / 0.90	1.00 / 0.80	1.23 / 0.90	1.00 / 0.80	1.23 / 0.90	1.00 / 0.80
COP [full-load/IPLV] [1]	2.80 / 3.05	2.80 / 3.05	2.80 / 3.05	2.86 / 3.91	3.52 / 4.40	2.86 / 3.91	3.52 / 4.40	2.86 / 3.91	3.52 / 4.40	2.86 / 3.91	3.52 / 4.40
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	400-500	400-500	400-500	450-550	500-600	450-550	500-600	450-550	500-600	450-550	500-600
Total Installed Cost ($/ton)	475-600	475-600	475-600	525-650	575-700	525-650	575-700	525-650	575-700	525-650	575-700
Annual Maintenance Cost ($/ton)	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40

* 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]2010 typical efficiency based on ASHRAE 90.1-2007.
[3]2010 mid efficiency based on FEMP recommendations.

- 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 chiller market share.
- 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).
- The ASHRAE 90.1-2007 minimum efficiency requirements for air-cooled reciprocating chillers are the same as for 90.1-2004 (COP=2.80 full-load; COP=3.05 IPLV).
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (published 11/03) include a full -load efficiency of 1.23 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.90 kW/ton for chillers with seasonally variable loads.
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Performance / Cost Characteristics » Commercial Screw Chillers

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300
Efficiency [full-load/IPLV] (kW/ton[1])	1.26 / 1.15	1.26 / 1.15	1.26 / 1.15	1.22 / 0.94	0.94 / 0.79	1.22 / 0.94	0.94 / 0.79	1.22 / 0.94	0.94 / 0.79	1.22 / 0.94	0.94 / 0.79
COP [full-load/IPLV] [1]	2.80 / 3.05	2.80 / 3.05	2.80 / 3.05	2.88 / 3.74	3.02 / 4.45	2.88 / 3.74	3.02 / 4.45	2.88 / 3.74	3.02 / 4.45	2.88 / 3.74	3.02 / 4.45
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	300-400	300-400	300-400	350-450	400-500	350-450	400-500	350-450	400-500	350-450	400-500
Total Installed Cost ($/ton)	375-500	375-500	375-500	400-525	450-575	400-525	450-575	400-525	450-575	400-525	450-575
Annual Maintenance Cost ($/ton)	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50

* 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]2010 typical efficiency based on ASHRAE 90.1-2007.
[3]2010 mid efficiency based on FEMP recommendations.

- 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).
- The ASHRAE 90.1-2007 minimum efficiency requirements for air-cooled screw chillers are the same as for 90.1-2004 (COP=2.80 full-load; COP=3.05 IPLV).
- The most recent Federal Energy Management Program (FEMP) recommendations for 150+ ton screw chillers (published 12/10) include a full -load efficiency of 1.22 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.94 kW/ton for chillers with seasonally variable loads.
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Improved heat-exchangers

Performance / Cost Characteristics » Commercial Scroll Chillers

DATA	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	20-140	20-140	20-140	20-140	20-140	20-140
Efficiency [full-load/IPLV] (kW/ton[1])	1.26 / 1.15	1.26 / 1.15	1.19/0.80	1.19/0.80	1.19/0.80	1.19/0.80
COP [full-load/IPLV] [1]	2.80 / 3.05	2.80 / 3.05	2.96/4.40	2.96/4.40	2.96/4.40	2.96/4.40
Average Life (yrs)	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	300-400	300-400	350-450	350-450	350-450	350-450
Total Installed Cost ($/ton)	400-500	400-500	450-550	450-550	450-550	450-550
Annual Maintenance Cost ($/ton)	35-50	35-50	35-50	35-50	35-50	35-50

* 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.

- 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).
- The most recent Federal Energy Management Program (FEMP) recommendations for <150 ton scroll chillers (published 12/10) include a full -load efficiency of 1.19 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.80 kW/ton for chillers with seasonally variable loads.
- The highest efficiency screw chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Performance / Cost Characteristics » Commercial Rooftop Air Conditioners

DATA	2003	2007	2010	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	Mid-Range	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)	9.2	10.1	11.2	11.2	12	13.9	11.5	13.9	11.5	13.9	11.5	13.9
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3300-4500	4000-5100	5500-6500	5500-6500	7000-8000	20000-21000	5500-6500	20000-21000	5500-6500	20000-21000	5500-6500	20000-21000
Total Installed Cost ($)	5000-6200	5700-7000	7500-8500	7500-8500	9000-10000	22000-24000	7500-8500	22000-24000	7500-8500	22000-24000	7500-8500	22000-24000
Annual Maintenance Cost ($)	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300

* Capacity is *input*

- Effective January 1, 2010, the minimum efficiency standards for commercial rooftop air conditioners are as follows:

Air-Cooled Products	Efficiency Standards
≥ 65 - < 135 kBtu/h	11.2/11.0 EER
≥ 135 - < 240 kBtu/h	11.0/10.8 EER

- Above, two EERs are listed. The first refers to systems with electric resistance heat or no heating, and the second refers to systems with all other heating system types that are integrated into the unitary equipment.
- This analysis examined 90,000 BTU/h (7.5 ton), cooling only units.
- 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.

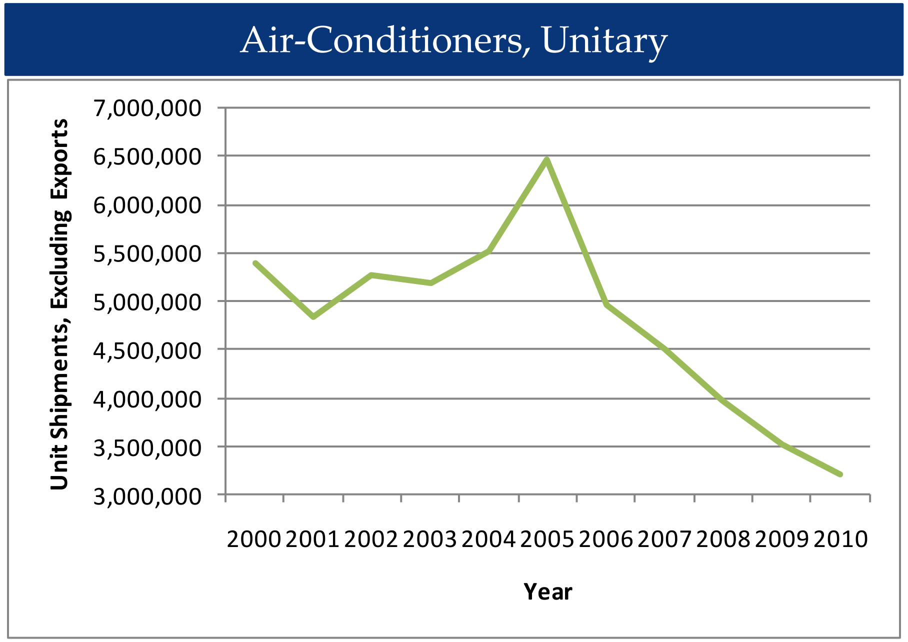
Performance / Cost Characteristics » Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners

DATA	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	25	25	11	11	11	11
Heating COP	NA	NA	1.4	1.4	1.4	1.4
Cooling COP	0.7	0.7	1.1	1.1	1.1	1.1
Average Life (yrs)	30	30	30	30	30	30
Retail Equipment Cost ($/ton)	775-835	775-835	3200-3300	2000-2100	1000-1100	1000-1100
Total Installed Cost ($/ton)	1200-1300	1200-1300	3700-3800	2500-2600	1500-1600	1500-1600
Annual Maintenance Cost ($)	55	55	55	55	55	55

* Capacity is *output*

- 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 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 currently estimated at less than 5,000 units per year. Nextaire expects the cost of their 11-ton unit to drop to approximately $12,000 within the next 15 years as a result of increasing sales volume which will allow more production automation and reduced manufacturing cost.

Since the last analysis was performed in 2007, there has been a decrease in unitary (rooftop) air conditioner shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

This data includes both residential and commercial units. It should be noted that the vast majority of rooftop air conditioners are residential, not commercial.

Performance / Cost Characteristics » Commercial Rooftop Heat Pumps

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)	9.3	9.8	11.0/ 10.8**	11.0	12.0	11	12	11	12	11	12
COP (Heating)	3.1	3.2	3.3	3.3	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
Retail Equipment Cost ($)	3500-4500	4000-5000	5000-6000	5000-6000	5500-6500	5000-6000	5500-6500	5000-6000	5500-6500	5000-6000	5500-6500
Total Installed Cost ($)	5000-6500	6000-7100	6500-7300	6500-7300	7900-9500	6500-7300	7900-9500	6500-7300	7900-9500	6500-7300	7900-9500
Annual Maintenance Cost ($)	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150

* Capacity is *output*

** The first EER refers to systems with electric resistance heat or no heating, and the second refers to systems with all other heating system types that are integrated into the unitary equipment.

- Effective January 1, 2010, the minimum efficiency standards for commercial rooftop heat pumps are as follows:

Air-Cooled Products	Efficiency Standards
≥ 65 - < 135 kBtu/h	11.0./10.8 EER 3.3 COP @47^{0}F
≥ 135 - < 240 kBtu/h	10.6/10.4 EER 3.2 COP @47^{0}F

- Above, two EERs are listed. The first refers to systems with electric resistance heat or no heating, and the second refers to systems with all other heating system types that are integrated into the unitary equipment.

Performance / Cost Characteristics » Commercial Ground Source Heat Pumps

DATA	2003	2007	2010		2020		2030		2035	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	80-100	80-100	80-100	80-100	80-100	80-100	80-100	80-100	80-100	80-100
COP (Heating)	3.4	3.5	3.5	4.9	3.5	4.9	3.5	4.9	3.5	4.9
EER (Cooling)	13.8	14	14	27.8	14	27.8	14	27.8	14	27.8
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	7000-8000	7000-8000	7000-8000	10000-12000	7000-8000	10000-12000	7000-8000	10000-12000	7000-8000	10000-12000
Total Installed Cost ($)	14000-15000	14000-15000	14000-15000	17000-20000	14000-15000	17000-20000	14000-15000	17000-20000	14000-15000	17000-20000
Annual Maintenance Cost (¢/sqft)	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15

* Capacity is *output*

- There is no Federal standard for commercial ground source heat pumps.
- Commercial design applications vary in size, style, and configuration.
- 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 employ groundwater, or surface water such as a pond or lake, but water supply and water quality issues impose limitations on such applications.
- Input and output ratios (i.e., efficiencies) of a given machine change with different entering water temperatures, air flow rates, water flow rates, and relative humidity.
- Useful life is based on the expected life of the compressor. Replacement cost would be less than installed cost, since the ground loop is already in place and would have a useful life much longer than the compressor. A closed-loop system can last up to 50 years.
- There is an expectation that large, central facilities are used in commercial buildings. This is not always the case. Distributed, small units with zonal ducting and controls are almost always more efficient and less expensive.

Performance / Cost Characteristics » Commercial Electric Resistance Heaters

DATA	2010		2020		2030		2035	
	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBTU/h)*	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
Average Life (yrs)	18	18	18	18	18	18	18	18
Retail Equipment Cost ($)	500-700	3400-3800	500-700	3400-3800	500-700	3400-3800	500-700	3400-3800
Total Installed Cost ($)	600-800	3500-3900	600-800	3500-3900	600-800	3500-3900	600-800	3500-3900
Annual Maintenance Cost ($) **	-	-	-	-	-	-	-	-

* Capacity is *output*

** Annual Maintenance Cost is negligible

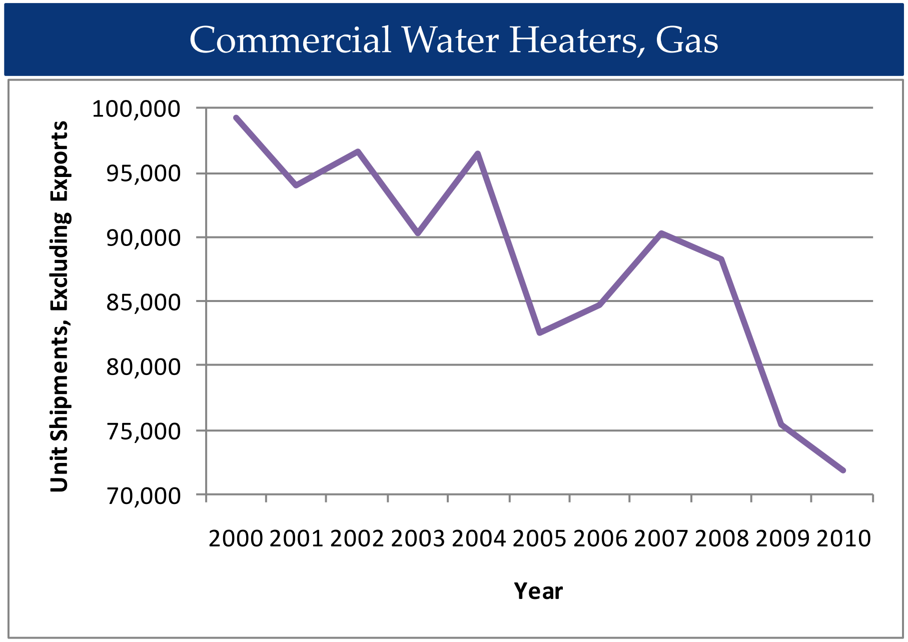
- This analysis examined electric unit heaters
- Electric unit heaters range in capacity from 14 to 170 kBtu/hr, with 17 and 170 kBtu/hr being the most typical units on the market
- Electric resistance heaters are considered 100% efficient because there is no heat loss through ducts or combustion. For this analysis, the efficiency is 98% to account for IR losses and fan inefficiency.
- Installation time and costs are estimated to be minimal

Performance / Cost Characteristics » Commercial Gas-Fired Water Heaters

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical 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	78	80	80	96	80	96	80	96	80	96
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost ($)	2800-4200	3000-4500	3500-4500	3500-4500	5000-6500	3500-4500	5000-6500	3500-4500	5000-6500	3500-4500	5000-6500
Total Installed Cost ($)	3200-4700	3500-5000	4000-5000	4000-5000	5500-7000	4000-5000	5500-7000	4000-5000	5500-7000	4000-5000	5500-7000
Annual Maintenance Cost ($)	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200

- Commercial gas-fired water heaters with a capacity of 75,000 BTU/h or more must meet a thermal efficiency standard of 80% as stipulated in ASHRAE Standard 90.1-2007.
- Baseline units are constructed quite similarly to residential units, though typically at higher storage and/or input capacities.
- High-efficiency, integrated commercial storage water heaters 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 for water heaters consists of sediment and scale removal once or twice per year. Estimated cost for a gas water heater would be $100 per year for one cleaning performed by a plumber.

Since the last analysis was performed in 2007, there has been a decrease in commercial gas-fired water heater shipments.



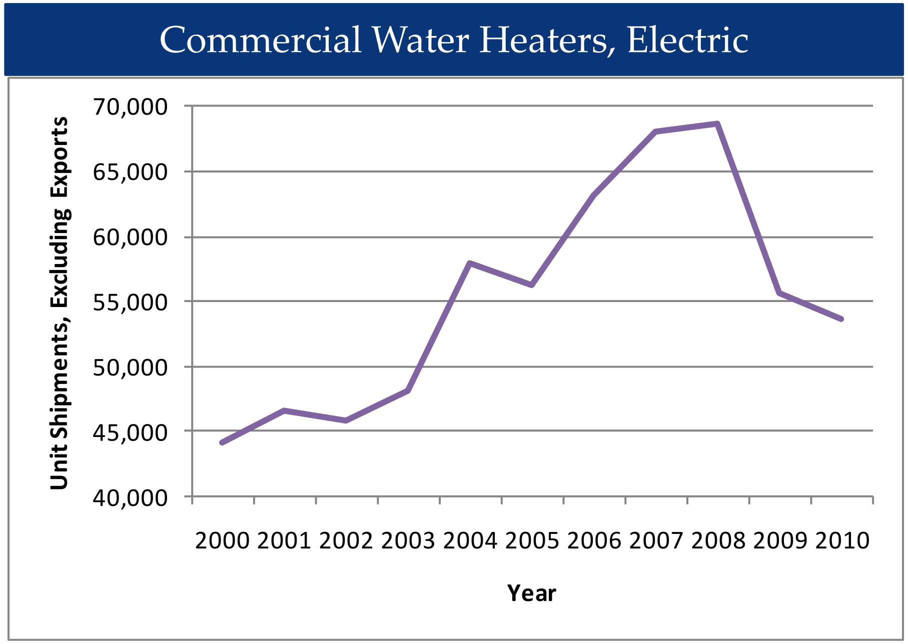
Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Commercial Electric Resistance Water Heaters

DATA	2003	2007	2010	2010	2020	2030	2035
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (gal)	120	120	120	120	120	120	120
Typical Capacity (kW)	45	45	45	45	45	45	45
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (yrs)	14	14	14	14	14	14	14
Retail Equipment Cost ($)	3400-5300	3400-5300	3400-5300	3400-5300	3400-5300	3400-5300	3400-5300
Total Installed Cost ($)	4000-6000	4000-6000	4000-6000	4000-6000	4000-6000	4000-6000	4000-6000
Annual Maintenance Cost ($)	50	50	50	50	50	50	50

- The EPACT standard will remain in effect for electric water heaters.

Since the last analysis was performed in 2007, there has been a decrease in commercial electric resistance water heater shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Commercial Oil-Fired Water Heaters

DATA	2003	2007	2010	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	70	70	70	70	70	70	70	70	70	70	70	70
Typical Input Capacity (kBTU/h)	300	300	300	300	300	300	300	300	300	300	300	300
Thermal Efficiency (%)	78	79	78	80	82	85	80	85	80	85	80	85
Average Life (yrs)	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20
Retail Equipment Cost ($)	4100	4150	4100	4200	4300	4400	4200	4400	4200	4400	4200	4400
Total Installed Cost ($)	4600	4650	4600	4700	4800	4900	4700	4900	4700	4900	4700	4900
Annual Maintenance Cost ($)	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200

- Commercial oil-fired water heaters with a capacity of 105,000 BTU/h or more must meet a thermal efficiency standard of 78% as stipulated in ASHRAE Standard 90.1-2007.
- Condensing commercial water heaters do not exist, the highest attainable efficiency with oil-fired storage water heaters is thus about 86% TE.
- Maintenance for commercial oil-fired water heaters consists of sediment and scale removal once or twice per year.

Performance / Cost Characteristics » Commercial Gas-Fired Instantaneous Water Heaters

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230
Thermal Efficiency (%)	76	77	80	84	85	84	85	84	90	84	90
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	500-750	600-850	800-1000	1250-1300	1350-1450	1250-1300	1350-1450	1250-1300	1350-1450	1250-1300	1350-1450
Total Installed Cost ($)	650-900	750-1000	900-1250	1500-1800	1600-2000	1500-1800	1600-2000	1500-1800	1600-2000	1500-1800	1600-2000
Annual Maintenance Cost ($)	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- Commercial gas-fired instantaneous water heaters with a capacity of 200,000 BTU/h or more must meet a thermal efficiency standard of 80% as stipulated in ASHRAE Standard 90.1-2007.
- Commercial instantaneous systems 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.

Performance / Cost Characteristics » Commercial Electric Booster Water Heaters

DATA	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (kBtu/hr)	100-200	100-200	100-200	100-200	100-200	100-200
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	3-8	3-8	3-8	3-8	3-8	3-8
Retail Equipment Cost ($)	1200-1500	1200-1500	1200-1500	1200-1500	1200-1500	1200-1500
Total Installed Cost ($)	1400-1700	1400-1700	1400-1700	1400-1700	1400-1700	1400-1700
Annual Maintenance Cost ($) *	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

Performance / Cost Characteristics » Commercial Gas Booster Water Heaters

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200
Thermal Efficiency (%)	79	79	80	80	90	82	92	85	95	85	95
Average Life (yrs)	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8
Retail Equipment Cost ($)	5000-6000	5000-6000	5000-6000	5000-6000	10000-11000	5000-6000	10000-11000	5000-6000	10000-11000	5000-6000	10000-11000
Total Installed Cost ($)	5300-6300	5300-6300	5300-6300	5300-6300	10300-11300	5300-6300	10300-11300	5300-6300	10300-11300	5300-6300	10300-11300
Annual Maintenance Cost ($)	150	150	150	150	150	150	150	150	150	150	150

- 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 90.1-2007 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.

Appendix A
Data Sources

Navigant Consulting, Inc.
1801 K Street, NW, Suite 500
Washington, D.C. 20006
(202) 973-2400

www.navigantconsulting.com

Data Sources » Residential Gas-Fired Water Heaters

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (gal)	AHRI / Distributors	EERE			AHRI / Distributors	NCI		
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			Distributors / RS Means 2010			
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Oil Water Heaters

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical / High		
Typical Capacity (gal)	AHRI / Distributors	EERE	AHRI		EERE	NCI		
Energy Factor	AHRI	EERE	AHRI					
Average Life (yrs)	Ka-BOOM!							
Retail Equipment Cost ($)	Distributors	EERE						
Total Installed Cost ($)	Distributors / RS Means 2007	EERE						
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Electric Resistance Water Heaters

SOURCES	2005	2010	2010		2020	2030	2035
	Installed Base	Current Standard	Typical	High	Typical / High		
Typical Capacity (gal)	AHRI / Distributors	EERE			NCI		
Energy Factor	AHRI	EERE	DEER, 2008	AHRI			
Average Life (yrs)	EERE						
Retail Equipment Cost ($)	Distributors	EERE					
Total Installed Cost ($)	Distributors / RS Means 2010	EERE					
Annual Maintenance Cost ($)	EERE						

Data Sources » Residential Heat Pump Water Heaters

SOURCES	2005	2010		2020	2030	2035
	Installed Base	ENERGY STAR	High	Typical / High		
Typical Capacity (gal)	AHRI	EERE		NCI		
Energy Factor	AHRI	ENERGY STAR	AHRI			
Average Life (yrs)	ACEEE, 2007	EERE				
Retail Equipment Cost w/o Tank($)	RS Means 2010 / ACEEE, 2007	EERE / Distributors				
Total Installed Cost w/o Tank ($)	RS Means 2010 / ACEEE, 2007	EERE / Distributors				
Annual Maintenance Cost ($)	EERE					

Data Sources » Residential Instantaneous Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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 (BTU/h)</td><td colspan="5">EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Energy Factor</td><td>Distributors</td><td>EERE</td><td>AHRI</td><td>ENERGY STAR</td><td>Distributors</td></tr>
<tr><td>Average Life (yrs)</td><td>ENERGY STAR</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost w/o Tank ($)</td><td>Distributors /
RS Means 2010</td><td colspan="4">EERE</td></tr>
<tr><td>Total Installed Cost w/o Tank ($)</td><td>DEER, 2008</td><td colspan="4">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>NCI</td><td colspan="4">EERE</td></tr>
</table>

Data Sources » Residential Solar Water Heaters

SOURCES	2005	2010	2010	2020	2030	2035
	Installed Base	Typical	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.

Final

Data Sources » Residential Gas-Fired Furnaces

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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/h)</td><td colspan="2">AHRI</td><td colspan="2">Distributors</td><td>AHRI</td><td colspan="3" rowspan="7">NCI</td></tr>
<tr><td>AFUE (%)</td><td>AHRI</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Electric Consumption (kWh/yr)</td><td>AHRI</td><td colspan="3">EERE</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="4">EERE</td><td>Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE</td></tr>
</table>

Data Sources » Residential Oil-Fired Furnaces

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI			Distributors	AHRI			
AFUE (%)	AHRI	EERE	AHRI	ENERGY STAR	AHRI			
Electric Consumption (kWh)	AHRI	EERE						
Average Life (yrs)	Appliance Magazine, 2005	EERE				NCI		
Retail Equipment Cost ($)	EERE			Distributors	EERE			
Total Installed Cost ($)	EERE							
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Hydronic Heating Systems (Boilers)

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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/h)</td><td colspan="5">EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>AFUE (%)</td><td>AHRI</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="5">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE</td></tr>
</table>

Data Sources » Residential Room Air Conditioners

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBTU/h)	Distributors		AHAM			NCI		
EER	Distributors	Federal Standard	AHAM	ENERGY STAR	AHAM			
Average Life (yrs)	Appliance Magazine, 2005	Ka-BOOM!	Ka-BOOM! / Appliance Magazine, 2010					
Retail Equipment Cost ($)	Distributors							
Total Installed Cost ($)	Distributors							
Annual Maintenance Cost ($)	NCI							

Data Sources » Residential Central Air Conditioners

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBTU/h)	Distributors		EERE			NCI		
SEER	Distributors	Federal Standard	EERE	ENERGY STAR	EERE			
Average Life (yrs)	Appliance Magazine, 2005	EERE						
Retail Equipment Cost ($)	Distributors		EERE / Distributors					
Total Installed Cost ($)	Distributors	EERE						
Annual Maintenance Cost ($)	NCI	EERE						

Data Sources » Residential Air Source Heat Pumps

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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/h)</td><td colspan="2">Distributors / Product Literature</td><td colspan="3">AHRI</td><td colspan="3" rowspan="7">NCI</td></tr>
<tr><td>HSPF (Heating)</td><td>AHRI</td><td>Federal Standard</td><td>AHRI</td><td>ENERGY STAR</td><td>AHRI / CEC</td></tr>
<tr><td>SEER (Cooling)</td><td>AHRI</td><td>Federal Standard</td><td>AHRI</td><td>ENERGY STAR</td><td>AHRI / CEC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors / RS Means 2010 / NCI</td><td colspan="4">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors / RS Means 2010 / NCI</td><td colspan="4">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">NCI</td></tr>
</table>

Data Sources » Residential Ground Source Heat Pumps

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	Mid-Range	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI/SAIC					NCI		
COP (Heating)	SAIC	ASHRAE 90.1-2007, ENERGY STAR						
EER (Cooling)	SAIC	ASHRAE 90.1-2007, ENERGY STAR						
Average Life (yrs)	System life 25 years, ground loop life 50 years (EERE)							
Retail Equipment Cost ($)	Distributors / CEC							
Total Installed Cost ($)	Distributors / CEC							
Annual Maintenance Cost ($)	SAIC							

Data Sources » Residential Gas Heat Pumps

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th>2010</th><th>2020</th><th>2030</th><th>2035</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th colspan="3">Typical</th></tr>
<tr><td>Typical Capacity (kBTU/h)</td><td colspan="3">Manufacturer/SAIC</td><td colspan="3" rowspan="8">SAIC</td></tr>
<tr><td>Heating (GCOP)</td><td>Manufacturer/SAIC</td><td>Manufacturer/SAIC</td><td>Manufacturer/SAIC</td></tr>
<tr><td>Cooling (GCOP)</td><td>Manufacturer/SAIC</td><td>CEC/T24</td><td>Manufacturer/SAIC</td></tr>
<tr><td>Annual Electric Use (kWh/yr)</td><td colspan="3">Manufacturer/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3">SAIC</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="3">SAIC</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3">SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="3">SAIC</td></tr>
</table>

Data Sources » Residential Refrigerator / Freezer

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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>Energy Consumption (kWh/yr)</td><td>Distributors</td><td>ENERGY STAR</td><td>CEC</td><td>ENERGY STAR</td><td>CEC</td><td colspan="3" rowspan="5">NCI</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td>Ka-BOOM!</td><td colspan="3">Ka-BOOM! /
Appliance Magazine, 2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE /
Distributors</td><td colspan="4">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Distributors /
RS Means 2010</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>NCI</td><td colspan="4">EERE</td></tr>
</table>

Data Sources » Residential Natural Gas Cooktops

SOURCES	2005	2010		2020	2030	2035
	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBTU/h)	Distributors / Product Literature	EERE		NCI		
Cooking Efficiency (%)	Distributors / Product Literature	EERE				
Average Life (yrs)	Appliance Magazine, 2005	Appliance Magazine, 2010				
Retail Equipment Cost ($)	EERE					
Total Installed Cost ($)	EERE					
Annual Maintenance Cost ($)	NCI / EERE					

Data Sources » Residential Clothes Washers

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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 (ft3)</td><td>Distributors</td><td colspan="2">CEC</td><td>ENERGY STAR</td><td>CEC</td><td rowspan="10" colspan="3">NCI</td></tr>
<tr><td>Modified Energy Factor (ft3/kWh/cycle)</td><td>Distributors</td><td>Standards</td><td>CEC</td><td>ENERGY STAR</td><td>CEC</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005 / EERE</td><td colspan="4">Ka-BOOM! / Appliance Magazine, 2010</td></tr>
<tr><td>Water Consumption (gal/cycle)</td><td>EERE / Distributors</td><td colspan="4">CEC</td></tr>
<tr><td>Hot Water Energy (kWh/cycle)</td><td colspan="5">EERE / Distributors</td></tr>
<tr><td>Machine Energy (kWh/cycle)</td><td colspan="5">EERE / Distributors</td></tr>
<tr><td>Dryer Energy (kWh/cycle)</td><td colspan="5">EERE / Distributors</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="3">EERE / Distributors</td><td>DEER, 2008</td><td>EERE / Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3">RS Means 2010</td><td>DEER, 2008</td><td>RS Means 2010</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">NCI</td></tr>
</table>

Data Sources » Residential Clothes Dryers

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical / High		
Typical Capacity (ft3)	NCI	CEC			CEC / Distributors	NCI		
EF (lb/kWh)	NCI	EERE						
Machine Energy (kWh/cycle)	NCI	EERE						
Average Life (yrs)	NCI	Ka-BOOM! / Appliance Magazine, 2010						
Retail Equipment Cost ($)	NCI	EERE						
Total Installed Cost ($)	NCI	EERE						
Annual Maintenance Cost ($)	EERE	EERE						

Data Sources » Residential Dishwashers

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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 Annual Use (kWh/yr)</td><td>Product Literature</td><td>EERE</td><td>Distributors</td><td>ENERGY STAR</td><td>CEC</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Efficiency (cycle/kWh)</td><td>NCI</td><td colspan="2">EERE</td><td colspan="2">CEC</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td colspan="4">Ka-BOOM! /
Appliance Magazine, 2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE</td><td colspan="3">Distributors</td><td>EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>EERE</td><td colspan="2">DEER, 2008</td><td>DEER, 2008</td><td>EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">NCI</td></tr>
</table>

Data Sources » Commercial Gas-Fired Furnaces

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="2">2010</th><th>2020</th><th>2030</th><th>2035</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">Arthur D. Little, 1997</td><td colspan="3">AHRI</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>AFUE</td><td colspan="2">ASHRAE Standard 90.1-2004</td><td>ASHRAE Standard 90.1-2004 / CEC</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">2003 ASHRAE Handbook – HVAC Applications</td><td colspan="3">Appliance Magazine, 2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">RS Means 2010/ NCI / Distributors</td><td colspan="3">RS Means 2010</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="2">RS Means 2010/ NCI / Distributors</td><td colspan="3">RS Means 2010</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">RS Means 2010/ NCI / Distributors</td></tr>
</table>

Data Sources » Commercial Oil-Fired Furnaces

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th>2010</th><th>2020</th><th>2030</th><th>2035</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 Capacity (kBTU/h)</td><td colspan="2">NCI /
Distributors /
AHRI</td><td colspan="2">AHRI</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>ASHRAE Standard
90.1-2004</td><td>AHRI</td><td>AHRI /
CEC</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">2003 ASHRAE Handbook –
HVAC Applications</td><td colspan="2">Appliance Magazine, 2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="4">RS Means 2010</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="4">RS Means 2010</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="4">NCI / Distributors</td></tr>
</table>

Data Sources » Commercial Electric Boilers

SOURCES	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical		
Typical Capacity (kW)	BSRIA			SAIC		
Efficiency (%)	SAIC					
Average Life (yrs)	ASHRAE 2007 HVAC Applications					
Retail Equipment Cost ($)	RS Means/SAIC					
Total Installed Cost ($)	RS Means/SAIC					
Annual Maintenance Cost ($)	RS Means/SAIC					

Data Sources » Commercial Gas-Fired Boilers

SOURCES	2003	2007	2010	2010			2020	2030	2035
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical / High		
Typical Capacity (kBTU/h)	Arthur D. Little / Building Services Research and Information Association & Ducker Research Company, 1997, 1998	NCI	EERE				NCI		
Combustion Efficiency (%)	ASHRAE Standard 90.1-2004		CEC	AHRI					
Average Life (yrs)	Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / Appliance Magazine, 2005		EERE						
Retail Equipment Cost ($)	CEC / RS Means 2010	DEER, 2008	EERE / Appliance Magazine, 2010						
Total Installed Cost ($)	CEC / RS Means 2010	NCI	EERE / Appliance Magazine, 2010						
Annual Maintenance Cost ($)	NCI		EERE / Appliance Magazine, 2010						

Data Sources » Commercial Oil-Fired Boilers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="2">2010</th><th>2020</th><th>2030</th><th>2035</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>Building Services Research and Information Association & Ducker Research Company, 1997, 1998</td><td>NCI</td><td colspan="3">EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Combustion Efficiency (%)</td><td colspan="3">ASHRAE Standard 90.1-2004</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / NCI</td><td colspan="3">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors / RS Means 2010 / NCI</td><td colspan="3">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="2">Distributors / RS Means 2010 / NCI</td><td colspan="3">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="2">NCI</td><td colspan="3">EERE</td></tr>
</table>

Data Sources » Commercial Gas-Fired Chillers

SOURCES	2003		2007		2010		2020		2030		2035	
	Installed Base: Absorp-tion	Installed Base: Engine-Driven	Installed Base: Absorp-tion	Installed Base: Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven
Typical Capacity (tons)	BSRIA/Distributors											
Efficiency (kW/ton)	Product Literature/SAIC											
COP												
Average Life (yrs)	2007 ASHRAE Applications Handbook/Distributors											
Retail Equipment Cost ($/ton)	Distributors/RS Means/SAIC											
Total Installed Cost ($/ton)												
Annual Maintenance Cost ($/ton)												

Data Sources » Commercial Centrifugal Chillers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2010</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2035</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Mid</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="2">US Census</td><td colspan="9">SAIC</td></tr>
<tr><td>Efficiency (kW/ton)</td><td colspan="7" rowspan="2">DEER/FEMP/Product Literature</td><td colspan="4" rowspan="2">SAIC</td></tr>
<tr><td>COP</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="11">2007 ASHRAE Applications Handbook</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="11" rowspan="2">RS Means/Distributors/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="11">SAIC</td></tr>
</table>

Data Sources » Commercial Reciprocating Chillers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2010</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2035</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Mid</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="2">BSRIA / DEER</td><td colspan="9">SAIC</td></tr>
<tr><td>Efficiency (kW/ton)</td><td colspan="7" rowspan="2">DEER/FEMP/Product Literature</td><td colspan="4" rowspan="2">SAIC</td></tr>
<tr><td>COP</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="11">Manufacturers</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="11" rowspan="2">RS Means/Distributors/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="11">SAIC</td></tr>
</table>

Data Sources » Commercial Screw Chillers

SOURCES	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	SAIC										
Efficiency (kW/ton)	DEER/FEMP/Product Literature							SAIC			
COP											
Average Life (yrs)	Manufacturers										
Retail Equipment Cost ($/ton)	RS Means/Distributors/SAIC										
Total Installed Cost ($/ton)											
Annual Maintenance Cost ($/ton)	SAIC										

Data Sources » Commercial Scroll Chillers

SOURCE	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	SAIC/Manufacturers					
Efficiency [full-load/IPLV] (kW/ton[1])	Product Literature			SAIC		
COP [full-load/IPLV]						
Average Life (yrs)	Manufacturers					
Retail Equipment Cost ($/ton)	RS Means/SAIC					
Total Installed Cost ($/ton)						
Annual Maintenance Cost ($/ton)	SAIC					

Data Sources » Commercial Rooftop Air Conditioners

SOURCES	2003	2007	2010	2010			2020	2030	2035
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI / NCI						NCI		
Efficiency (EER)	ASHRAE Standard 90.1-2004	Distributors / NCI	EERE		AHRI				
Average Life (yrs)	2003 ASHRAE Handbook – HVAC Applications		Appliance Magazine, 2010						
Retail Equipment Cost ($)	NCI / LBNL, 2003	Distributors / NCI / DEER, 2008	EERE		Distributors				
Total Installed Cost ($)	NCI / LBNL, 2003	Distributors / NCI / DEER, 2008	EERE		Distributors				
Annual Maintenance Cost ($)	EERE								

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

SOURCES	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	Distributors					
Heating COP	NA		Product Literature	Distributors/SAIC		
Cooling COP	Product Literature					
Average Life (yrs)	Distributors/SAIC					
Retail Equipment Cost ($/ton)						
Total Installed Cost ($/ton)						
Annual Maintenance Cost ($)						

Data Sources » Commercial Rooftop Heat Pumps

SOURCES	2003	2007	2010	2010		2020	2030	2035
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI					NCI		
Efficiency (EER)	ASHRAE Standard 90.1-2004		EERE					
COP (Heating)	NCI / EERE		EERE					
Average Life (yrs)	2003 ASHRAE Handbook - HVAC Applications							
Retail Equipment Cost ($)	Distributors / RS Means 2010 / NCI / DEER							
Total Installed Cost ($)	Distributors / RS Means 2010 / NCI / DEER							
Annual Maintenance Cost ($)	Distributors / RS Means 2010 / NCI / DEER							

Data Sources » Commercial Ground Source Heat Pumps

SOURCES	2003	2007	2010		2020	2030	2035
	Installed Base		Typical	High	Typical / High		
Typical Capacity (kBTU/h)	GHPC				NCI		
COP (Heating)	IGSPHA / GHPC						
EER (Cooling)	GHPC						
Average Life (yrs)	GHPC						
Retail Equipment Cost ($)	NCI / Distributors						
Total Installed Cost ($)	NCI / Distributors						
Annual Maintenance Cost (¢/sqft)	GHPC						

Data Sources » Commercial Electric Resistance Heaters

DATA	2010		2020		2030		2035	
	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBTU/h)	Distributors		NCI					
Efficiency (%)	NCI							
Average Life (yrs)	Technology Cost and Performance File for Commercial Model for AEO2010							
Retail Equipment Cost ($)	Distributors							
Total Installed Cost ($)	Distributors							
Annual Maintenance Cost ($)	NCI							

Data Sources » Commercial Gas-Fired Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="2">2010</th><th>2020</th><th>2030</th><th>2035</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="3">Arthur D. Little / Distributors / AHRI</td><td colspan="2">AHRI</td><td colspan="3" rowspan="7">NCI</td></tr>
<tr><td>Typical Input Capacity (BTU/h)</td><td colspan="2">Arthur D. Little / AHRI</td><td colspan="2">CEC</td><td>AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="3">EERE / ASHRAE Standard 90.1-2004</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / Appliance Magazine, 2005</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors / CEC / NCI</td><td colspan="3">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Distributors / CEC / NCI</td></tr>
<tr><td>Annual Maintenance Cost (¢/sqft)</td><td colspan="5">NCI</td></tr>
</table>

Data Sources » Commercial Electric Resistance Water Heaters

SOURCES	2003	2007	2010	2010	2020	2030	2035
	Installed Base		Current Standard	Typical	Typical		
Typical Capacity (gal)	NCI / Product Literature		AHRI		NCI		
Typical Capacity (kW)	Product Literature						
Thermal Efficiency (%)	Product Literature	ASHRAE Standard 90.1-2004	AHRI				
Average Life (yrs)	Appliance Magazine, 2005 / Building Services Research and Information Association & Ducker Research Company, 1997, 1998	Appliance Magazine, 2005					
Retail Equipment Cost ($)	Distributors / NCI	Distributors					
Total Installed Cost ($)	Distributors / NCI	NCI					
Annual Maintenance Cost ($)	NCI						

Data Sources » Commercial Oil-Fired Water Heaters

SOURCES	2003	2007	2010	2010			2020	2030	2035
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical / High		
Typical Capacity (gal)	NCI	AHRI / NCI					NCI		
Typical Input Capacity (kBTU/h)	NCI	AHRI / NCI	AHRI / CEC						
Thermal Efficiency (%)	NCI	ASHRAE Standard 90.1-1999	ANSI / ASHRAE / IESNA Standard 90.1-2007	AHRI / CEC					
Average Life (yrs)	NCI	Appliance Magazine, 2005							
Retail Equipment Cost ($)	NCI	Distributors / NCI							
Total Installed Cost ($)	NCI	Distributors / NCI	NCI						
Annual Maintenance Cost ($)	NCI	Distributors / NCI	NCI						

Data Sources » Commercial Gas-Fired Instantaneous Water Heaters

SOURCES	2003	2007	2010	2010		2020	2030	2035
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Capacity (gal)	Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / AHRI	AHRI	Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / AHRI			NCI		
Thermal Efficiency (%)	AHRI		ANSI / ASHRAE / IESNA Standard 90.1-2007					
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	CEC / NCI / Distributors	Distributors / NCI						
Total Installed Cost ($)	CEC / NCI / Distributors							
Annual Maintenance Cost ($)	CEC / NCI / Distributors							

Data Sources » Commercial Electric Booster Water Heaters

DATA	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical		
Typical Capacity (gal)	SAIC/Distributors			SAIC		
Thermal Efficiency (%)	Product Literature					
Average Life (yrs)						
Retail Equipment Cost ($)	SAIC/Distributors					
Total Installed Cost ($)						
Annual Maintenance Cost ($)						

Data Sources » Commercial Gas Booster Water Heaters

SOURCES	2003	2007	2010	2010		2020	2030	2035
	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 ($)	Distributors/SAIC							
Total Installed Cost ($)								
Annual Maintenance Cost ($)								

Appendix B
References

Navigant Consulting, Inc.
1801 K Street, NW, Suite 500
Washington, D.C. 20006
(202) 973-2400

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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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September 22, 2011

DISCLAIMER

September 2011

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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.

- 2005 and 2007 baselines, as well as today's (2010)
  - 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 2035
  - 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 real, 2010 dollars.

Definitions

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2005 and 2007, to the highest efficiency equipment that is expected to be commercially available by 2035, assuming advanced adoption. Below are definitions for the terms used in characterizing the status of each technology.

- 2005/2007 Installed Base: the currently installed and "in use" equipment for that year. Represents the installed stock of equipment, does not represent sales.
- 2010 Current Standard: the minimum efficiency required by current standards, or typical where no standard exists.
- 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).

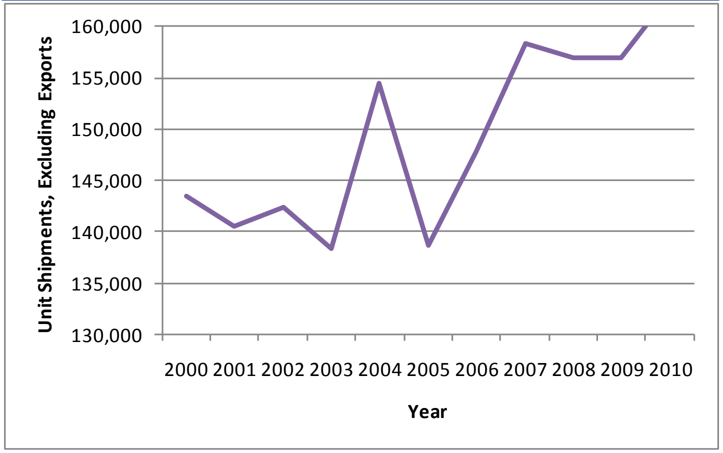
The market for the reviewed products has changed since the analysis performed in 2007 and is reflected in the efficiency and cost characteristics.

- Over the past three years, the Environmental Protection Agency (EPA) established ENERGY STAR specifications for a number of new products, including residential water heaters.
- Typical air conditioners have improved efficiencies as a result of increased Federal standards or otherwise. In 2007, the typical Energy Efficiency Ratio (EER) for a residential room air conditioner was 10.0, today it is 10.8; the typical EER for a commercial rooftop air conditioner was 10.1, today it is 11.2.
- Overall, there has been an increased market acceptance of energy efficient products driven by initiatives such as LEED and other green building programs.

Historical Shipment Data

Due to the severe recession and dramatic contraction in the housing market, over the past few years there has been a trend of decreased appliance shipments, except in commercial appliances where a specific trend is not evident. In 2010, shipments have increased across all appliance types.

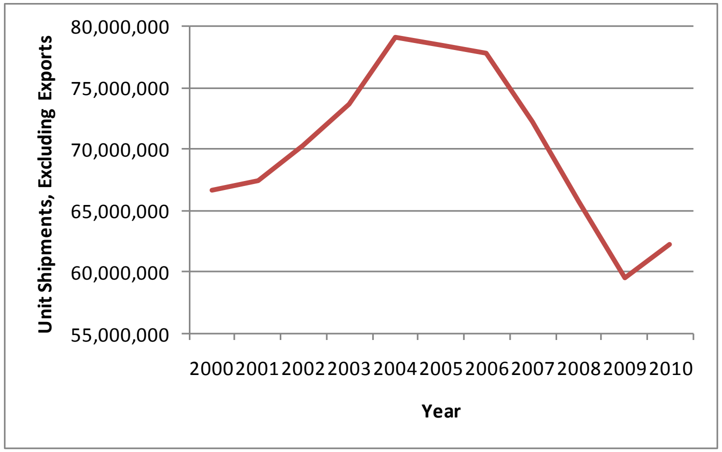
Commercial Appliances



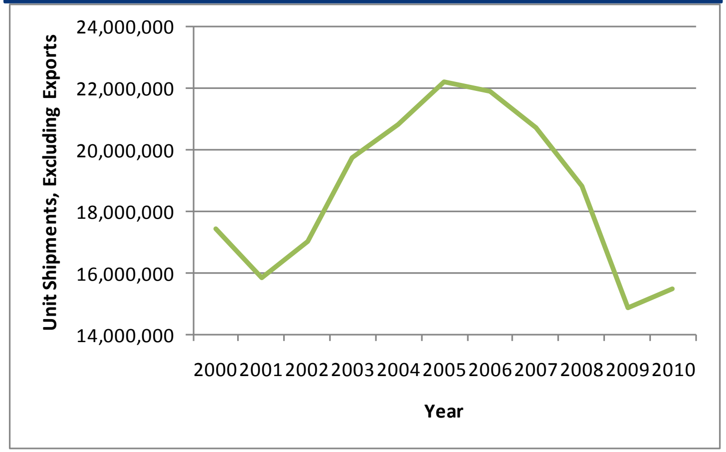
Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Throughout the presentation, shipment trends for specific products are depicted. Overall, the recession and contraction of the housing market has significantly affected each product.

Major Appliances



Comfort Conditioning



Final

Performance / Cost Characteristics » Residential Gas-Fired Water Heaters

Higher efficiencies and different costs than ref. case

DATA	2005	2010	2010			2020		2030		2035	
	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	0.85	0.62	0.85	0.62	1.4	0.85	1.4
Average Life (yrs)	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15
Retail Equipment Cost ($)	470-510	470-510	480-510	780-810	1500-3000	450-500	1380-2880	450-500	1960-3360	1168.5	1893.50-3293.5
Total Installed Cost ($)	920-960	920-960	930-960	1230-1260	1950-3450	1050-1100	1980-3480	1050-1100	2670-3570	1900-3400	2610-3510
Annual Maintenance Cost ($)	-	-	13	17	17	13	17	13	17	13	17

- 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.

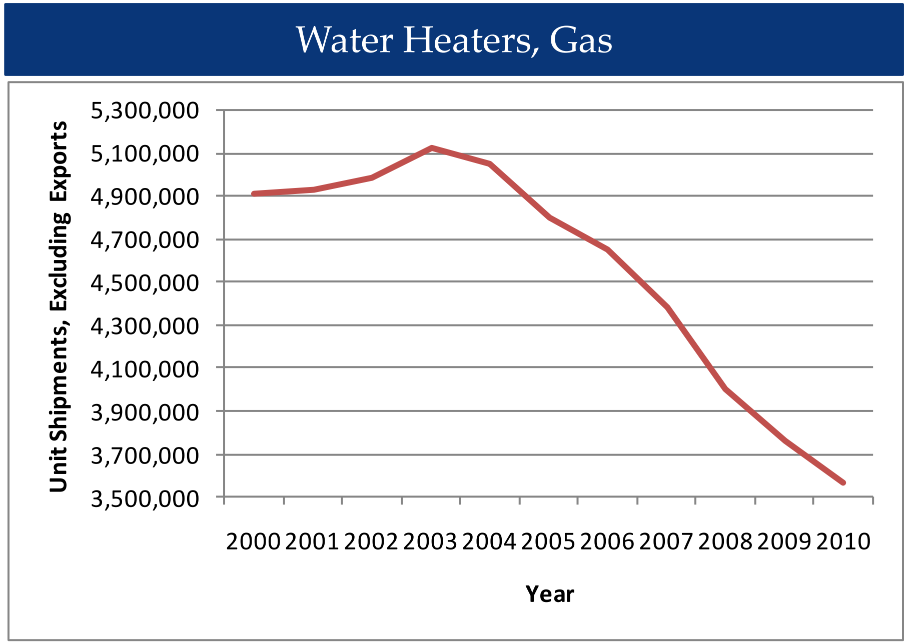
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

  EF=0.675-(0.0015*Gal) for a volume $\leq$ 55 gallons and

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

- Per discussions with National Labs, there is a potential trend towards a capacity of 50 gallons after 2020.
- 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.
- Generally, there are no storage gas water heaters between approximately 0.7 and 0.8 EF, which would fall in the "near-condensing" range of operation. Gas-fired water heaters are typically either condensing or non-condensing models.
- Gas heat pump water heaters use a gas-fired engine-driven heat pump or a gas-fired absorption heat pump to heat water. Waste heat from the engine could also be recovered for water heating. These units are not commercially available.

Since the last analysis was performed in 2007, there has been a decrease in residential gas-fired water heater shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Oil Water Heaters

Same as Reference Case

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	30	30	30	30	30	30	30	30	30	30	30
Energy Factor	0.5	0.53	0.54	0.62	0.68	0.62	0.68	0.62	0.68	0.62	0.68
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9
Retail Equipment Cost ($)	1200-1300	1300-1400	1350-1450	1450-1550	1600-1700	1440-1540	1600-1700	1420-1520	1600-1700	1420-1520	1600-1700
Total Installed Cost ($)	1800-1900	1900-2000	1950-2050	2050-2150	2200-2300	2040-2140	2200-2300	2020-2120	2200-2300	2020-2120	2200-2300
Annual Maintenance Cost ($)	-	-	157	157	157	157	157	157	157	157	157

- 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, hence the range of efficiencies tops out at near-condensing efficiency levels.
- The max-tech model on the market is achieved using a proprietary “turbo flue” design.

Performance / Cost Characteristics » Residential Electric Resistance Water Heaters

Same as Reference Case

DATA	2005	2010	2010		2020		2030		2035	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50
Energy Factor	0.9	0.9	0.92	0.95	0.95	0.96	0.95	0.96	0.95	0.96
Average Life (yrs)	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15
Retail Equipment Cost ($)	250-300	250-300	275-325	350-375	350-375	400-450	350-375	400-450	350-375	400-450
Total Installed Cost ($)	550-600	550-600	575-625	650-675	650-675	700-750	650-675	700-750	650-675	700-750
Annual Maintenance Cost ($)	-	-	6	6	6	6	6	6	6	6

- 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:

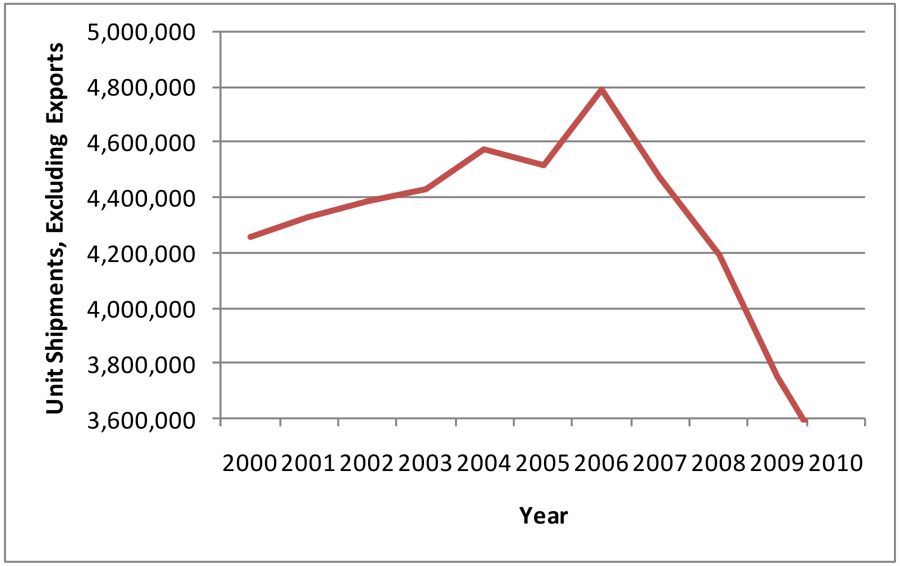
  EF=0.96-(0.0003*Gal) for a volume ≤ 55 gallons and

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

- Electric resistance water heater capacities usually range between 30 and 119 gallons.
- The max tech model, EF=2.35 at 50 gallons, is a heat pump water heater and is described in the following slides.

Since the last analysis was performed in 2007, there has been a decrease in residential electric resistance water heater shipments.

Water Heaters, Electric



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Heat Pump Water Heaters

Lower costs and higher efficiencies than ref. case

DATA	2005	2010		2020		2030		2035	
	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	2.35	2.1	3	2.5	3.2	2.5	3.5
Average Life (yrs)	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15	13-15
Retail Equipment Cost ($)	1400-1700	1400-1700	1500-2000	1265-1465	1690-1890	1170-1470	1690-1890	1125-1425	1690-1890
Total Installed Cost ($)	1500-2200	1500-2200	1600-2500	1365-1965	1790-2390	1270-1970	1790-2390	1225-1925	1790-2390
Annual Maintenance Cost ($)	15	15	15	15	15	15	15	15	15

- There is not a unique Federal standard for heat pump water heaters (HPWH). Because integrated HPWHs are in the same product class as electric resistance water heaters under DOE's classifications, the Federal standard that applies to electric resistance water heaters applies here as well.
- Since 1990, significant R&D efforts have gone into developing HPWHs. Improvements have advanced efficiency and reliability; however, the high first cost still precludes high-volume market penetration.
- Although there is an installed base listed for 2005, the market penetration of HPWHs was quite low at that time.
- Three major domestic storage water heater manufacturers (Rheem, AO Smith, and GE) have an integrated HPWH model on the market; however, new and established competitors offer integrated or retrofit units (for existing electric or indirect storage water heaters).
- Stiebel Eltron has an 80 gallon, 2.5 energy factor high efficiency HPWH. This unit was not included in the analysis presented on the previous slide because it has a significantly larger capacity than the units included, making for a difficult comparison.
- Sales are estimated to be limited and driven in part by rebates and tax credits at the utility, local, state, and Federal level. Hence, it is not surprising that all HPWH products on the market meet ENERGY STAR minimums and that no HPWH products are being offered below the ENERGY STAR efficiency level.
- While resistive heating elements are virtually 100% efficient at transferring heat to the water inside a water heater, there is a jump in efficiency when heat pump technology is adopted since the COP of heat pump systems is usually between 2 and 3, at least on a seasonal basis.
- Due to the typically slow rate at which heat pumps raise the water temperature in a storage water heater, it is not unusual for heat pump systems to use resistive heat for some proportion of the water heating process to meet consumer expectations. All HPWH systems examined by DOE allow the consumer to adjust the HPWH behavior.

Final

Performance / Cost Characteristics » Residential Instantaneous Water Heaters

Same as Reference Case

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (BTU/h)	185	185	185	185	185	185	185	185	185	185	185
Energy Factor	0.82	0.82	0.82	0.82	0.98	0.82	0.98	0.82	0.98	0.82	0.98
Average Life (yrs)	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20
Retail Equipment Cost ($)	1050-1150	1050-1150	1050-1150	1050-1150	2150-2250	1050-1150	2150-2250	1050-1150	2150-2250	1050-1150	2150-2250
Total Installed Cost ($)	1550-1650	1550-1650	1550-1650	1550-1650	2650-2750	1550-1650	2650-2750	1550-1650	2650-2750	1550-1650	2650-2750
Annual Maintenance Cost ($)	85	85	85	85	85	85	85	85	85	85	85

- Most instantaneous hot water heaters sold in 2010 are gas-fired and have an efficiency of 0.80 EF or above, which is also the qualifying criteria for ENERGY STAR
- Navien manufactures the highest efficiency gas-fired model currently available on the market, which has 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, all of which are imported and private-labeled.
- 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 3/4 inch from the typical ½ inch and change the venting.
- There is at least one electric (whole house) instantaneous water heater (4 chamber model) available on the market. This product retails for approximately $700-$750.

Performance / Cost Characteristics » Residential Solar Water Heaters

Lower costs than ref. case

DATA	2005	2010	2010	2020	2030	2035
	Installed Base	Current Standard	Typical / ENERGY STAR[2]	Typical[2]	Typical[2]	Typical[2]
Typical Capacity (sq. ft.)	42-63	NA	42-63	42-63	42-63	42-63
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[1] ($)	3300-5200	NA	3300-5200	2900-4600	2400-3900	2400-3900
Total Installed Cost[1] ($)	7600-10000	NA	7600-10,000	7100-9300	6700-8700	6700-8700
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.

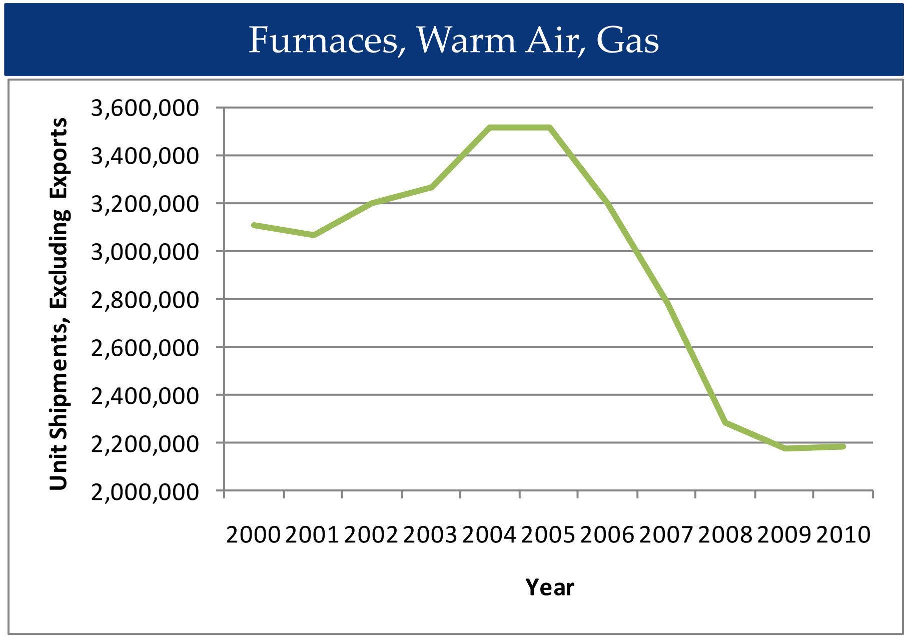
Performance / Cost Characteristics » Residential Gas-Fired Furnaces

Same as Reference Case

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	75	75	75	75	75	75	75	75	75	75	75
AFUE (%)	78	78	80	90	98	90	98	90	98	90	98
Electric Consumption (kWh/yr)	780	780	430	371	340	371	340	371	340	371	340
Average Life (yrs)	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25
Retail Equipment Cost ($)	700-800	700-800	700-800	1200-2200	2200-3200	1200-2200	1700-1800	1200-2200	1700-1800	1200-2200	1700-1800
Total Installed Cost ($)	2000-3000	2000-3000	2000-3000	2500-3000	3500-4000	2500-3000	3000-3500	2500-3000	3000-3500	2500-3000	3000-3500
Annual Maintenance Cost ($)	50	50	50	50	50	50	50	50	50	50	50

- The current standard for residential gas-fired furnaces is 78% AFUE; however, virtually all furnaces on the market have an AFUE of 80% or better.
- The minimum criteria for an ENERGY STAR qualified gas-fired furnace is 90% AFUE.
- York and Lennox manufacture the highest efficiency models currently available on the market, which have an efficiency of 98%.
- The high efficiency furnaces available are condensing furnaces, which use an additional heat exchanger to extract additional energy from the gases. Higher end models have variable speed blowers.
- 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 percent.
- 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 will breach the appliance or vent over time and hence allow flue gases into the structure.
- High-efficiency condensing furnaces typically have aluminized steel heat exchangers and low NO_x emissions, flexible installation, direct vent, and sealed combustion systems. The furnace does not use room air for combustion, but instead draws the 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 PSC or electronically commutated motors (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.

Since the last analysis was performed in 2007, there has been a decrease in gas-fired furnace shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

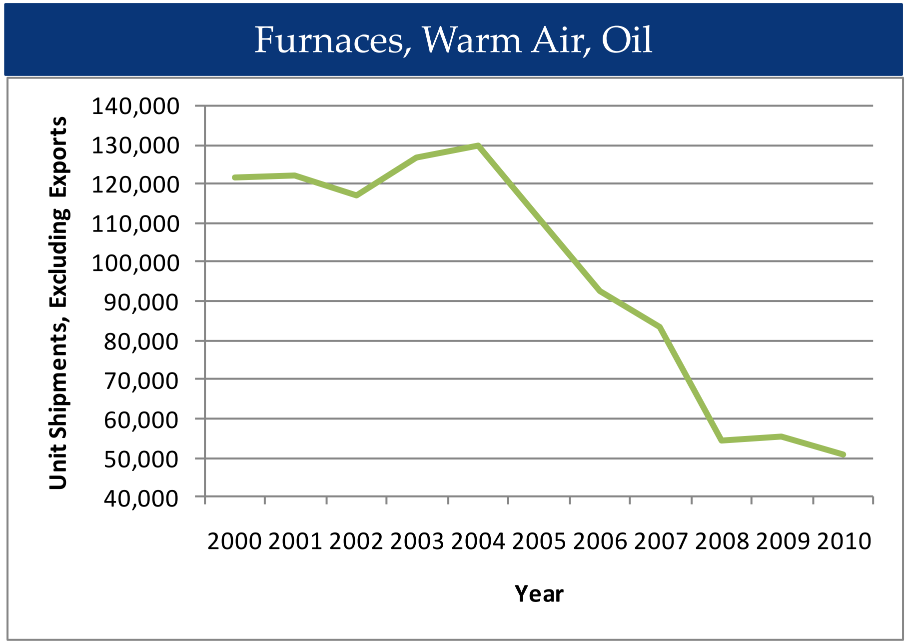
Performance / Cost Characteristics » Residential Oil-Fired Furnaces

Same as Reference Case

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	78	80	85	98	82	98	82	98	82	98
Electric Consumption (kWh/yr)	1001	1001	1001	944	900	950	900	950	900	950	900
Average Life (yrs)	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25	15-25
Retail Equipment Cost ($)	2000-2200	2000-2200	2000-2200	2200-2800	3200-3800	1900-2100	3200-3800	1800-2000	3200-3800	1775-1975	3200-3800
Total Installed Cost ($)	3000-3500	3000-3500	3000-3500	3500-4000	4500-5000	2900-3100	4500-5000	2800-3000	4500-5000	2775-2975	4500-5000
Annual Maintenance Cost ($)	120	120	120	120	120	120	120	120	120	120	120

- The current NAECA Standard for oil-fired, forced air furnaces is 78% AFUE.
- The ENERGY STAR criteria for oil-fired furnaces is 85% 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.
- There are condensing residential oil-fired furnaces on the market that operate at about 95% AFUE. They have a 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.

Since the last analysis was performed in 2007, there was initially a decrease with a recent slight increase in oil-fired furnace shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Hydronic Heating Systems (Boilers)

Higher efficiencies for typical and high efficiency units

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	78	80	82	85	98	85	98	85	99	85	99
Average Life (yrs)	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30
Retail Equipment Cost ($)	1000-1100	1000-1800	1200-2000	2100-2500	2500-3500	2100-2500	2500-3500	2100-2500	2500-3500	2100-2500	2500-3500
Total Installed Cost ($)	2800-2900	2800-3800	3000-4000	4000-4500	4500-5500	4000-4500	4500-5500	4000-4500	4500-5500	4000-4500	4500-5500
Annual Maintenance Cost ($)	130	130	130	130	130	130	130	130	130	130	130

- The NAECA standard for hot-water residential gas boilers is 80% AFUE, while the ENERGY STAR standard for boilers is 85% AFUE. The highest available efficiency is 98% AFUE.
- Hydronic systems represent about 6% of all U.S. residential heating systems.
- The bulk of U.S. boiler sales is for non-condensing boilers, primarily manufactured in North America. These are typically high-mass systems whose heat exchangers are made of iron or steel and which have simple on/off burners.
- 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. In the future, higher efficiency boilers may involve modulating burners, power venting, and electronic ignition.
- 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). The market for boilers is primarily in retrofit applications.

Performance / Cost Characteristics » Residential Room Air Conditioners

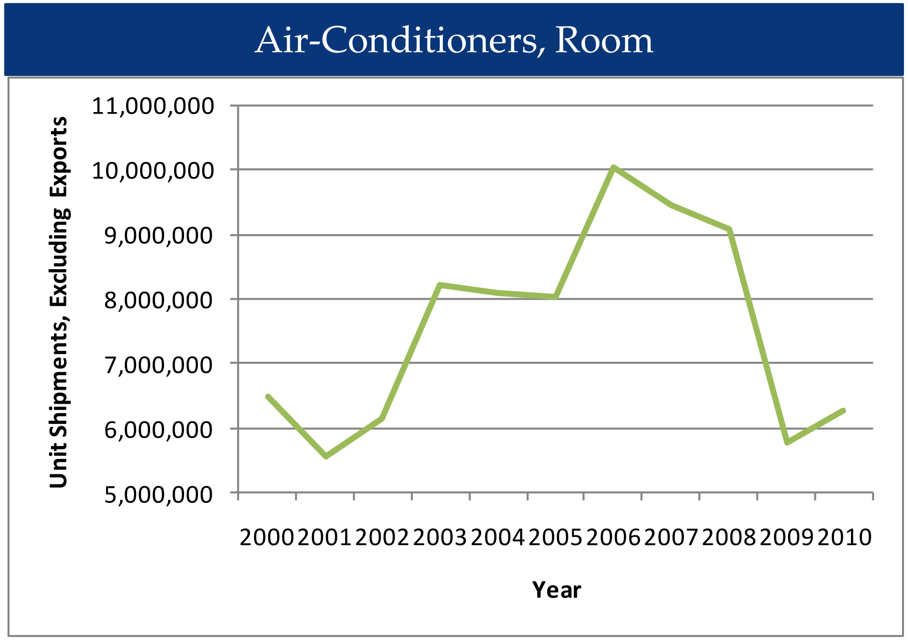
Higher efficiencies than ref. case

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
EER	9.8	9.8	9.8	10.8	11.5	11	13	12	13	12	13
Average Life (yrs)	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13
Retail Equipment Cost ($)	230-300	230-300	230-300	250-320	400-470	250-320	480-550	250-320	480-550	250-320	480-550
Total Installed Cost ($)	230-300	230-300	230-300	250-320	400-470	250-320	480-550	250-320	480-550	250-320	480-550
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- The residential room air conditioners analyzed in this study are window room air conditioners.
- The ENERGY STAR criteria requires an EER of 10.8, which also represents the most common efficiency on the market.
- According to the AHAM Directory of Certified Products, the most efficient product on the market has an EER of 11.5. Based on the DOE Building Technologies Program (BTP) R&D, it is anticipated that units may reach an EER of 13.0 by 2030.
- A wider range of costs reflects a variation in the marketplace
- It is assumed that the homeowners will install their own room air conditioner.
- 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.
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards will be updated in 2014 from 9.8 to 11.0

Since the last analysis was performed in 2007, there has been a decrease in room air conditioner shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Central Air Conditioners

Higher efficiencies for high efficiency units

DATA	2005	2010	2010			2020		2030		2035	
	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	10.2	13	13.7	14.5	24	14	24	15	26	16	26
Average Life (yrs)	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19	14-19
Retail Equipment Cost ($)	1000-1500	2000-2500	2050-3750	2500-4200	6500-13500	2500-4200	6500-13500	2500-4200	6500-13500	2500-4200	6500-13500
Total Installed Cost ($)	2500-2700	2500-3500	2550-4750	3000-5200	7000-14500	4000-6200	8000-15000	4000-6200	8000-15000	4000-6200	8000-15000
Annual Maintenance Cost ($)	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120	20-120

- The current NAECA minimum SEER is 13.0.
- The ENERGY STAR criteria is 14.5 SEER and 12 EER for split systems, which is close to the efficiency of the typical product on the market.
- Energy efficiency is driven by several factors:
  - Heat exchanger (surface area, number of tube rows, tube & fin vs. micro-channel)
  - Compressor choices (i.e., type of compressor 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, TXV, or EEV expansion devices)

  As an example, above 16 SEER, units typically have very large heat exchangers, an ECM evaporator fan motor and a two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, but does not affect the EER. Manufacturers have used the SEER boost to develop high-SEER condensing units with smaller enclosures.
- The high efficiency units currently available use an evaporator ECM fan motor and have modulating capacity.
- Efficiency levels beyond 21 SEER are made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and EEVs.

Final

Performance / Cost Characteristics » Residential Air Source Heat Pumps

Higher efficiency and lower costs than ref. case

DATA	2005	2010	2010			2020		2030		2035	
	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
HSPF (Heating)	6.8	8	8	8.2	10.7	8.1	11	8.3	12	8.5	12
SEER (Cooling)	10	14	14	14.5	22	14.2	23	15	24	15.3	25
Average Life (yrs)	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16	14-16
Retail Equipment Cost ($)	3500-4000	4000-4500	4000-4500	5500-6000	7000-7500	4000-4500	7040-7290	3940-4140	6500-6750	3940-4140	6300-6800
Total Installed Cost ($)	4500-5500	5000-6000	5000-6000	6500-7500	8000-10000	5000-6000	7130-9780	4900-5100	6800-10000	4900-5100	6525-11225
Annual Maintenance Cost ($)	120	120	120	120	120	120	120	120	120	120	120

- The NAECA minimum HSPF is 7.7 and the minimum SEER is 13.
- The ENERGY STAR criteria states a minimum HSPF of 8.2 and a minimum SEER of 14.5.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, resistance heat is supplemented; however, when the 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.
- High efficiency cooling does not necessarily lead to high efficiency heating. The range of SEER/HSPF combinations is very broad.

Final

Performance / Cost Characteristics » Residential Ground Source Heat Pumps

Higher typical efficiencies and lower costs than ref. case

DATA	2005	2010	2010			2020		2030		2035	
	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	3.1	3.5	4.3	3.5	5	3.6	5	3.7	5
EER (Cooling)	12	13.4	13.4	16.1	23	16.1	30	17.1	30	18	30
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	4000-6000	4000-6000	4000-6000	5000-7000	7000-9000	3900-5900	7000-9000	3800-5800	7000-9000	3800-5800	7000-9000
Total Installed Cost ($)	9000-11000	9000-11000	9000-11000	10000-12000	12000-14000	8900-10900	12000-14000	8800-10800	12000-14000	8800-10800	12000-14000
Annual Maintenance Cost ($)	70	70	70	70	70	70	70	70	70	70	70

- There are currently 19 ground source heat pump manufacturers in the US.
- Heating COP does not correlate with cooling EER (coefficient of determination, R^2 = 0.62). The highest efficiency GSHP is the Envision by WaterFurnace International, Inc. (30 EER & 5.0 COP).
- 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.
- Electronically commutated motors (ECMs) improve performance on high end models.

Performance / Cost Characteristics » Residential Gas Heat Pumps

Higher efficiencies and lower costs than ref. case

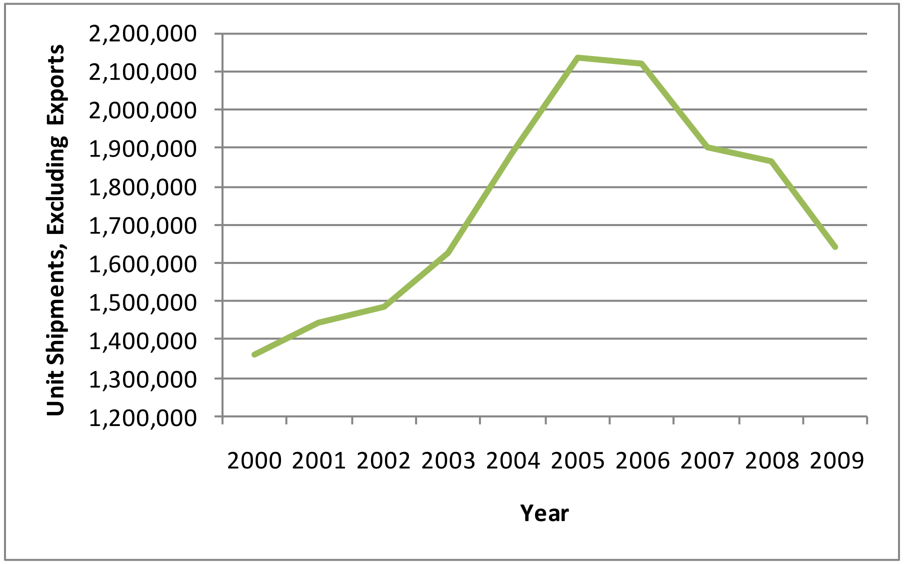
DATA	2005	2010	2010	2020	2030	2035
	Installed Base	Current Standard[1]	Typical	Typical	Typical	Typical
Typical Capacity (kBTU/h)	60	60	60	60	60	60
Heating (GCOP)	1.3	NA	1.3	1.4	1.5	1.5
Cooling (GCOP)	0.6	NA	0.6	0.7	0.75	0.75
Annual Electric Use (kWh/yr)	2000	2000	2000	1500	1500	1500
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($)	6500-7500	6500-7500	6500-7500	6400-7400	6300-7300	6300-7300
Total Installed Cost ($)	8500-9500	8500-9500	8500-9500	8400-9400	8300-9300	8300-9300
Annual Maintenance Cost ($)	150	150	150	150	150	150

[1]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 are not currently covered by NAECA. CEC Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for gas heat pumps, and two residential size units are listed there; Robur and Yazaki. Both units are 5-ton cooling capacity, which is too big for all but larger homes. The Yazaki unit offers cooling only and appears to be available only in Europe at the moment. 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.
- Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market.

Since the last analysis was performed in 2007, there has been a decrease in both air source and ground source heat pump shipments.

Heat Pumps



Source: Appliance Magazine 2010

Performance / Cost Characteristics » Residential Refrigerator / Freezer

Higher efficiencies for typical units than ref. case

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Capacity (cu. ft.)	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6
Energy Consumption (kWh/yr)	840	453	475	408	285	475	285	408	285	408	285
Average Life (yrs)	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19
Retail Equipment Cost ($)	200-400	400-500	400-500	425-525	800-1200	400-500	800-1200	400-500	800-1200	400-500	800-1200
Total Installed Cost ($)	200-500	400-600	400-600	425-625	800-1300	400-600	800-1300	400-600	800-1300	400-600	800-1300
Annual Maintenance Cost ($)	6	6	6	6	6	6	6	6	6	6	6

- The current NAECA standard for a typical top-mount refrigerator/freezers is 453 kWh/yr while the typical top-mount refrigerator/freezer currently consumes approximately 475 kWh/yr. The best available top-mount refrigerator/freezer uses 285 kWh/yr.
- According to NAECA standards, for a refrigerator/freezer to qualify as ENERGY STAR, it must be at least 20% more energy efficient than the minimum Federal government standard. This equates to an annual energy use of approximately 408 kWh/yr.
- EISA 2007 requires that DOE publish a final rule no later than December 31, 2010 to determine whether to amend the standards in effect for products manufactured on or after January 1, 2014.
- A wider range of costs reflects a variation in the marketplace
- Improvement opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Better gasketing
  - Optimized refrigerants (Isobutane vs. R134a) and air temperature
  - Magnetic refrigeration cycle (currently used in laboratory applications)
- All manufacturers are using at least some of these technologies in an attempt to reach ENERGY STAR qualification.
- According to the ACEEE – AHAM Consensus Agreement, the Joint Stakeholders agree to jointly petition DOE to initiate a rulemaking by January 1, 2012 to be completed by December 31, 2012 to revise the test procedure for refrigerators/freezers to incorporate measured ice maker energy use. Additionally, the Federal standards will be revised in 2014. For top-mount units without ice makers, the standard is represented by 7.35 AV+ 207.0 and for units with ice makers, the standard is represented by 7.65 AV+ 267.0, where AV is the adjusted volume.[1]

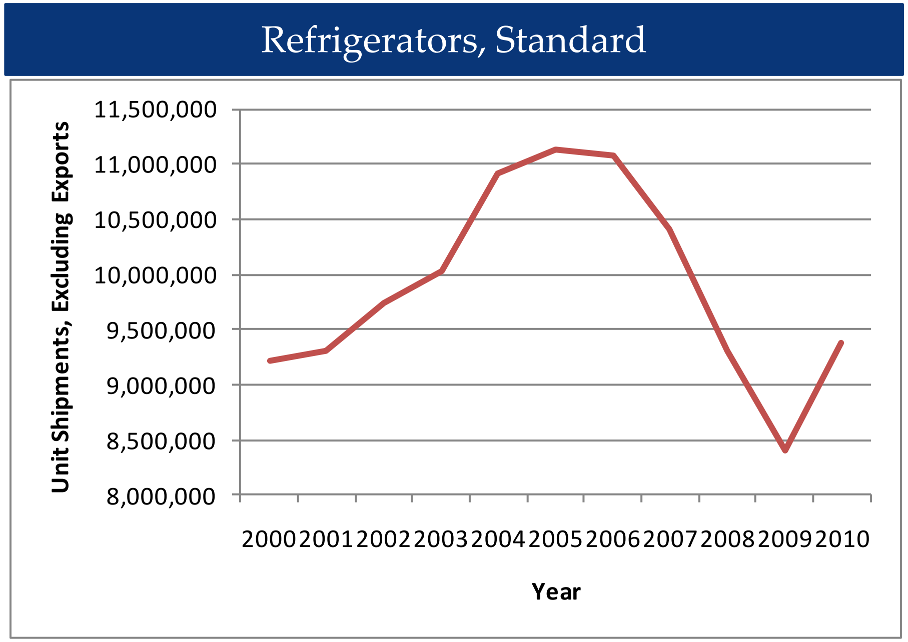
[1]Adjusted Volume (AV) for refrigerators is calculated as follows: AV = (Fresh Volume) + 1.63 x (Freezer Volume). When the new rulemaking is published, the formula for AV will become: AV = (Fresh Volume) + 1.76 x (Freezer Volume).

- This analysis focuses on top-mount refrigerator-freezers because they have the largest market share of all refrigerator-freezer product classes at 50.6%*. The market share for bottom- and side-mount refrigerator-freezers are as follows:
  - Bottom-mount: 12.5%*
  - Side-mount: 26.9 %*
- Top-mount refrigerator-freezers also have the greatest percent of total available units at 20.9%. The percent of total available units for bottom- and side-mount refrigerator-freezers are as follows:
  - Bottom-mount: 18.8%
  - Side-mount: 9.5%
- When looking at all product classes, the energy consumption ranges from approximately 790 kWh/yr** to 230 kWh/yr, with the typical energy consumption at the current standard level.
- There are also significant differences in average equipment cost across the product classes:
  - Top-mount: $400-$1500
  - Bottom-mount: $1700-$2100
  - Side-mount: $1400-$1800

* 2008 data
** A product operating at this level is less efficient than the current Federal standard

Sources: CEC, AHAM, Technical Support Document

Since the last analysis was performed in 2007, there has been a decrease in standard residential refrigerator / freezer shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Natural Gas Cooktops

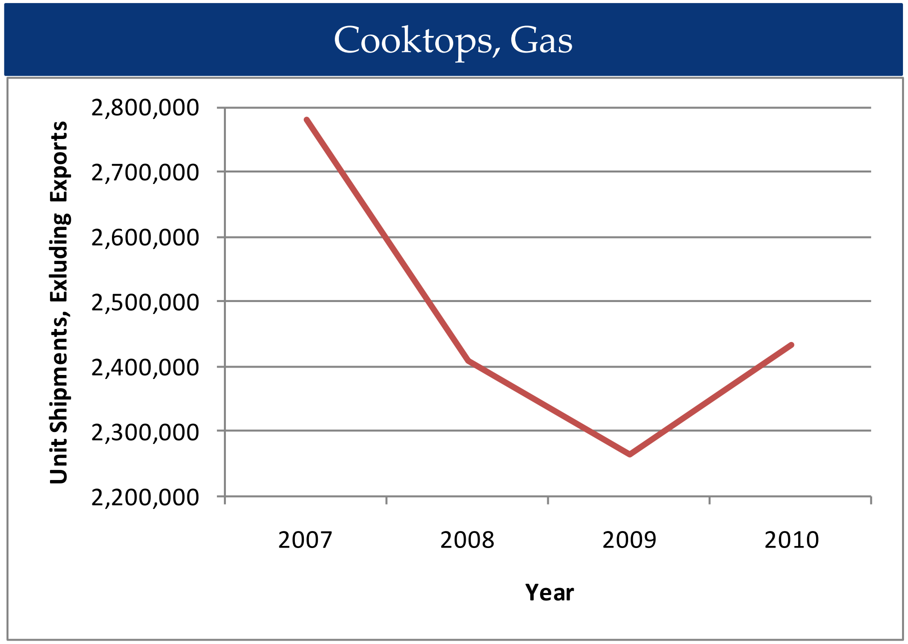
Same as Reference Case

DATA	2005	2010		2020		2030		2035	
	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)	9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12
Cooking Efficiency (%)	38	39.9	42	39.9	42	39.9	42	39.9	42
Average Life (yrs)	17-18	17-18	17-18	17-18	17-18	17-18	17-18	17-18	17-18
Retail Equipment Cost ($)	225-300	250-350	375-450	250-350	375-450	250-350	375-450	250-350	375-450
Total Installed Cost ($)	275-350	300-400	425-500	300-400	425-500	300-400	425-500	300-400	425-500
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- In 1990, gas cooktops were no longer allowed to have a constantly burning pilot light. Thus gas cooktops with an electrical supply must have electronic ignition systems.
- Efficiency levels vary little for cooktops on the market.
- The typical model on the market has a cooking efficiency of 39.9% and the highest efficiency model on the market has a cooking efficiency of 42%.

Since the last analysis was performed in 2007, there has been a decrease in residential natural gas cooktop shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Data is unavailable for dates prior to 2007.

Final

Performance / Cost Characteristics » Residential Clothes Washers

Same as Reference Case

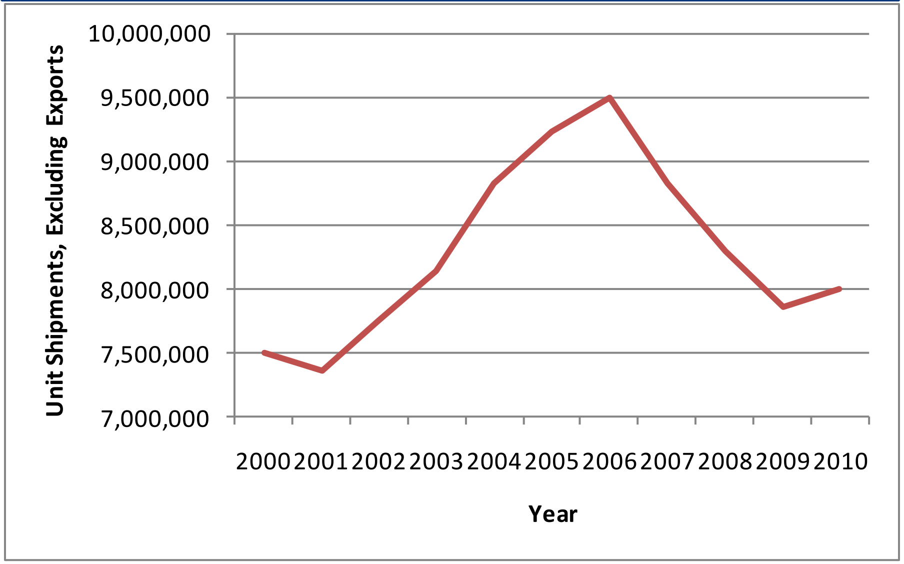
DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft3)	3	3.2	3	2.7	3.5	2.7	3.5	2.7	3.5	2.7	3.5
Modified Energy Factor (ft3/kWh/cycle)	2	1.26	2	2	3.88	2.2	3.88	2.2	3.88	2.2	3.88
Average Life (yrs)	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15
Water Consumption (gal/cycle)	14	30	11	20	13	11	13	11	13	11	13
Hot Water Energy (kWh/cycle)	0.4	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Machine Energy (kWh/cycle)	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dryer Energy (kWh/cycle)	0.7	1.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Retail Equipment Cost ($)	550-700	360-440	550-700	550-700	800-900	550-700	850-950	550-700	850-950	550-700	850-950
Total Installed Cost ($)	650-800	460-540	650-800	650-800	900-1000	650-800	950-1050	650-800	950-1050	650-800	950-1050
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- This analysis examined front-loading residential clothes washers. It should be noted that there are high efficiency top-loading residential clothes washers on the market as well, though front-loaders are inherently more efficient than top-loaders.
- The current standard for standard-size front-loading and top-loading clothes washers is a modified energy factor (MEF) of 1.26. The ENERGY STAR criteria is 2 MEF; however, the most common front-loading models on the market exceed the ENERGY STAR criteria and have a MEF of 2.2.
- Only clothes washers with capacities of greater than 1.6 ft^3 are eligible to earn ENERGY STAR.
- Energy efficiency improvement opportunities include:
  - Higher efficiency motors and higher spin speeds
  - Better load sensing (soiling and size and type of load)
  - Better controls / greater number of wash programs
  - Use of nylon beads
- The annual maintenance cost for residential clothes washers is negligible.
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards front-loading residential clothes washers will be updated in 2015 (and will remain current through the 2018 standard updates) to a MEF of 2.2 and a water factor (WF) of 4.5

Since the last analysis was performed in 2007, there has been a decrease in automatic residential clothes washer shipments.

Washers, Automatic



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Clothes Dryers

Same as Reference Case

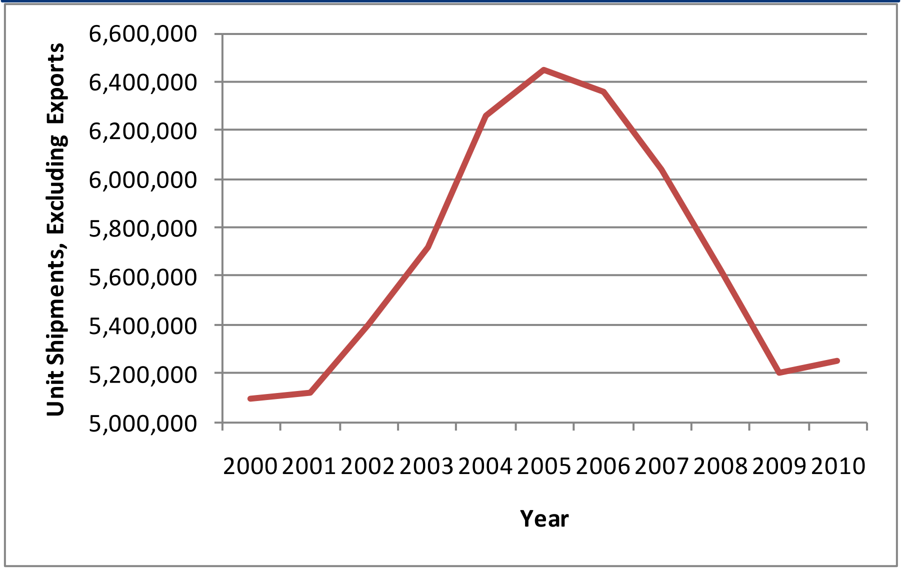
DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7
EF (lb/kWh)	electric: 3.01 gas: 2.67	electric: 3.01 gas: 2.67	electric: 3.1 gas: 2.75	gas: 2.85	electric: 3.16 gas: 3.02	electric: 3.17 gas: 2.81	electric: 4.51 gas: 3.02	electric: 3.17 gas: 2.81	electric: 4.51 gas: 3.02	electric: 3.17 gas: 2.81	electric: 4.51 gas: 3.02
Average Life (yrs)	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19	12-19
Retail Equipment Cost ($)	electric: 400-500 gas: 450-550	electric: 400-500 gas: 450-550	electric: 450-550 gas: 550-600	gas: 650-750	electric: 550-650 gas: 850-950	electric: 450-550 gas: 550-600	electric: 650-750 gas: 850-950	electric: 450-550 gas: 550-600	electric: 650-750 gas: 850-950	electric: 450-550 gas: 550-600	electric: 650-750 gas: 850-950
Total Installed Cost ($)	electric: 500-600 gas: 600-700	electric: 500-600 gas: 600-700	electric: 675-775 gas: 700-800	gas: 800-900	electric: 700-800 gas: 950-1050	electric: 675-775 gas: 700-800	electric: 900-1000 gas: 950-1050	electric: 675-775 gas: 700-800	electric: 900-1000 gas: 950-1050	electric: 675-775 gas: 700-800	electric: 900-1000 gas: 950-1050
Annual Maintenance Cost ($)*	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

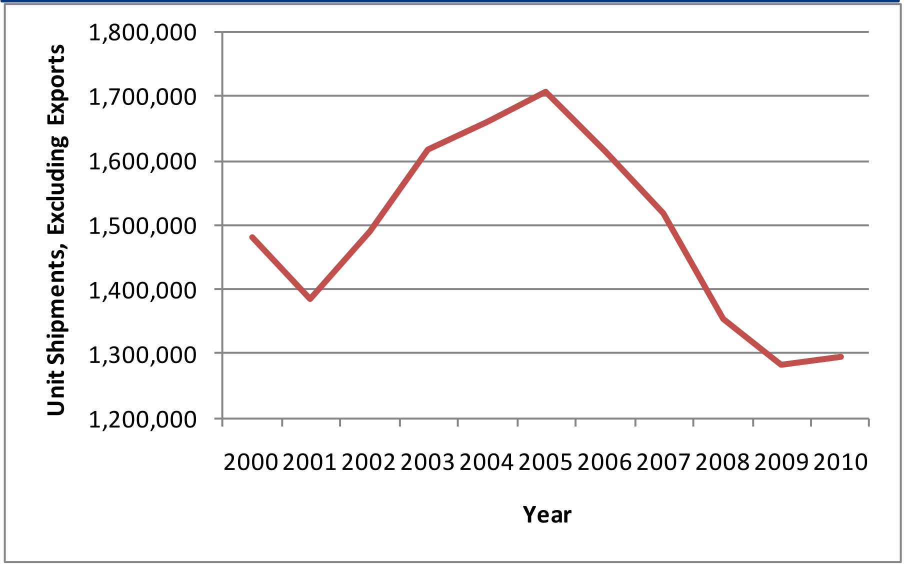
- The test procedure for residential clothes dryers was recently amended to include a new efficiency metric, combined energy factor (CEF), which adds a measure of standby/off-mode power. Although EF and CEF are both expressed in lbs/kWh of energy use, they can not be compared side-by-side since they are calculated differently.
- There are both gas and electric models of clothes dryers on the market:
  - For gas clothes dryers, the standard efficiency is 2.67 lb/kWh (CEF = 3.14 lb/kWh)
  - For electric clothes dryers, the standard efficiency is 3.01 lb/kWh (CEF = 3.55 lb/kWh)
- Improvement opportunities include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Heat pump (for electric clothes dryers): heat pump residential clothes dryers, which operate much like a small air conditioner, are currently available in Europe and are anticipated to make it to the US market by 2020.
  - Better control systems for cycle termination (not reflected per the current test procedure, however)
  - Using microwave technology
- No ENERGY STAR incentives currently exist to motivate manufacturers to adapt to existing energy efficiency opportunities. This is an especially important factor for heat pumps due to the high initial cost and the potential reliability issues.
- The high electric clothes dryer EF value of 4.51 represents a product with heat pump technology, which is planned to enter the market around 2020.
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards will be revised in 2015.
  - For gas clothes dryers, the standard efficiency will be 2.81 lb/kWh (CEF = 3.30 lb/kWh)
  - For electric clothes dryers, the standard efficiency will be 3.17 lb/kWh (CEF = 3.73 lb/kWh)

Since the last analysis was performed in 2007, there has been a decrease in residential clothes dryer shipments.

Dryers, Electric



Dryers, Gas



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Residential Dishwashers

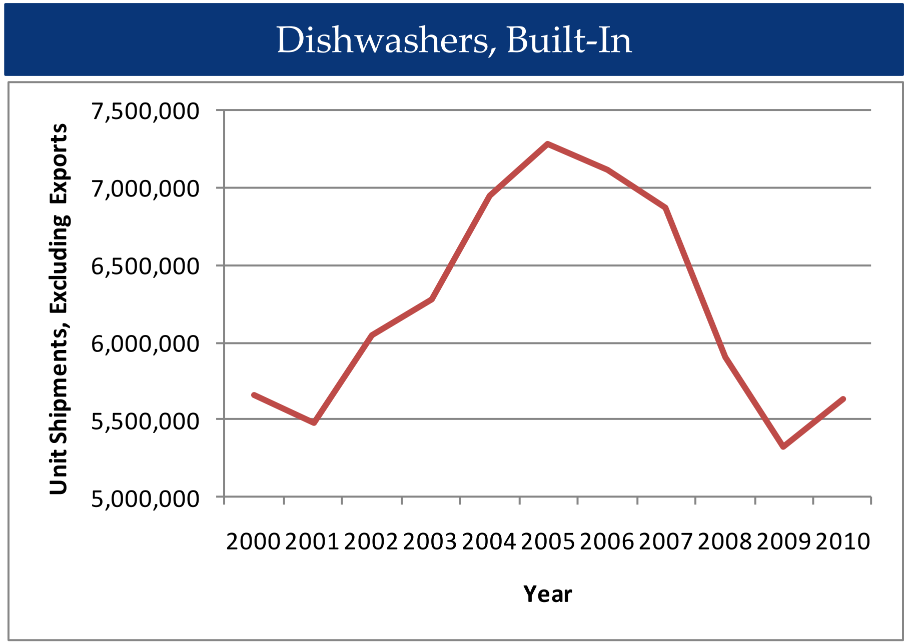
Higher efficiencies and lower costs for high efficiency units

DATA	2005	2010	2010			2020		2030		2035	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Annual Use (kWh/yr)	720	355	355	324	190	355	175	353	166	353	156
Efficiency (cycle/kWh)	0.30	0.61	0.61	0.66	1.13	0.61	1.23	0.61	1.30	0.61	1.38
Annual Hot Water Energy Use (kWh/yr)	286	261	261	185	100	261	100	260	100	260	100
Average Life (yrs)	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13	10-13
Retail Equipment Cost ($)	200-300	200-300	200-300	300-1200	900	200-300	800	200-300	800	200-300	800
Total Installed Cost ($)	300-400	300-400	300-400	400-1300	1200	300-400	1100	300-400	1100	300-400	1100
Annual Maintenance Cost ($)	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- The current standard was established by the EISA 2007 amendments to EPCA and stipulates a maximum of 355 kWh/yr of energy use and 6.5 gal/cycle of water use for standard sized dishwashers, which typically handle eight place settings plus six serving pieces.
- The current ENERGY STAR qualifying criteria require a maximum of 324 kWh/yr of energy use and 5.8 gal/cycle of water use for standard sized dishwashers.
- The most efficient dishwasher has an annual energy use of 190 kWh/yr, but at a high retail price and very small market share. Typical high efficiency units have an EF closer to the current standard.
- Dishwasher annual energy use is based on the U.S. DOE test procedure. This procedure is based on total energy use - including motor, dryer, booster heater (if present), and for hot water required from the water heater. The previous U.S. DOE test procedure was based on a usage estimate of 322 cycles per year, but as of September 2003 a new test procedure of 215 cycles per year was implemented.
- 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
  - Zeolithic drying
- According to the ACEEE – AHAM Consensus Agreement, the Federal standards will be revised in 2013. The updated standard stipulates a maximum of 307 kwh/year and 5.0 gal/cycle of water use.

Since the last analysis was performed in 2007, there has been a decrease in residential dishwasher shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Commercial Gas-Fired Furnaces

Higher efficiencies and lower costs than ref. case

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	400	400	400	400	400	400	400	400	400	400	400
Combustion Efficiency (%)**	76	77	80	80	82	80	90	80	93	80	93
Average Life (yrs)	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20
Retail Equipment Cost ($)	1800-2000	2000-2400	2700-2900	2700-2900	2900-3200	2700-2900	3360-3660	2700-2900	4060-4360	2700-2900	3830-4130
Total Installed Cost ($)	2800-3000	3000-3500	3050-3275	3050-3275	3275-3625	3050-3275	3735-4035	3050-3275	4205-4505	3050-3275	4435-4735
Annual Maintenance Cost ($)	300	300	300	300	300	300	300	300	300	300	300

*Capacity is *input*
** Gas furnaces less than 225,000 Btu/hr are rated by AFUE. Furnaces larger than 225,000 Btu/hr must been an 80% combustion efficiency.

- EPACT standard for a gas-fired furnace is 80% combustion efficiency at maximum rated capacity.
- According to the U.S. DOE, combustion efficiency is a measure of how effectively the heat content of a fuel is transferred into usable heat.
- 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 is based on two cleanings per year.

Performance / Cost Characteristics » Commercial Oil-Fired Furnaces

Same as Reference Case

DATA	2003	2007	2010	2010	2020	2030	2035
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (kBTU/h)*	400	400	400	400	400	400	400
Thermal Efficiency (%)	81	81	81	82	82	82	82
Average Life (yrs)	17-20	17-20	17-20	17-20	17-20	17-20	17-20
Retail Equipment Cost ($)	3000-3600	3000-3600	3000-3600	3600-3700	3600-3700	3600-3700	3600-3700
Total Installed Cost ($)	3575-4125	3575-4125	3575-4125	4125-4225	4125-4225	4125-4225	4125-4225
Annual Maintenance Cost ($)	300	300	300	300	300	300	300

* Capacity is *input*

- Commercial oil-fired furnaces with a capacity of 225,000 BTU/h or more must meet a thermal efficiency standard of 81% as stipulated in ASHRAE Standard 90.1-2007. The ASHRAE standard also mandates that furnaces that are not within the conditioned space must not have jacket losses that exceed 0.75% of the input rating.
- According to the U.S. DOE, thermal efficiency is interpreted as what is commonly known as "combustion efficiency" in other contexts, *i.e., 100 percent minus percent* flue loss
- The maintenance cost is based on two cleanings per year.

Performance / Cost Characteristics » Commercial Electric Boilers

Same as Reference Case

DATA	2003	2007	2010	2020	2030	2035
	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 ($)	6000-7000	6000-7000	6000-7000	6000-7000	6000-7000	6000-7000
Total Installed Cost ($)	7500-9000	7500-9000	7500-9000	7500-9000	7500-9000	7500-9000
Annual Maintenance Cost ($)	100-150	100-150	100-150	100-150	100-150	100-150

* 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).

Performance / Cost Characteristics » Commercial Gas-Fired Boilers

Same as Reference Case

DATA	2003	2007	2010	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	800	800	800	800	800	800	800	800	800	800	800	800
Combustion Efficiency (%)	76	77	80	80	90	98	80	98	82	98	82	98
Average Life (yrs)	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30	20-30
Retail Equipment Cost ($)	5000-6000	7000-9000	9000-11000	9000-11000	13500-16500	22500-27500	13500-16500	22500-27500	13500-16500	22500-27500	13500-16500	22500-27500
Total Installed Cost ($)	12000-13000	14000-16000	16000-18000	16000-18000	20500-23500	29500-34500	20500-23500	29500-34500	20500-23500	29500-34500	20500-23500	29500-34500
Annual Maintenance Cost ($)	450	450	450	450	450	450	450	450	450	450	450	450

* Capacity is *output*

- The current requirement for gas-fired boilers is a minimum combustion efficiency of 80% at the maximum rated capacity.
- 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.
- Since the last ASHRAE standard was published, ASHRAE has changed the metric for stating the efficiency of most classes of commercial boilers, excluding large oil hot water and large gas hot water boilers. Federal standards express efficiency in terms of combustion efficiency while efficiency levels in ASHRAE 90.1-2007 are expressed in terms of thermal efficiency. The thermal efficiency descriptor, as used in Standard 90.1-2007, accounts for jacket losses as well as flue losses, while combustion efficiency only accounts for flue losses.
- Small, gas-fired, hot water, commercial packaged boilers (input capacity between 300,000 and 2,500,000 Btu/hr) are the largest commercial packaged boiler equipment class in the market.
- The higher efficiency units typically include electronic ignition, power burners, and improved heat exchangers.

Performance / Cost Characteristics » Commercial Oil-Fired Boilers

Same as Reference Case

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Thermal Efficiency (%)	79	80	83	83.5	98	83.5	98	83.5	98	83.5	98
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	11000-12000	11000-12000	12300-13400	12300-13400	24000-26000	12300-13400	24000-26000	12300-13400	24000-26000	12300-13400	24000-26000
Total Installed Cost ($)	15000-16000	15000-16000	16600-17700	16600-17700	30000-35000	16600-17700	30000-35000	16600-17700	30000-35000	16600-17700	30000-35000
Annual Maintenance Cost ($)	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155	110-155

* Capacity is *output*

- Commercial oil-fired boilers must meet a thermal efficiency standard of 83%.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.
- Since the last ASHRAE standard was published, ASHRAE has changed the metric for stating the efficiency of commercial boilers. Federal standards expresses efficiency in terms of combustion efficiency while efficiency levels in ASHRAE 90.1-2007 are expressed in terms of thermal efficiency. The thermal efficiency descriptor, as used in Standard 90.1-2007, accounts for jacket losses as well as flue losses, while combustion efficiency only accounts for flue losses.

Final

Performance / Cost Characteristics » Commercial Gas-Fired Chillers[1]

Higher efficiencies and costs than ref. case

DATA	2003		2007		2010		2020		2030		2035	
	Installed Base: Absorp-tion	Installed Base: Engine -Driven	Installed Base: Absorp-tion	Installed Base: Engine–Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven
Typical Capacity (tons)*	150-1500	400	150-1500	400	150-1500	400	150-1500	400	150-1500	400	150-1500	400
Efficiency (kW/ton[2])	3.5	2.3	3.5	2.3	3.2	2.0	2.9	1.9	2.3	1.8	2.3	1.8
COP	1.0	1.5	1.0	1.5	1.1	1.8	1.2	1.9	1.5	2.0	1.5	2.0
Average Life (yrs)	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost ($/ton)	600-750	700-800	600-750	700-800	600-750	700-800	600-750	700-800	750-900	700-800	750-900	700-800
Total Installed Cost ($/ton)	750-900	850-950	750-900	850-950	750-900	850-950	750-900	850-950	900-1150	850-950	900-1150	850-950
Annual Maintenance Cost ($/ton)	15-30	35-45	15-30	35-45	15-30	35-45	15-30	35-45	15-30	35-45	15-30	35-45

* Capacity is *output*

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

[2]This is merely the cooling COP expressed in units of kW/ton for comparison to an electric chiller in terms of site efficiency; it does not represent the electrical consumption of the gas-fired chiller.

- 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 another 50% beyond that of a double effect chiller. Prototype direct-fired triple effect absorption chillers have been tested by York and Trane, but are not commercially available. 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. Incremental efficiency improvements may be expected for engine driven chillers. Engine driven chillers allow the opportunity to recover waste heat on site for useful purposes.

Performance / Cost Characteristics » Commercial Centrifugal Chillers

Higher efficiencies than ref. case

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	350	350	350	350	350	350	350	350	350	350	350
Efficiency [full-load/IPLV] (kW/ton[1])	0.70 / 0.67	0.70 / 0.67	0.58 / 0.55	0.56 / 0.45	0.48 / 0.39	0.56 / 0.43	0.46 / 0.36	0.56 / 0.41	0.46 / 0.36	0.56 / 0.41	0.46 / 0.36
COP [full-load/IPLV] [1]	5.0 / 5.2	5.0 / 5.2	6.1 / 6.4	6.3 / 7.8	7.3 / 9.0	6.3 / 8.2	7.6 / 9.7	6.3 / 8.6	7.6 / 9.7	6.3 / 8.6	7.6 / 9.7
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($/ton)	250-350	250-350	250-350	300-400	400-500	300-400	400-500	300-400	400-500	300-400	400-500
Total Installed Cost ($/ton)	300-450	300-450	300-450	350-500	450-600	350-500	450-600	350-500	450-600	350-500	450-600
Annual Maintenance Cost ($/ton)	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30	15-30

* 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]2010 typical efficiency based on ASHRAE 90.1-2007.
[3]2010 mid efficiency based on FEMP recommendations.

- 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.
- The ASHRAE 90.1-2007 minimum efficiency requirements for centrifugal chillers greater than 300 tons capacity are the same as for 90.1-2004 (COP=6.10 full-load; COP=6.40 IPLV).
- The Federal Energy Management Program (FEMP) recommends a full -load efficiency of 0.56 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.45 kW/ton for chillers with seasonally variable loads.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed compressors
  - 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.

Performance / Cost Characteristics » Commercial Reciprocating Chillers

Same as Reference Case

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200
Efficiency [full-load/IPLV] (kW/ton[1])	1.26 / 1.15	1.26 / 1.15	1.26 / 1.15	1.23 / 0.90	1.00 / 0.80	1.23 / 0.90	1.00 / 0.80	1.23 / 0.90	1.00 / 0.80	1.23 / 0.90	1.00 / 0.80
COP [full-load/IPLV] [1]	2.80 / 3.05	2.80 / 3.05	2.80 / 3.05	2.86 / 3.91	3.52 / 4.40	2.86 / 3.91	3.52 / 4.40	2.86 / 3.91	3.52 / 4.40	2.86 / 3.91	3.52 / 4.40
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	400-500	400-500	400-500	450-550	500-600	450-550	500-600	450-550	500-600	450-550	500-600
Total Installed Cost ($/ton)	475-600	475-600	475-600	525-650	575-700	525-650	575-700	525-650	575-700	525-650	575-700
Annual Maintenance Cost ($/ton)	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40	25-40

[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]2010 typical efficiency based on ASHRAE 90.1-2007.
[3]2010 mid efficiency based on FEMP recommendations.

- 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 chiller market share.
- 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).
- The ASHRAE 90.1-2007 minimum efficiency requirements for air-cooled reciprocating chillers are the same as for 90.1-2004 (COP=2.80 full-load; COP=3.05 IPLV).
- The most recent Federal Energy Management Program (FEMP) recommendations for reciprocating chillers (published 11/03) include a full -load efficiency of 1.23 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.90 kW/ton for chillers with seasonally variable loads.
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Performance / Cost Characteristics » Commercial Screw Chillers

Higher typical efficiencies than ref. case

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical[2]	Mid[3]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300	100-300
Efficiency [full-load/IPLV] (kW/ton[1])	1.26 / 1.15	1.26 / 1.15	1.26 / 1.15	1.22 / 0.94	0.94 / 0.79	1.20 / 0.90	0.94 / 0.79	1.10 / 0.85	0.94 / 0.79	1.10 / 0.85	0.94 / 0.79
COP [full-load/IPLV] [1]	2.80 / 3.05	2.80 / 3.05	2.80 / 3.05	2.88 / 3.74	3.02 / 4.45	2.93 / 3.91	3.02 / 4.45	3.20 / 4.14	3.02 / 4.45	3.20 / 4.14	3.02 / 4.45
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	300-400	300-400	300-400	350-450	400-500	350-450	400-500	350-450	400-500	350-450	400-500
Total Installed Cost ($/ton)	375-500	375-500	375-500	400-525	450-575	400-525	450-575	400-525	450-575	400-525	450-575
Annual Maintenance Cost ($/ton)	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50	10-50

* 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]2010 typical efficiency based on ASHRAE 90.1-2007.

[3]2010 mid efficiency based on FEMP recommendations.

- 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).
- The ASHRAE 90.1-2007 minimum efficiency requirements for air-cooled screw chillers are the same as for 90.1-2004 (COP=2.80 full-load; COP=3.05 IPLV).
- The most recent Federal Energy Management Program (FEMP) recommendations for 150+ ton screw chillers (published 12/10) include a full -load efficiency of 1.22 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.94 kW/ton for chillers with seasonally variable loads.
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Improved heat-exchangers

Performance / Cost Characteristics » Commercial Scroll Chillers

Same as Reference Case

DATA	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)*	20-140	20-140	20-140	20-140	20-140	20-140
Efficiency [full-load/IPLV] (kW/ton[1])	1.26 / 1.15	1.26 / 1.15	1.19/0.80	1.19/0.80	1.19/0.80	1.19/0.80
COP [full-load/IPLV] [1]	2.80 / 3.05	2.80 / 3.05	2.96/4.40	2.96/4.40	2.96/4.40	2.96/4.40
Average Life (yrs)	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	300-400	300-400	350-450	350-450	350-450	350-450
Total Installed Cost ($/ton)	400-500	400-500	450-550	450-550	450-550	450-550
Annual Maintenance Cost ($/ton)	35-50	35-50	35-50	35-50	35-50	35-50

* 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.

- 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).
- The most recent Federal Energy Management Program (FEMP) recommendations for <150 ton scroll chillers (published 12/10) include a full -load efficiency of 1.19 or less kW/ton for base-loaded chillers or an integrated part-load value efficiency of 0.80 kW/ton for chillers with seasonally variable loads.
- The highest efficiency screw chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Performance / Cost Characteristics » Commercial Rooftop Air Conditioners

Lower costs than ref. case

DATA	2003	2007	2010	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	Mid-Range	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)	9.2	10.1	11.2	11.2	12.7	13.9	11.2	13.9	11.2	13.9	11.2	13.9
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3300-4500	4000-5100	5500-6500	5500-6500	7000-8000	20000-21000	4900-5900	14875-15875	4900-5900	14875-15875	4900-5900	14875-15875
Total Installed Cost ($)	5000-6200	5700-7000	7500-8500	7500-8500	9000-10000	22000-24000	6900-7900	20700-22900	6900-7900	20700-22900	6900-7900	20700-22900
Annual Maintenance Cost ($)	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300

* Capacity is *input*

- Effective January 1, 2010, the minimum efficiency standards for commercial rooftop air conditioners are as follows:

Air-Cooled Products	Efficiency Standards
≥ 65 - < 135 kBtu/h	11.2/11.0 EER
≥ 135 - < 240 kBtu/h	11.0/10.8 EER

- Above, two EERs are listed. The first refers to systems with electric resistance heat or no heating, and the second refers to systems with all other heating system types that are integrated into the unitary equipment.
- This analysis examined 90,000 BTU/h (7.5 ton), cooling only units.
- 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.
- Future increases in efficiency will result from the inclusion of more efficient compressors, larger heat exchanges, further advances in enhanced heat exchanger surfaces, and through the use of evaporative coolers.

Performance / Cost Characteristics » Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners

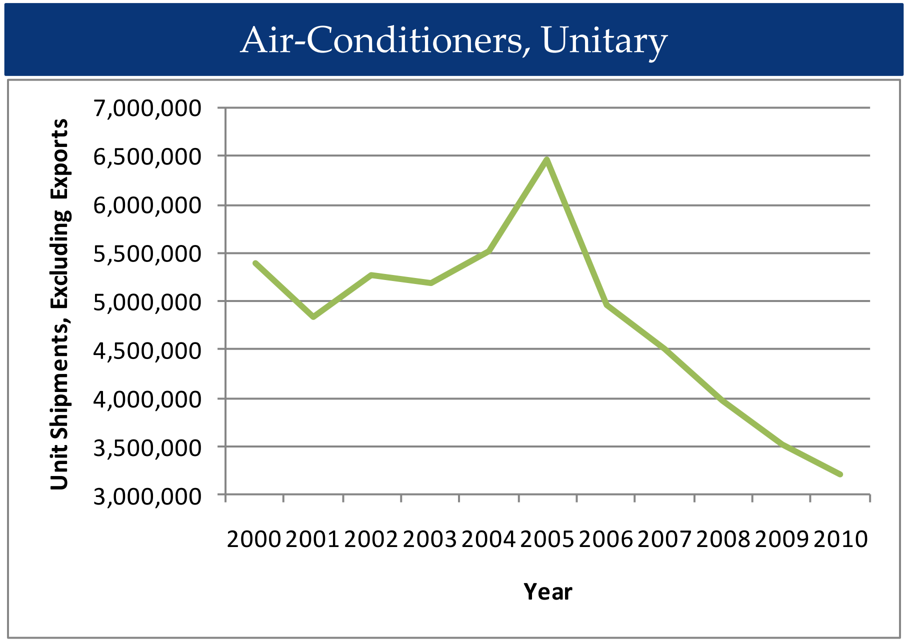
Same as Reference Case

DATA	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	25	25	11	11	11	11
Heating COP	NA	NA	1.4	1.4	1.4	1.4
Cooling COP	0.7	0.7	1.1	1.1	1.1	1.1
Average Life (yrs)	30	30	30	30	30	30
Retail Equipment Cost ($/ton)	775-835	775-835	775-835	775-835	775-835	775-835
Total Installed Cost ($/ton)	1200-1300	1200-1300	1200-1300	1200-1300	1200-1300	1200-1300
Annual Maintenance Cost ($)	55	55	55	55	55	55

* Capacity is *output*

- 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 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.

Since the last analysis was performed in 2007, there has been a decrease in unitary (rooftop) air conditioner shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

This data includes both residential and commercial units. It should be noted that the vast majority of rooftop air conditioners are residential, not commercial.

Performance / Cost Characteristics » Commercial Rooftop Heat Pumps

Higher efficiencies and higher cost than ref. case

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)	9.3	9.8	11.0/10.8*	11.0	12.0	11	13	11	15	11	15
COP (Heating)	3.1	3.2	3.3	3.3	3.4	3.3	3.4	3.3	3.4	3.3	3.8
Average Life (yrs)	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost ($)	3500-4500	4000-5000	5000-6000	5000-6000	5500-6500	5000-6000	6000-7000	5000-6000	6900-7900	5000-6000	6300-7300
Total Installed Cost ($)	5000-6500	6000-7100	6500-7300	6500-7300	7900-9500	6500-7300	8400-9400	6500-7300	9300-10300	6500-7300	8700-9700
Annual Maintenance Cost ($)	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150	100-150

* Capacity is *output*

** The first EER refers to systems with electric resistance heat or no heating, and the second refers to systems with all other heating system types that are integrated into the unitary equipment.

- Effective January 1, 2010, the minimum efficiency standards for commercial rooftop heat pumps are as follows:

Air-Cooled Products	Efficiency Standards
≥ 65 - < 135 kBtu/h	11.0./10.8 EER 3.3 COP @47^{0}F
≥ 135 - < 240 kBtu/h	10.6/10.4 EER 3.2 COP @47^{0}F

- Above, two EERs are listed. The first refers to systems with electric resistance heat or no heating, and the second refers to systems with all other heating system types that are integrated into the unitary equipment.
- Installed costs vary widely depending on size of building and unit for retrofit applications.

Performance / Cost Characteristics » Commercial Ground Source Heat Pumps

Lower installed costs than ref. case

DATA	2003	2007	2010		2020		2030		2035	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBTU/h)*	80-100	80-100	80-100	80-100	80-100	80-100	80-100	80-100	80-100	80-100
COP (Heating)	3.4	3.5	3.5	4.9	3.5	4.9	3.5	4.9	3.5	4.9
EER (Cooling)	13.8	14	14	27.8	14	27.8	14	27.8	14	27.8
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	7000-8000	7000-8000	7000-8000	10000-12000	7000-8000	10000-12000	7000-8000	10000-12000	7000-8000	10000-12000
Total Installed Cost ($)	14000-15000	14000-15000	14000-15000	17000-20000	12000-13000	15000-17000	12000-13000	15000-17000	12000-13000	15000-17000
Annual Maintenance Cost (¢/sqft)	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15	12-15

* Capacity is *output*

- There is no Federal standard for commercial ground source heat pumps.
- Commercial design applications vary in size, style, and configuration.
- 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 employ groundwater, or surface water such as a pond or lake, but water supply and water quality issues impose limitations on such applications.
- Input and output ratios (i.e., efficiencies) of a given machine change with different entering water temperatures, air flow rates, water flow rates, and relative humidity.
- Useful life is based on the expected life of the compressor. Replacement cost would be less than installed cost, since the ground loop is already in place and would have a useful life much longer than the compressor. A closed-loop system can last up to 50 years.
- There is an expectation that large, central facilities are used in commercial buildings. This is not always the case. Distributed, small units with zonal ducting and controls are almost always more efficient and less expensive.
- Adoption of commercial ground source heat pumps is slow due to the high initial cost.

Performance / Cost Characteristics » Commercial Electric Resistance Heaters

Same as Reference Case

DATA	2010		2020		2030		2035	
	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBTU/h)*	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
Average Life (yrs)	18	18	18	18	18	18	18	18
Retail Equipment Cost ($)	500-700	3400-3800	500-700	3400-3800	500-700	3400-3800	500-700	3400-3800
Total Installed Cost ($)	600-800	3500-3900	600-800	3500-3900	600-800	3500-3900	600-800	3500-3900
Annual Maintenance Cost ($) **	-	-	-	-	-	-	-	-

* Capacity is *output*

* *Annual Maintenance Cost is negligible

- This analysis examined electric unit heaters
- Electric unit heaters range in capacity from 14 to 170 kBtu/hr, with 17 and 170 kBtu/hr being the most typical units on the market
- Electric resistance heaters are considered 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

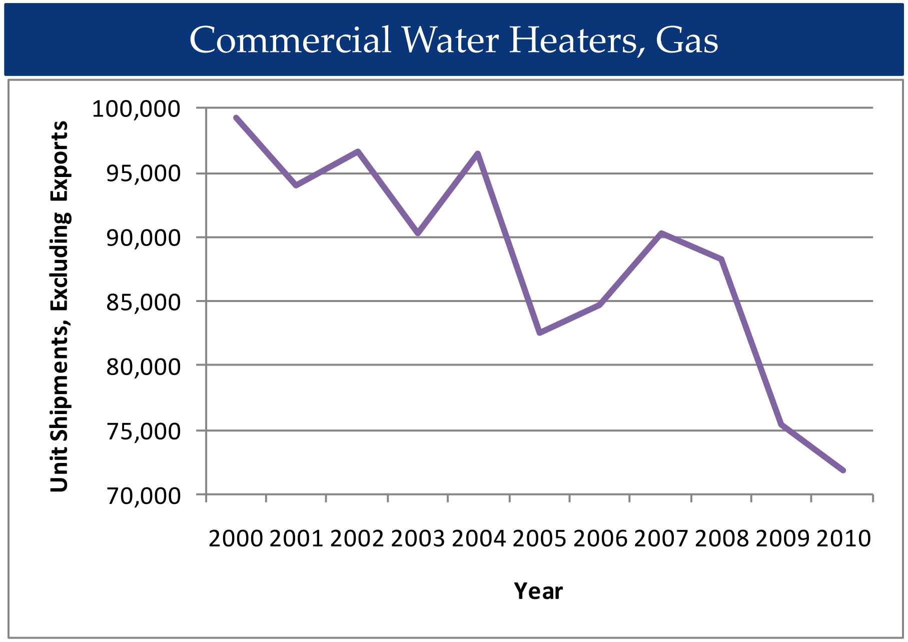
Performance / Cost Characteristics » Commercial Gas-Fired Water Heaters

Higher efficiencies for high efficiency units

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical 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	78	80	80	96	80	96	80	99	80	99
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost ($)	2800-4200	3000-4500	3500-4500	3500-4500	5000-6500	3500-4500	5000-6500	3500-4500	5000-6500	3500-4500	5000-6500
Total Installed Cost ($)	3200-4700	3500-5000	4000-5000	4000-5000	5500-7000	4000-5000	5500-7000	4000-5000	5500-7000	4000-5000	5500-7000
Annual Maintenance Cost ($)	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200

- Commercial gas-fired water heaters with a capacity of 75,000 BTU/h or more must meet a thermal efficiency standard of 80% as stipulated in ASHRAE Standard 90.1-2007.
- Baseline units are constructed quite similarly to residential units, though typically at higher storage and/or input capacities.
- High-efficiency, integrated commercial storage water heaters 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 for water heaters consists of sediment and scale removal once or twice per year. Estimated cost for a gas water heater would be $100 per year for one cleaning performed by a plumber.

Since the last analysis was performed in 2007, there has been a decrease in commercial gas-fired water heater shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

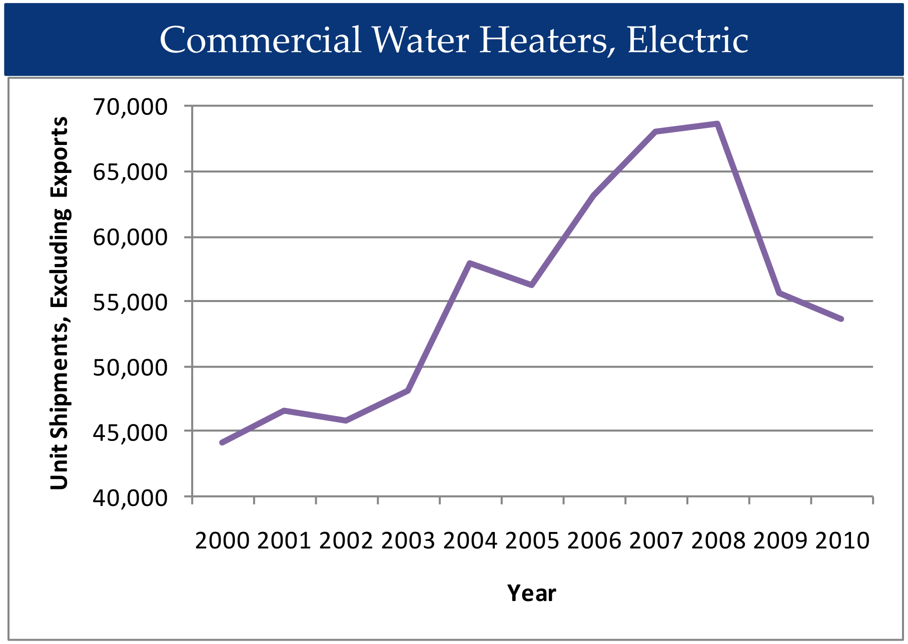
Performance / Cost Characteristics » Commercial Electric Resistance Water Heaters

Same as Reference Case

DATA	2003	2007	2010	2010	2020	2030	2035
	Installed Base		Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (gal)	120	120	120	120	120	120	120
Typical Capacity (kW)	45	45	45	45	45	45	45
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (yrs)	14	14	14	14	14	14	14
Retail Equipment Cost ($)	3400-5300	3400-5300	3400-5300	3400-5300	3400-5300	3400-5300	3400-5300
Total Installed Cost ($)	4000-6000	4000-6000	4000-6000	4000-6000	4000-6000	4000-6000	4000-6000
Annual Maintenance Cost ($)	50	50	50	50	50	50	50

- The EPACT standard will remain in effect for electric water heaters.
- The most efficient units on the market include an electric booster element as backup.

Since the last analysis was performed in 2007, there has been a decrease in commercial electric resistance water heater shipments.



Source: Appliance Magazine 2010, U.S. Appliance Shipment Statistics Monthly: January 2011

Performance / Cost Characteristics » Commercial Oil-Fired Water Heaters

Same as Reference Case

DATA	2003	2007	2010	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	70	70	70	70	70	70	70	70	70	70	70	70
Typical Input Capacity (kBTU/h)	300	300	300	300	300	300	300	300	300	300	300	300
Thermal Efficiency (%)	78	79	78	80	82	85	80	85	80	85	80	85
Average Life (yrs)	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20	12-20
Retail Equipment Cost ($)	4100	4150	4100	4200	4300	4400	4200	4400	4200	4400	4200	4400
Total Installed Cost ($)	4600	4650	4600	4700	4800	4900	4700	4900	4700	4900	4700	4900
Annual Maintenance Cost ($)	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200

- Commercial oil-fired water heaters with a capacity of 105,000 BTU/h or more must meet a thermal efficiency standard of 78% as stipulated in ASHRAE Standard 90.1-2007.
- Condensing commercial water heaters do not exist, the highest attainable efficiency with oil-fired storage water heaters is thus about 86% TE.
- Maintenance for commercial oil-fired water heaters consists of sediment and scale removal once or twice per year.

Performance / Cost Characteristics » Commercial Gas-Fired Instantaneous Water Heaters

Higher efficiencies for high efficiency units

DATA	2003	2007	2010	2010		2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230	180-230
Thermal Efficiency (%)	76	77	80	84	85	84	90	84	92	84	92
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($)	500-750	600-850	800-1000	1250-1300	1350-1450	1250-1300	1350-1450	1250-1300	1350-1450	1250-1300	1350-1450
Total Installed Cost ($)	650-900	750-1000	900-1250	1500-1800	1600-2000	1500-1800	1600-2000	1500-1800	1600-2000	1500-1800	1600-2000
Annual Maintenance Cost ($)	-	-	-	-	-	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

- Commercial gas-fired instantaneous water heaters with a capacity of 200,000 BTU/h or more must meet a thermal efficiency standard of 80% as stipulated in ASHRAE Standard 90.1-2007.
- Commercial instantaneous systems 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.
- Using multiple water heaters located at the source improves the efficiency of the system, but at a higher installed cost. Each smaller, point-of-use electric instantaneous water heater retails for approximately $150-$250. They typically have a storage capacity of 2-7 gallons.

Performance / Cost Characteristics » Commercial Electric Booster Water Heaters

Same as Reference Case

DATA	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (kBtu/hr)	100-200	100-200	100-200	100-200	100-200	100-200
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	3-8	3-8	3-8	3-8	3-8	3-8
Retail Equipment Cost ($)	1200-1500	1200-1500	1200-1500	1200-1500	1200-1500	1200-1500
Total Installed Cost ($)	1400-1700	1400-1700	1400-1700	1400-1700	1400-1700	1400-1700
Annual Maintenance Cost ($) *	-	-	-	-	-	-

* Annual Maintenance Cost is negligible

Performance / Cost Characteristics » Commercial Gas Booster Water Heaters

Same as Reference Case

DATA	2003	2007	2010			2020		2030		2035	
	Installed Base		Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200
Thermal Efficiency (%)	79	79	80	80	90	82	92	85	95	85	95
Average Life (yrs)	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8	3-8
Retail Equipment Cost ($)	5000-6000	5000-6000	5000-6000	5000-6000	10000-11000	5000-6000	10000-11000	5000-6000	10000-11000	5000-6000	10000-11000
Total Installed Cost ($)	5300-6300	5300-6300	5300-6300	5300-6300	10300-11300	5300-6300	10300-11300	5300-6300	10300-11300	5300-6300	10300-11300
Annual Maintenance Cost ($)	150	150	150	150	150	150	150	150	150	150	150

- Booster water heaters are used for high water temperature applications, which typically include commercial dishwashers, laundromats, hospitals, and car washes where water temperature must reach higher than 180^{0}F.
- 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 90.1-2007 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.

Appendix A
Data Sources

Navigant Consulting, Inc.
1801 K Street, NW, Suite 500
Washington, D.C. 20006
(202) 973-2400

www.navigantconsulting.com

Data Sources » Residential Gas-Fired Water Heaters

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (gal)	AHRI / Distributors	EERE			AHRI / Distributors	NCI		
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			Distributors / RS Means 2010			
Annual Maintenance Cost ($)	EERE							

Data Sources » Residential Oil Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>Mid-Level</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td>EERE</td><td colspan="2">AHRI</td><td>EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Energy Factor</td><td>AHRI</td><td>EERE</td><td colspan="3">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">Ka-BOOM!</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors</td><td colspan="4">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors / RS Means 2007</td><td colspan="4">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE</td></tr>
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Data Sources » Residential Electric Resistance Water Heaters

<table>
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<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td colspan="3">EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Energy Factor</td><td>AHRI</td><td>EERE</td><td>DEER, 2008</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors</td><td colspan="3">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors / RS Means 2010</td><td colspan="3">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="4">EERE</td></tr>
</table>

Data Sources » Residential Heat Pump Water Heaters

SOURCES	2005	2010		2020	2030	2035
	Installed Base	ENERGY STAR	High	Typical / High		
Typical Capacity (gal)	AHRI	EERE		NCI		
Energy Factor	AHRI	ENERGY STAR	AHRI			
Average Life (yrs)	ACEEE, 2007	EERE				
Retail Equipment Cost w/o Tank($)	RS Means 2010 / ACEEE, 2007	EERE / Distributors				
Total Installed Cost w/o Tank ($)	RS Means 2010 / ACEEE, 2007	EERE / Distributors				
Annual Maintenance Cost ($)	EERE					

Data Sources » Residential Instantaneous Water Heaters

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (BTU/h)	EERE					NCI		
Energy Factor	Distributors	EERE	AHRI	ENERGY STAR	Distributors			
Average Life (yrs)	ENERGY STAR	EERE						
Retail Equipment Cost w/o Tank ($)	Distributors / RS Means 2010	EERE						
Total Installed Cost w/o Tank ($)	DEER, 2008	EERE						
Annual Maintenance Cost ($)	NCI	EERE						

Data Sources » Residential Solar Water Heaters

SOURCES	2005	2010	2010	2020	2030	2035
	Installed Base	Typical	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

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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/h)</td><td colspan="2">AHRI</td><td colspan="2">Distributors</td><td>AHRI</td><td colspan="3" rowspan="7">NCI / Max Tech
(Desroches)</td></tr>
<tr><td>AFUE (%)</td><td>AHRI</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Electric Consumption (kWh/yr)</td><td>AHRI</td><td colspan="3">EERE</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="4">EERE</td><td>Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE</td></tr>
</table>

Data Sources » Residential Oil-Fired Furnaces

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</th></tr>
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<tr><td>Typical Capacity (kBTU/h)</td><td colspan="3">AHRI</td><td>Distributors</td><td>AHRI</td><td colspan="3" rowspan="7">NCI / Max Tech (Desroches)</td></tr>
<tr><td>AFUE (%)</td><td>AHRI</td><td>EERE</td><td>AHRI</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Electric Consumption (kWh)</td><td>AHRI</td><td colspan="4">EERE</td></tr>
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</table>

Data Sources » Residential Hydronic Heating Systems (Boilers)

<table>
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<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/h)</td><td colspan="5">EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>AFUE (%)</td><td>AHRI</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="5">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE</td></tr>
</table>

Data Sources » Residential Room Air Conditioners

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBTU/h)	Distributors		AHAM			NCI		
EER	Distributors	Federal Standard	AHAM	ENERGY STAR	AHAM			
Average Life (yrs)	Appliance Magazine, 2005	Ka-BOOM!	Ka-BOOM! / Appliance Magazine, 2010					
Retail Equipment Cost ($)	Distributors							
Total Installed Cost ($)	Distributors							
Annual Maintenance Cost ($)	NCI							

Data Sources » Residential Central Air Conditioners

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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/h)</td><td colspan="2">Distributors</td><td colspan="3">EERE</td><td colspan="3" rowspan="6">NCI / Max Tech (Desroches)</td></tr>
<tr><td>SEER</td><td>Distributors</td><td>Federal Standard</td><td>EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors</td><td colspan="3">EERE / Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors</td><td colspan="4">EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>NCI</td><td colspan="4">EERE</td></tr>
</table>

Data Sources » Residential Air Source Heat Pumps

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (kBTU/h)	Distributors / Product Literature		AHRI			NCI / Max Tech (Desroches)		
HSPF (Heating)	AHRI	Federal Standard	AHRI	ENERGY STAR	AHRI / CEC			
SEER (Cooling)	AHRI	Federal Standard	AHRI	ENERGY STAR	AHRI / CEC			
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	Distributors / RS Means 2010 / NCI	EERE						
Total Installed Cost ($)	Distributors / RS Means 2010 / NCI	EERE						
Annual Maintenance Cost ($)	NCI							

Data Sources » Residential Ground Source Heat Pumps

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	Mid-Range	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI/SAIC					NCI / Max Tech (Desroches)		
COP (Heating)	SAIC	ASHRAE 90.1-2007, ENERGY STAR						
EER (Cooling)	SAIC	ASHRAE 90.1-2007, ENERGY STAR						
Average Life (yrs)	System life 25 years, ground loop life 50 years (EERE)							
Retail Equipment Cost ($)	Distributors / CEC							
Total Installed Cost ($)	Distributors / CEC							
Annual Maintenance Cost ($)	SAIC							

Data Sources » Residential Gas Heat Pumps

SOURCES	2005	2010	2010	2020	2030	2035
	Installed Base	Current Standard	Typical	Typical		
Typical Capacity (kBTU/h)	Manufacturer/SAIC			SAIC		
Heating (GCOP)	Manufacturer/SAIC	Manufacturer/SAIC	Manufacturer/SAIC			
Cooling (GCOP)	Manufacturer/SAIC	CEC/T24	Manufacturer/SAIC			
Annual Electric Use (kWh/yr)	Manufacturer/SAIC					
Average Life (yrs)	SAIC					
Retail Equipment Cost ($)	SAIC					
Total Installed Cost ($)	SAIC					
Annual Maintenance Cost ($)	SAIC					

Data Sources » Residential Refrigerator / Freezer

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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>Energy Consumption (kWh/yr)</td><td>Distributors</td><td>ENERGY STAR</td><td>CEC</td><td>ENERGY STAR</td><td>CEC</td><td colspan="3" rowspan="5">NCI / Max Tech
(Desroches)</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td>Ka-BOOM!</td><td colspan="3">Ka-BOOM! /
Appliance Magazine, 2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE /
Distributors</td><td colspan="4">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Distributors /
RS Means 2010</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>NCI</td><td colspan="4">EERE</td></tr>
</table>

Data Sources » Residential Natural Gas Cooktops

SOURCES	2005	2010		2020	2030	2035
	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBTU/h)	Distributors / Product Literature	EERE				
Cooking Efficiency (%)	Distributors / Product Literature	EERE				
Average Life (yrs)	Appliance Magazine, 2005	Appliance Magazine, 2010		NCI		
Retail Equipment Cost ($)	EERE					
Total Installed Cost ($)	EERE					
Annual Maintenance Cost ($)	NCI / EERE					

Data Sources » Residential Clothes Washers

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High		
Typical Capacity (ft3)	Distributors	CEC		ENERGY STAR	CEC	NCI / Max Tech (Desroches)		
Modified Energy Factor (ft3/kWh/cycle)	Distributors	Standards	CEC	ENERGY STAR	CEC			
Average Life (yrs)	Appliance Magazine, 2005 / EERE	Ka-BOOM! / Appliance Magazine, 2010						
Water Consumption (gal/cycle)	EERE / Distributors	CEC						
Hot Water Energy (kWh/cycle)	EERE / Distributors							
Machine Energy (kWh/cycle)	EERE / Distributors							
Dryer Energy (kWh/cycle)	EERE / Distributors							
Retail Equipment Cost ($)	EERE / Distributors			DEER, 2008	EERE / Distributors			
Total Installed Cost ($)	RS Means 2010			DEER, 2008	RS Means 2010			
Annual Maintenance Cost ($)	NCI							

Data Sources » Residential Clothes Dryers

SOURCES	2005	2010	2010			2020	2030	2035
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical / High		
Typical Capacity (ft3)	NCI	CEC			CEC / Distributors	NCI / Max Tech (Desroches)		
EF (lb/kWh)	NCI	EERE						
Machine Energy (kWh/cycle)	NCI	EERE						
Average Life (yrs)	NCI	Ka-BOOM! / Appliance Magazine, 2010						
Retail Equipment Cost ($)	NCI	EERE						
Total Installed Cost ($)	NCI	EERE						
Annual Maintenance Cost ($)	EERE	EERE						

Data Sources » Residential Dishwashers

<table>
<tr><th rowspan="2">SOURCES</th><th>2005</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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 Annual Use (kWh/yr)</td><td>Product Literature</td><td>EERE</td><td>Distributors</td><td>ENERGY STAR</td><td>CEC</td><td colspan="3" rowspan="6">NCI / Max Tech (Desroches)</td></tr>
<tr><td>Efficiency (cycle/kWh)</td><td>NCI</td><td colspan="2">EERE</td><td colspan="2">CEC</td></tr>
<tr><td>Average Life (yrs)</td><td>Appliance Magazine, 2005</td><td colspan="4">Ka-BOOM! /
Appliance Magazine, 2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE</td><td colspan="3">Distributors</td><td>EERE</td></tr>
<tr><td>Total Installed Cost ($)</td><td>EERE</td><td colspan="2">DEER, 2008</td><td>DEER, 2008</td><td>EERE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">NCI</td></tr>
</table>

Data Sources » Commercial Gas-Fired Furnaces

SOURCES	2003	2007	2010	2010		2020	2030	2035
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Capacity (kBTU/h)	Arthur D. Little, 1997		AHRI			NCI		
AFUE	ASHRAE Standard 90.1-2004		ASHRAE Standard 90.1-2004 / CEC	AHRI				
Average Life (yrs)	2003 ASHRAE Handbook – HVAC Applications		Appliance Magazine, 2010					
Retail Equipment Cost ($)	RS Means 2010/ NCI / Distributors		RS Means 2010					
Total Installed Cost ($)	RS Means 2010/ NCI / Distributors		RS Means 2010					
Annual Maintenance Cost ($)	RS Means 2010/ NCI / Distributors							

Data Sources » Commercial Oil-Fired Furnaces

SOURCES	2003	2007	2010	2010	2020	2030	2035
	Installed Base		Current Standard	Typical	Typical		
Typical Capacity (kBTU/h)	NCI / Distributors / AHRI		AHRI		NCI		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004	AHRI	AHRI / CEC	AHRI			
Average Life (yrs)	2003 ASHRAE Handbook – HVAC Applications		Appliance Magazine, 2010				
Retail Equipment Cost ($)	RS Means 2010						
Total Installed Cost ($)	RS Means 2010						
Annual Maintenance Cost ($)	NCI / Distributors						

Data Sources » Commercial Electric Boilers

SOURCES	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical		
Typical Capacity (kW)	BSRIA			SAIC		
Efficiency (%)	SAIC					
Average Life (yrs)	ASHRAE 2007 HVAC Applications					
Retail Equipment Cost ($)	RS Means/SAIC					
Total Installed Cost ($)	RS Means/SAIC					
Annual Maintenance Cost ($)	RS Means/SAIC					

Data Sources » Commercial Gas-Fired Boilers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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 Capacity (kBTU/h)</td><td>Arthur D. Little /
Building Services Research and Information Association & Ducker Research Company, 1997, 1998</td><td>NCI</td><td colspan="4">EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Combustion Efficiency (%)</td><td colspan="2">ASHRAE Standard 90.1-2004</td><td>CEC</td><td colspan="3">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">Building Services Research and Information Association & Ducker Research Company, 1997, 1998 /
Appliance Magazine, 2005</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>CEC /
RS Means 2010</td><td>DEER, 2008</td><td colspan="4">EERE /
Appliance Magazine, 2010</td></tr>
<tr><td>Total Installed Cost ($)</td><td>CEC /
RS Means 2010</td><td>NCI</td><td colspan="4">EERE /
Appliance Magazine, 2010</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="2">NCI</td><td colspan="4">EERE /
Appliance Magazine, 2010</td></tr>
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Data Sources » Commercial Oil-Fired Boilers

<table>
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<tr><td>Typical Capacity (kBTU/h)</td><td>Building Services Research and Information Association & Ducker Research Company, 1997, 1998</td><td>NCI</td><td colspan="3">EERE</td><td colspan="3" rowspan="6">NCI</td></tr>
<tr><td>Combustion Efficiency (%)</td><td colspan="3">ASHRAE Standard 90.1-2004</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / NCI</td><td colspan="3">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors / RS Means 2010 / NCI</td><td colspan="3">EERE</td></tr>
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<tr><td>Annual Maintenance Cost ($)</td><td colspan="2">NCI</td><td colspan="3">EERE</td></tr>
</table>

Data Sources » Commercial Gas-Fired Chillers

SOURCES	2003		2007		2010		2020		2030		2035	
	Installed Base: Absorp-tion	Installed Base: Engine-Driven	Installed Base: Absorp-tion	Installed Base: Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven	Absorp-tion	Engine-Driven
Typical Capacity (tons)	BSRIA/Distributors											
Efficiency (kW/ton)	Product Literature/SAIC											
COP												
Average Life (yrs)	2007 ASHRAE Applications Handbook/Distributors											
Retail Equipment Cost ($/ton)	Distributors/RS Means/SAIC											
Total Installed Cost ($/ton)												
Annual Maintenance Cost ($/ton)												

Data Sources » Commercial Centrifugal Chillers

SOURCES	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	US Census		SAIC								
Efficiency (kW/ton)	DEER/FEMP/Product Literature							SAIC			
COP	DEER/FEMP/Product Literature							SAIC			
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	2007	2010			2020		2030		2035	
	Installed Base		Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	BSRIA / DEER		SAIC								
Efficiency (kW/ton)	DEER/FEMP/Product Literature							SAIC			
COP											
Average Life (yrs)	Manufacturers										
Retail Equipment Cost ($/ton)	RS Means/Distributors/SAIC										
Total Installed Cost ($/ton)											
Annual Maintenance Cost ($/ton)	SAIC										

Data Sources » Commercial Screw Chillers

SOURCES	2003	2007	2010			2020		2030		2035	
	Installed Base		Typical	Mid	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	SAIC										
Efficiency (kW/ton)	DEER/FEMP/Product Literature							SAIC			
COP	DEER/FEMP/Product Literature							SAIC			
Average Life (yrs)	Manufacturers										
Retail Equipment Cost ($/ton)	RS Means/Distributors/SAIC										
Total Installed Cost ($/ton)	RS Means/Distributors/SAIC										
Annual Maintenance Cost ($/ton)	SAIC										

Data Sources » Commercial Scroll Chillers

SOURCES	2003	2007	2010	2020	2030	2035
	Installed Base		Typical	Typical	Typical	Typical
Typical Capacity (tons)	SAIC/Manufacturers					
Efficiency [full-load/IPLV] (kW/ton)	Product Literature			SAIC		
COP [full-load/IPLV]						
Average Life (yrs)	Manufacturers					
Retail Equipment Cost ($/ton)	RS Means/SAIC					
Total Installed Cost ($/ton)						
Annual Maintenance Cost ($/ton)	SAIC					

Data Sources » Commercial Rooftop Air Conditioners

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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 Capacity (kBTU/h)</td><td colspan="6">AHRI / NCI</td><td colspan="3" rowspan="6">NCI / Max Tech (Desroches)</td></tr>
<tr><td>Efficiency (EER)</td><td>ASHRAE Standard 90.1-2004</td><td>Distributors / NCI</td><td colspan="2">EERE</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">2003 ASHRAE Handbook – HVAC Applications</td><td colspan="4">Appliance Magazine, 2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>NCI / LBNL, 2003</td><td>Distributors / NCI / DEER, 2008</td><td colspan="2">EERE</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>NCI / LBNL, 2003</td><td>Distributors / NCI / 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

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th>2020</th><th>2030</th><th>2035</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">Distributors</td></tr>
<tr><td>Heating COP</td><td colspan="2">NA</td><td>Product Literature</td><td colspan="3" rowspan="7">Distributors/SAIC</td></tr>
<tr><td>Cooling COP</td><td colspan="3">Product Literature</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3" rowspan="4">Distributors/SAIC</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td></tr>
<tr><td>Total Installed Cost ($/ton)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial Rooftop Heat Pumps

SOURCES	2003	2007	2010	2010		2020	2030	2035
	Installed Base		Current Standard	Typical	High	Typical / High		
Typical Capacity (kBTU/h)	AHRI					NCI / Max Tech (Desroches)		
Efficiency (EER)	ASHRAE Standard 90.1-2004		EERE					
COP (Heating)	NCI / EERE		EERE					
Average Life (yrs)	2003 ASHRAE Handbook - HVAC Applications							
Retail Equipment Cost ($)	Distributors / RS Means 2010 / NCI / DEER							
Total Installed Cost ($)	Distributors / RS Means 2010 / NCI / DEER							
Annual Maintenance Cost ($)	Distributors / RS Means 2010 / NCI / DEER							

Data Sources » Commercial Ground Source Heat Pumps

SOURCES	2003	2007	2010		2020	2030	2035
	Installed Base		Typical	High	Typical / High		
Typical Capacity (kBTU/h)	GHPC				NCI / Max Tech (Desroches)		
COP (Heating)	IGSPHA / GHPC						
EER (Cooling)	GHPC						
Average Life (yrs)	GHPC						
Retail Equipment Cost ($)	NCI / Distributors						
Total Installed Cost ($)	NCI / Distributors						
Annual Maintenance Cost (¢/sqft)	GHPC						

Data Sources » Commercial Electric Resistance Heaters

DATA	2010		2020		2030		2035	
	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBTU/h)	Distributors		NCI					
Efficiency (%)	NCI							
Average Life (yrs)	Technology Cost and Performance File for Commercial Model for AEO2010							
Retail Equipment Cost ($)	Distributors							
Total Installed Cost ($)	Distributors							
Annual Maintenance Cost ($)	NCI							

Data Sources » Commercial Gas-Fired Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="2">2010</th><th>2020</th><th>2030</th><th>2035</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="3">Arthur D. Little / Distributors / AHRI</td><td colspan="2">AHRI</td><td colspan="3" rowspan="7">NCI / Max Tech (Desroches)</td></tr>
<tr><td>Typical Input Capacity (BTU/h)</td><td colspan="2">Arthur D. Little / AHRI</td><td colspan="2">CEC</td><td>AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="3">EERE / ASHRAE Standard 90.1-2004</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / Appliance Magazine, 2005</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="2">Distributors / CEC / NCI</td><td colspan="3">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">Distributors / CEC / NCI</td></tr>
<tr><td>Annual Maintenance Cost (¢/sqft)</td><td colspan="5">NCI</td></tr>
</table>

Data Sources » Commercial Electric Resistance Water Heaters

SOURCES	2003	2007	2010	2010	2020	2030	2035
	Installed Base		Current Standard	Typical	Typical		
Typical Capacity (gal)	NCI / Product Literature		AHRI		NCI / Max Tech (Desroches)		
Typical Capacity (kW)	Product Literature						
Thermal Efficiency (%)	Product Literature	ASHRAE Standard 90.1-2004	AHRI				
Average Life (yrs)	Appliance Magazine, 2005 / Building Services Research and Information Association & Ducker Research Company, 1997, 1998	Appliance Magazine, 2005					
Retail Equipment Cost ($)	Distributors / NCI	Distributors					
Total Installed Cost ($)	Distributors / NCI	NCI					
Annual Maintenance Cost ($)	NCI						

Data Sources » Commercial Oil-Fired Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="3">2010</th><th>2020</th><th>2030</th><th>2035</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 Capacity (gal)</td><td>NCI</td><td colspan="5">AHRI / NCI</td><td colspan="3" rowspan="7">NCI</td></tr>
<tr><td>Typical Input Capacity (kBTU/h)</td><td>NCI</td><td>AHRI / NCI</td><td colspan="4">AHRI / CEC</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>NCI</td><td>ASHRAE Standard 90.1-1999</td><td>ANSI / ASHRAE / IESNA Standard 90.1-2007</td><td colspan="3">AHRI / CEC</td></tr>
<tr><td>Average Life (yrs)</td><td>NCI</td><td colspan="5">Appliance Magazine, 2005</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>NCI</td><td colspan="5">Distributors / NCI</td></tr>
<tr><td>Total Installed Cost ($)</td><td>NCI</td><td>Distributors / NCI</td><td colspan="4">NCI</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>NCI</td><td>Distributors / NCI</td><td colspan="4">NCI</td></tr>
</table>

Data Sources » Commercial Gas-Fired Instantaneous Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2007</th><th>2010</th><th colspan="2">2010</th><th>2020</th><th>2030</th><th>2035</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>Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / AHRI</td><td>AHRI</td><td colspan="3">Building Services Research and Information Association & Ducker Research Company, 1997, 1998 / AHRI</td><td colspan="3" rowspan="6">NCI / Max Tech (Desroches)</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="2">AHRI</td><td colspan="3">ANSI / ASHRAE / IESNA Standard 90.1-2007</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>CEC / NCI / Distributors</td><td colspan="4">Distributors / NCI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="5">CEC / NCI / Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">CEC / NCI / Distributors</td></tr>
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Data Sources » Commercial Electric Booster Water Heaters

<table>
<tr><th rowspan="2">DATA</th><th>2003</th><th>2007</th><th>2010</th><th>2020</th><th>2030</th><th>2035</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th colspan="3">Typical</th></tr>
<tr><td>Typical Capacity (gal)</td><td colspan="3">SAIC/Distributors</td><td colspan="3" rowspan="6">SAIC</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="3" rowspan="2">Product Literature</td></tr>
<tr><td>Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="3" rowspan="3">SAIC/Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial Gas Booster Water Heaters

<table>
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<tr><td>Average Life (yrs)</td><td colspan="5">Product Literature/SAIC</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="5" rowspan="3">Distributors/SAIC</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Appendix B
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APPENDIX C

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

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DISCLAIMER

December 2012

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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.

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

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

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

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

Definitions

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

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

Calculations

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

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

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

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

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

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

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

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

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

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

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

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

Residential General Service Incandescent Lamps (60 and 75 Watts)

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

Performance/Cost Characteristics » Residential Reflector Lighting

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

Performance/Cost Characteristics » Residential Reflector Lighting

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

Residential Reflector Lamps

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

Performance/Cost Characteristics » Residential Compact Fluorescent Lighting

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

Residential Compact Florescent Lamps

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

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

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

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

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

Residential Linear Fluorescent Lighting (T12/T8)

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

Residential Linear Fluorescent Lighting (T12/T8)

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

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

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

Residential Linear Fluorescent Lighting (T5)

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

Residential Linear Fluorescent Lighting (T5)

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

Performance/Cost Characteristics » Residential Torchieres

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

Performance/Cost Characteristics » Residential Torchieres

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

Residential Torchieres

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

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

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

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

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

Residential Solid-State Lighting

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

Performance/Cost Characteristics » Commercial General Service Incandescent Lighting

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

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

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

Commercial General Service Incandescent Lighting

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

Performance/Cost Characteristics » Commercial Compact Fluorescent Lamps

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

Commercial Compact Fluorescent Lamps

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

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

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

Performance/Cost Characteristics » Commercial Halogen Lighting (Edison)

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

Commercial Halogen Lighting

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

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

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

Commercial Solid-State Lighting (Edison Socket Substitute)

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

Final

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

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

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

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

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

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

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

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

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

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

Commercial 4-ft T5 Linear Fluorescent Lighting

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

Commercial 4-ft T5 Linear Fluorescent Lighting

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

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

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

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

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

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

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

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

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

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

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

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

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

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

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

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

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

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

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

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

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

Commercial HID Low Bay Lighting (Metal Halide)

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

Commercial HID Low Bay Lighting (Metal Halide)

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

Final

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

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

Commercial HID Low Bay Lighting (High Pressure Sodium)

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

Commercial HID Low Bay Lighting (High Pressure Sodium)

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

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

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

Commercial Solid-State Lighting (Low Bay Applications)

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

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

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

Commercial HID High Bay Lighting (Metal Halide)

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

Commercial HID High Bay Lighting (Metal Halide)

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

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

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

Commercial HID High Bay Lighting (High Pressure Sodium)

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

Commercial HID High Bay Lighting (High Pressure Sodium)

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

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

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

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

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

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

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

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

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

Commercial Solid-State Lighting (High Bay Applications)

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

Commercial Supermarket Display Cases

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

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

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

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

Commercial Supermarket Display Cases

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

Commercial Compressor Rack Systems

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

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

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

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

Commercial Compressor Rack Systems

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

Commercial Condensers

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

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

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

Commercial Condensers

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

Commercial Walk-In Refrigerators

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

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

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

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

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

Commercial Walk-In Refrigerators

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

Commercial Walk-In Refrigerators

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

Commercial Walk-In Freezers

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

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

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

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

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

Commercial Walk-In Freezers

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

Commercial Walk-In Freezers

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

Commercial Reach-In Refrigerators

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

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

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

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

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

Commercial Reach-In Refrigerators

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

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

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

Commercial Reach-In Freezers

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

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

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

[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2011 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $816.

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

Commercial Reach-In Freezers

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

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

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

Commercial Ice Machines

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

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

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

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

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

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

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

Commercial Ice Machines

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

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

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

Commercial Ice Machines: EPACT 2005

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

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

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

Commercial Beverage Merchandisers

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

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

[2] ENERGY STAR® set energy consumption levels for glass door beverage merchandisers that went into effect in 2009. The 2011 Typical values are based on this energy consumption level.

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

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

Commercial Beverage Merchandisers

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

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

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

Commercial Refrigerated Vending Machines

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

[1] DOE's Federal energy standards for Refrigerated Beverage Vending Machines will go into effect on August 31, 2012. The 2020 Typical values are based on this standard.

[2] Energy use is based on a zone-cooled machine tested in 75°F steady state ambient conditions.

[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $75 and $104 respectively. Installation cost for 2011 and beyond is based on DOE's Refrigerated Beverage Vending Machine rulemaking which assumes a cost of $84.

[4] Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils and also includes an annualized cost for refurbishments/remanufacturing.

Commercial Refrigerated Vending Machines

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

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

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

Commercial Constant Air Volume Ventilation

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

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

Commercial Constant Air Volume Ventilation

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

Commercial Variable Air Volume Ventilation

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

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

Commercial Variable Air Volume Ventilation

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

Commercial Fan Coil Unit

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

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

Commercial Fan Coil Unit

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

Appendix A
Data Sources

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

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

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

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

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

DATA SOURCES	2005	2009	2011			2013*		2020**	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	75W	75W	75W	75W	75W	75W	75W	75W	75W
Lamp Wattage	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Lumens									
Lamp Efficacy (lm/W)			Calculated						
Lamp Price			Distributor Websites						
Lamp Cost ($/klm)			Calculated						
Average Lamp Life (1000 hrs)			Product Catalogs						
CRI									

Data Sources » Residential Reflector Lamps

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

Data Sources » Residential Reflector Lamps

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

Final

Data Sources » Residential Compact Fluorescent Lamps

DATA SOURCES	2005	2009	2011				2020		2030		2040	
	Installed Base		Energy Star	Low	Typical	High	Typical	High	Typical	High	Typical	High
	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W	13W
Lamp Wattage	2008 EIA Reference Case		Product Catalogs	Product Catalogs			NCI, 2012					
Lamp Lumens												
Lamp Efficacy (lm/W)			Calculated	Calculated								
Lamp Price				Distributor Websites								
Lamp Cost ($/klm)				Calculated								
Average Lamp Life (1000 hrs)			Product Catalogs	Product Catalogs								
CRI												

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

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th colspan="2">2009</th><th colspan="7">2011</th></tr>
<tr><th colspan="3">Installed Base</th><th>Current Standard</th><th>Mid-Level T12</th><th>High T12</th><th>Baseline T8</th><th>Mid-Level T8</th><th>High T8</th></tr>
<tr><th>32WT8</th><th>40WT12</th><th>32WT8</th><th>40WT12</th><th>40WT12</th><th>34WT12</th><th>32WT8</th><th>32WT8</th><th>28WT8</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="12">2008 EIA Reference Case</td><td colspan="9" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>System Wattage</td><td colspan="9" rowspan="4">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Price ($)</td><td colspan="9">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>Ballast Price ($)</td><td colspan="9">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="9">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="9" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="9">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
</table>

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

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

Data Sources » Residential Linear Fluorescent Lamps (T5)

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

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<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th colspan="3">2009</th><th colspan="3">2011</th></tr>
<tr><th colspan="4">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>Typical</th><th>Inc.</th><th>Hal.</th><th>CFL</th><th>Inc.</th><th>Hal.</th><th>CFL</th></tr>
<tr><td>Lamp Wattage</td><td colspan="4" rowspan="7">2008 EIA Reference Case</td><td colspan="3" rowspan="2">Product Catalogs</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td></tr>
<tr><td>Lamp Price</td><td colspan="3">Distributor Websites</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">Product Catalogs</td></tr>
<tr><td>CRI</td></tr>
</table>

Data Sources » Residential Torchieres

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

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

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

Data Sources » Commercial General Service Incandescent Lighting

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

Data Sources » Commercial Compact Fluorescent Lamps

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>26W</th><th>26W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th><th>23W</th></tr>
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<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">Distributor Websites; NCI 2012; RSMeans 2007; Calculated</td></tr>
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Data Sources » Commercial Halogen Lighting (PAR 38)

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

Data Sources » Commercial Halogen Lighting (Edison)

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><th>90W Edison</th><th>90W Halogen</th><th>90W Halogen</th><th>90W Halogen</th><th>90W Halogen</th><th>90W Halogen</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td rowspan="2">Distributor Websites; Calculated</td><td colspan="3" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="4">Distributor Websites; Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>System Cost ($/klm)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td rowspan="2">Distributor Websites</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2">NCI 2012; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial Solid State Lighting (Edison Socket Substitute)

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

Data Sources » Commercial 4-ft T8 Linear Fluorescent Lighting

<table>
<tr><th rowspan="3">DATA</th><th>2003</th><th>2007</th><th colspan="5">2011</th></tr>
<tr><th colspan="2">Installed Base</th><th>Baseline</th><th>High Efficiency</th><th>HE w/ Occ. Sensor</th><th>HE w/ Spec. Reflector</th><th>HE w/ OS & Spec. Ref.</th></tr>
<tr><th>32WT8</th><th>32WT8</th><th>32WT8</th><th>28WT8</th><th>28WT8</th><th>28WT8</th><th>28WT8</th></tr>
<tr><td>System Wattage</td><td rowspan="12">2008 EIA Reference Case</td><td colspan="6" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="6" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="6" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="6">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
</table>

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

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

Data Sources » Commercial 4-ft T5 Linear Fluorescent Lighting

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>28WT5</th><th>28WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th></tr>
<tr><td>System Wattage</td><td rowspan="11">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td><td colspan="6" rowspan="11">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="3">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
</table>

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

DATA SOURCES	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8
Wattage	2008 EIA Reference Case	Calculated				
Lumens		Product Catalogs				
Efficacy (lm/W)		Product Catalogs		2012 SSL MYPP		
Cost ($/klm)				2012 Energy Savings Forecast Model		
Life (1000 hrs)						
CRI				NCI, 2012		
CCT						
Total Installed Cost ($)				RSMeans 2007; Calculated		
Annual Maintenance Cost ($)						

Data Sources » Commercial 8-ft Linear Fluorescent Lighting

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

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

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

Data Sources » Commercial 8-ft Linear Fluorescent Lighting (High Output)

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

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

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

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

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

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

<table>
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<tr><th colspan="2">Installed Base</th><th>HPS</th><th>HPS</th><th>HPS</th><th>HPS</th></tr>
<tr><th>LED</th><th>LED</th><th>100W HPS LED</th><th>100W HPS LED</th><th>100W HPS LED</th><th>100W HPS LED</th></tr>
<tr><td>Typical Wattage</td><td colspan="2" rowspan="9">2008 EIA Reference Case</td><td colspan="4">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="4">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3" rowspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

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

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

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

<table>
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<tr><th colspan="3">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>400W MV</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th><th>150W HPS</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3">DOE Energy Conservation Standards, 2010</td></tr>
<tr><td>CRI</td><td colspan="3">Product Catalogs</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial T5 HO Lighting (High Bay Applications)

<table>
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<tr><th colspan="2">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>54WT5HO</th><th>54WT5HO</th><th>54WT5HO</th><th>51WT5HO</th><th>54WT5HO</th><th>51WT5HO</th><th>54WT5HO</th><th>51WT5HO</th><th>54WT5HO</th><th>51WT5HO</th></tr>
<tr><td>System Wattage</td><td rowspan="11">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated</td><td colspan="6" rowspan="11">NCI, 2012</td></tr>
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<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="3">DOE Ballast Energy Conservation Standard, 2011</td></tr>
</table>

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

DATA SOURCES	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	150W HPS LED	150W HPS LED	150W HPS LED	150W HPS LED
Typical Wattage	2008 EIA Reference Case		Calculated			
Lumens			Product Catalogs			
Efficacy (lm/W)			Product Catalogs	2012 SSL MYPP		
Cost ($/klm)				2012 Energy Savings Forecast Model		
Average Lamp Life (1000 hrs)						
CRI				NCI, 2012		
CCT						
Total Installed Cost ($)				RSMeans 2007; Calculated		
Annual Maintenance Cost ($)						

Data Sources » Commercial Supermarket Display Cases

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td>DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2009 / DOE, 2011 / FMI, 2012 / NCI Analysis 2012</td></tr>
<tr><td>Median Store Size (ft^3)</td><td colspan="5">Food Marketing Institute (FMI), 2012</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td rowspan="5">DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009 / NCI Analysis, 2012</td><td colspan="3" rowspan="5">DOE, 2011</td></tr>
<tr><td>Average Life (yrs)</td><td rowspan="4">NCI, 2009</td></tr>
<tr><td>Retail Equipment Cost</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td></tr>
</table>

Final

Data Sources » Commercial Compressor Rack Systems

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="2">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Total Capacity (MBtu/hr)</td><td>ADL, 1996</td><td rowspan="5">NCI, 2009 / NCI Analysis, 2012</td><td rowspan="6" colspan="8">NCI, 2009 / NCI Analysis, 2012 / ADL, 1996</td></tr>
<tr><td>Power Input (kW)</td><td>Copeland, 2008</td></tr>
<tr><td>Energy Use (MWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td></tr>
<tr><td>Average Life (yrs)</td><td>Kysor-Warren, 2008</td></tr>
<tr><td>Total Installed Cost ($1000)</td><td>NCI, 2009 / NCI Analysis, 2012</td></tr>
<tr><td>Annual Maintenance Cost ($1000)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td>ADL, 1996 / NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Condensers

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

Data Sources » Commercial Walk-In Refrigerators

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td rowspan="2">ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009</td><td colspan="3" rowspan="8">DOE, 2011</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft²)</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008</td></tr>
<tr><td>Insulated Box Average Life (yrs)</td><td rowspan="2">ADL, 1996 / PG&E, 2004</td></tr>
<tr><td>Compressor Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost</td><td rowspan="2">ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / FMI, 2005 / NCI Analysis, 2008</td><td>DOE, 2011 / NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Walk-In Freezers

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td rowspan="2">ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009</td><td colspan="3" rowspan="8">DOE, 2011</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^2)</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008</td></tr>
<tr><td>Insulated Box Average Life (yrs)</td><td rowspan="2">ADL, 1996 / PG&E, 2004</td></tr>
<tr><td>Compressor Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost</td><td rowspan="2">ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / FMI, 2005 / NCI Analysis, 2008</td><td>DOE, 2011 / NCI Analysis, 2012</td></tr>
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Data Sources » Commercial Reach-In Refrigerators

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr/ft^3)</td><td>NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Reach-In Freezers

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr/ft^3)</td><td>NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Ice Machines

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Output (lbs/day)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="6">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Water Use (gal/100 lbs)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/100 lbs)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ACEEE, 2002 / NCI Analysis, 2012</td><td colspan="3" rowspan="4">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Retail Equipment Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost (with Bin)</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / NCI Analysis, 2008</td><td>NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6">DOE, 2011 / NCI Analysis, 2012</td></tr>
</table>

Final

Data Sources » Commercial Beverage Merchandisers

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="6">NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996 / Distributor Web Sites</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Refrigerated Vending Machines

DATA SOURCES	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2008 / NCI Analysis, 2008	NCI, 2009 / NCI Analysis, 2012	DOE, 2009			DOE, 2009 / NCI Analysis, 2012					
Can Capacity	CEC, 2005 / NREL, 2003 / FEMP, 2004										
Energy Use (kWh/yr)	ADL, 1996 / CEC, 2008 / NREL, 2003		DOE, 2009 / ENERGY STAR, 2012								
Average Life (yrs)	DOE, 2008		DOE, 2009								
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008										
Annual Maintenance Cost	DOE, 2008										

Data Sources » Commercial Constant Air Volume Ventilation

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

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

Data Sources » Commercial Variable Air Volume Ventilation

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

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

Data Sources » Commercial Fan Coil Unit

<table>
<tr><th rowspan="2">DATA</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Minimum[3]</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>System Airflow (CFM)</td><td colspan="11">800 CFM is typical for a 2-ton fan coil unit</td></tr>
<tr><td>System Fan Power (kW)</td><td colspan="2" rowspan="2">ADL 1999, NCI 2008</td><td rowspan="2">ASHRAE 90.1-2007</td><td colspan="8" rowspan="2">SAIC & Mfrs</td></tr>
<tr><td>Specific Fan Power (W/CFM)</td></tr>
<tr><td>Annual Fan Energy Use (kWh/yr)[1]</td><td colspan="11">Calculated – see note 1</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="11">2011 ASHRAE Handbook: HVAC Applications</td></tr>
<tr><td>Total Installed Cost ($)[2]</td><td colspan="11">RS Means 2012</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="11">ASHRAE 2000, NCI 2008</td></tr>
</table>

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

Appendix B
References

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APPENDIX D

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

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December 19, 2012

DISCLAIMER

December 2012

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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, assuming an accelerated adoption of technology.

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

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

Methodology

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

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

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

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

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

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

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

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

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

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

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

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

Advanced Case Final

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

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

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

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

Residential General Service Incandescent Lamps (60 and 75 Watts)

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

Performance/Cost Characteristics » Residential Reflector Lighting

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

Performance/Cost Characteristics » Residential Reflector Lighting

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

Residential Reflector Lamps

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

Performance/Cost Characteristics » Residential Compact Fluorescent Lighting

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

Residential Compact Florescent Lamps

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

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2005	2009		2011					
	Installed Base			Current Standard	Mid-Level T12	High T12	Baseline T8	Mid-Level T8	High T8
	32WT8	40WT12	32WT8	40WT12	40WT12	34WT12	32WT8	32WT8	28WT8
Lamp Wattage	64	80	64	80	80	68	64	64	56
Lamp Lumens	5040	5720	5040	5720	6500	5580	5040	5420	5120
System Wattage	65	70	65	70	70	60	65	65	57
System Lumens	4435	3890	4435	3890	4420	3794	4435	4770	4506
Lamp Efficacy (lm/W)	78.8	71.5	78.8	71.5	81.3	82.1	78.8	84.7	91.4
System Efficacy (lm/W)	68.7	55.6	68.7	55.6	63.1	63.8	68.7	73.8	79.7
Lamp Price ($)	$3.35	$1.85	$1.71	$1.85	$5.91	$5.79	$1.71	$2.67	$2.88
Ballast Price ($)	$15.71	$11.22	$9.94	$11.22	$11.22	$11.22	$9.94	$9.94	$9.94
Lamp Cost ($/klm)	$0.66	$0.32	$0.34	$0.32	$0.91	$1.04	$0.34	$0.49	$0.56
Average Lamp Life (1000 hrs)	20	15	20	15	24	24	20	20	18
CRI	75	70	75	70	85	85	75	82	82
Ballast Efficiency (BLE)	83.0%	77.7%	87.2%	77.7%	77.7%	77.7%	87.2%	87.2%	87.2%

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2020		2030		2040	
	Typical T8	High T8	Typical T8	High T8	Typical T8	High T8
	32WT8	28WT8	32WT8	28WT8	32WT8	28WT8
Lamp Wattage	64	56	64	56	64	56
Lamp Lumens	5740	5274	5785	5444	5830	5615
System Wattage	65	57	65	57	65	57
System Lumens	5052	4641	5091	4791	5130	4941
Lamp Efficacy (lm/W)	89.7	94.2	90.4	97.2	91.1	100.3
System Efficacy (lm/W)	78.2	82.1	78.8	84.8	79.4	87.4
Lamp Price ($)	$2.72	$2.79	$2.62	$2.70	$2.53	$2.60
Ballast Price ($)	$9.64	$9.64	$9.31	$9.31	$8.98	$8.98
Lamp Cost ($/klm)	$0.47	$0.53	$0.45	$0.50	$0.43	$0.46
Average Lamp Life (1000 hrs)	25	19	26	19	26	20
CRI	85	82	85	82	85	82
Ballast Efficiency (BLE)	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%

Residential Linear Fluorescent Lighting (T12/T8)

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

Residential Linear Fluorescent Lighting (T12/T8)

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized residential ballasts have a minimum BLE = 0.993 / (1 + 0.41 * Avg Total Lamp Arc power ^ (- 0.25)). Residential ballasts also must have a minimum power factor of 0.5.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR residential fixtures require ≥ 65 lm/W per lamp-ballast platform before September 1, 2013 and ≥ 70 lm/W per lamp-ballast platform thereafter.
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2005	2009	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
Lamp Wattage	56	56	56	52	56	52	56	52	56	52
Lamp Lumens	5320	5320	5320	5320	5468	5480	5632	5657	5796	5834
System Wattage	63	63	63	59	61	57	61	57	61	57
System Lumens	5320	5320	5320	5320	5468	5480	5632	5657	5796	5834
Lamp Efficacy (lm/W)	95.0	95.0	95.0	102.3	97.6	105.4	100.6	108.8	103.5	112.2
System Efficacy (lm/W)	84.3	84.3	84.3	90.7	89.8	96.9	92.5	100.1	95.2	103.2
Lamp Price ($)	$3.56	$3.18	$3.18	$3.97	$3.08	$3.85	$2.98	$3.72	$2.87	$3.59
Ballast Price ($)	$20.94	$20.94	$20.94	$20.94	$26.31	$26.31	$25.41	$25.41	$24.50	$24.50
Lamp Cost ($/klm)	$0.67	$0.60	$0.60	$0.75	$0.56	$0.70	$0.53	$0.66	$0.50	$0.62
Average Lamp Life (1000 hrs)	20	20	20	25	21	26	21	27	22	27
CRI	85	85	85	85	85	85	85	85	85	85
Ballast Efficiency (BLE)	88.7%	88.7%	88.7%	88.7%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%

Residential Linear Fluorescent Lighting (T5)

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

Residential Linear Fluorescent Lighting (T5)

- Currently no federal standards exist for the T5 lamps or their corresponding ballasts.
- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 86 lm/W.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Fixture prices, installation costs, and maintenance costs are not included for the residential sector.

Performance/Cost Characteristics » Residential Torchieres

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

Performance/Cost Characteristics » Residential Torchieres

DATA	2020			2030			2040		
	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	Inc.	Hal.	CFL	Inc.	Hal.	CFL	Inc.	Hal.	CFL
Lamp Wattage	150	150	40	150	150	40	150	150	40
Lamp Lumens	2760	2783	2799	2788	2922	2939	2816	3068	3086
Lamp Efficacy (lm/W)	18.4	18.6	70.0	18.6	19.5	73.5	18.8	20.5	77.1
Lamp Price	$2.80	$3.78	$12.02	$2.73	$3.69	$11.72	$2.66	$3.60	$11.43
Lamp Cost ($/klm)	$1.01	$1.36	$4.30	$0.98	$1.26	$3.99	$0.94	$1.17	$3.70
Average Lamp Life (1000 hrs)	0.8	3.2	9.8	0.9	3.5	10.1	0.9	3.7	10.5
CRI	100	100	82	100	100	82	100	100	82

Residential Torchieres

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

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2005	2009	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	A19 LED	A19 LED	A19 LED	A19 LED	A19 LED
Typical Wattage	36	18	13	3.8	3.6	3.5
Lumens	630	800	800	800	800	800
Efficacy (lm/W)	17.3	44.0	60.0	210.0	224.0	230.0
Lamp Price ($)	$189.82	$68.00	$26.40	$2.16	$1.12	$0.80
Cost ($/klm)	$301.00	$85.00	$33.00	$2.70	$1.40	$1.40
Average Life (1000 hrs)	50	20	25	90	100	100
CRI	92	80	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2005	2009	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	PAR38 LED	PAR38 LED	PAR38 LED	PAR38 LED	PAR38 LED
Typical Wattage	36	28	20	4.8	4.5	4.3
Lumens	630	1000	1000	1000	1000	1000
Efficacy (lm/W)	17.3	36.0	50.0	210.0	224.0	230.0
Lamp Price ($)	$189.82	$164.00	$51.00	$2.70	$1.40	$1.00
Cost ($/klm)	$301.00	$164.00	$51.00	$2.70	$1.40	$1.00
Average Life (1000 hrs)	50	20	25	90	100	100
CRI	92	80	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700

Residential Solid-State Lighting

- The residential solid-state lighting characterized in this report are replacements for a 60W A19 lamp and a 75W PAR38 lamp. These represent the most common uses of LED technology in the residential sector.
- This report characterizes two distinct applications for LEDs in the residential sector rather than one, as was done in the 2008 EIA Reference Case. Because of rapid LED technology development, the market is best characterized by the state of the technology at a given time rather than a range of performance at any one time.
- Assumptions for 2011:
  - 60W A19 equivalent: 13W LED emitting 800 lumens
  - 75W PAR38 equivalent: 20W LED emitting 1000 lumens
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.

Performance/Cost Characteristics » Commercial General Service Incandescent Lighting

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

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

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

Commercial General Service Incandescent Lighting

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

Performance/Cost Characteristics » Commercial Compact Fluorescent Lamps

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Low	Typical	High	Typical	High	Typical	High	Typical	High
	26W	26W	23W	23W	23W	23W	23W	23W	23W	23W	23W
System Wattage	26	26	23	23	23	23	23	23	23	23	23
System Lumens	1068	1068	976	976	1010	1025	1060	1076	1113	1130	1169
Lamp Efficacy (lm/W)	67.3	67.3	69.6	69.6	72.0	73.0	75.6	76.7	79.3	80.5	83.3
System Efficacy (lm/W)	41.1	41.1	42.4	42.4	43.9	44.6	46.1	46.8	48.4	49.1	50.8
Lamp Cost ($/klm)	$4.01	$3.28	$1.56	$1.56	$1.73	$1.52	$1.69	$1.49	$1.65	$1.45	$1.61
System Cost ($/klm)	$22.14	$18.12	$23.05	$23.05	$22.65	$22.48	$22.09	$21.92	$21.54	$21.37	$21.00
Average Lamp Life (1000 hrs)	10.0	10.0	10.0	12.0	12.0	12.4	12.4	12.8	12.8	13.2	13.2
CRI	82	82	82	82	82	82	82	82	82	82	82
Total Installed Cost ($)	$96.56	$79.02	$80.00	$80.00	$80.00	$78.00	$78.00	$76.05	$76.05	$74.15	$74.15
Annual Maintenance Cost ($)	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39	$0.39

Commercial Compact Fluorescent Lamps

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

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003		2007		2011		2020		2030		2040	
	Installed Base				Typical	Typical	Typical	Typical	Typical	Typical	Typical	Typical
	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR	90W PAR 38	70W HIR
System Wattage	90	70	90	70	90	70	90	70	90	70	90	70
System Lumens	1218	1172	1218	1172	1230	1306	1291	1372	1355	1441	1423	1513
Lamp Efficacy (lm/W)	14.6	18.0	14.6	18.0	14.7	20.1	15.4	21.1	16.2	22.1	17.0	23.2
System Efficacy (lm/W)	13.5	16.7	13.5	16.7	13.7	18.7	14.3	19.6	15.1	20.6	15.8	21.6
Lamp Cost ($/klm)	$4.98	$6.76	$4.07	$5.53	$2.87	$11.19	$2.80	$10.91	$2.73	$10.64	$2.66	$10.37
System Cost ($/klm)	$19.01	$21.46	$15.56	$17.56	$19.35	$27.34	$18.87	$26.65	$18.39	$25.99	$17.93	$25.34
Average Lamp Life (1000 hrs)	2.5	3.0	2.5	3.0	2.4	3.6	2.6	3.9	2.8	4.2	3.0	4.5
CRI	100	100	100	100	100	100	100	100	100	100	100	100
Total Installed Cost ($)	$96.56	$97.92	$79.02	$80.13	$81.00	$93.00	$80.19	$92.07	$79.39	$91.15	$78.59	$90.24
Annual Maintenance Cost ($)	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22	$1.47	$1.22

Performance/Cost Characteristics » Commercial Halogen Lighting (Edison)

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	90W Edison	90W Edison	90W Edison	90W Edison	90W Edison	90W Edison
System Wattage	90	90	72	72	72	72
System Lumens	1218	1218	1395	1465	1538	1615
Lamp Efficacy (lm/W)	14.6	14.6	20.8	21.9	23.0	24.1
System Efficacy (lm/W)	13.5	13.5	19.4	20.3	21.4	22.4
Lamp Cost ($/klm)	$4.98	$4.07	$1.33	$1.30	$1.26	$1.23
System Cost ($/klm)	$19.01	$15.56	$15.76	$15.37	$14.99	$14.61
Average Lamp Life (1000 hrs)	2.5	2.5	1.0	1.1	1.2	1.2
CRI	100	100	100	100	100	100
Total Installed Cost ($)	$96.56	$79.02	$80.00	$78.00	$76.05	$74.15
Annual Maintenance Cost ($)	$1.92	$1.57	$1.41	$1.41	$1.41	$1.41

Commercial Halogen Lighting

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

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	BR30 LED	BR30 LED	BR30 LED	BR30 LED	BR30 LED
Wattage	36	13	11	3.1	2.9	2.8
Lumens	548	650	650	650	650	650
Efficacy (lm/W)	15.1	51.0	60.0	210.0	224.0	230.0
Lamp Cost ($/klm)	$392.68	$205.00	$80.00	$10.00	$5.30	$3.60
Life (1000 hrs)	50	25	50	100	100	100
CRI	92	85	90	92	92	92
CCT	2700	3000	2700	2700	2700	2700
Total Installed Cost ($)	$270.44	$186.77	$105.52	$60.02	$56.96	$55.86
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (Edison Socket Substitute)

- The commercial solid-state lighting characterized is a replacement for a 65W BR30 lamp. This represents the most common use of LED technology in Edison sockets in the commercial sector.
- Assumptions for 2011:
  - 65W BR30 equivalent: 11W LED emitting 650 lumens in a downlight fixture
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

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

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2020					2030					2040				
	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max	Base	HE	HE w/ OS	HE w/ SR	HE Max
	32WT8	28WT8	28WT8	28WT8	28WT8	32WT8	F28T8	F28T8	F28T8	F28T8	F32T8	F28T8	F28T8	F28T8	F28T8
System Wattage	62	54	54	54	54	62	54	54	54	54	62	54	54	54	54
System Lumens	3738	3434	3434	4061	4061	3767	3545	3545	4192	4192	3796	3656	3656	4323	4323
Lamp Efficacy (lm/W)	89.7	94.2	94.2	94.2	94.2	90.4	97.2	97.2	97.2	97.2	91.1	100.3	100.3	100.3	100.3
System Efficacy (lm/W)	60.5	63.5	63.5	75.1	75.1	60.9	65.5	65.5	77.5	77.5	61.4	67.6	67.6	79.9	79.9
Cost ($/klm)	$0.53	$0.59	$0.59	$0.59	$0.59	$0.51	$0.56	$0.56	$0.56	$0.56	$0.49	$0.52	$0.52	$0.52	$0.52
Cost ($/klm l/b/f)	$12.40	$13.55	$14.40	$16.61	$17.33	$11.88	$12.67	$13.47	$15.53	$16.21	$11.37	$11.85	$12.59	$14.53	$15.16
Average Lamp Life (1000 hrs)	25	19	9	19	9	26	19	10	19	10	26	20	10	20	10
CRI	85	82	82	82	82	85	82	82	82	82	85	82	82	82	82
Total Installed Cost ($)	$75.01	$75.19	$78.11	$96.11	$99.04	$73.42	$73.59	$76.42	$93.79	$96.62	$71.83	$71.99	$74.72	$91.47	$94.20
Annual Maintenance Cost ($)	$3.03	$3.16	$4.41	$3.16	$4.41	$3.03	$3.16	$4.41	$3.16	$4.41	$3.03	$3.16	$4.41	$3.16	$4.41
Ballast Efficiency (BLE)	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%	91.1%

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

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

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

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

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
System Wattage	66	63	63	59	61	57	61	57	61	57
System Lumens	4698	4698	4698	4698	4783	4838	4973	4995	5118	5152
Lamp Efficacy (lm/W)	95.0	95.0	95.0	102.3	96.7	105.4	100.6	108.8	103.5	112.2
System Efficacy (lm/W)	71.2	74.4	74.4	80.1	78.6	85.6	81.7	88.4	84.1	91.1
Cost ($/klm)	$1.53	$0.67	$0.67	$0.84	$0.64	$0.79	$0.59	$0.74	$0.56	$0.69
Cost ($/klm l/b/f)	$28.68	$28.46	$28.46	$28.84	$27.12	$27.16	$25.18	$25.41	$23.60	$23.76
Average Lamp Life (1000 hrs)	20	20	20	25	21	26	21	27	22	27
CRI	85	85	85	85	85	85	85	85	85	85
Total Installed Cost ($)	$164.95	$161.39	$161.39	$163.17	$157.38	$159.10	$152.92	$154.59	$148.46	$150.07
Annual Maintenance Cost ($)	$2.81	$2.93	$2.93	$2.71	$2.93	$2.71	$2.93	$2.71	$2.93	$2.71
Ballast Efficiency (BLE)	88.7%	88.7%	88.7%	88.7%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%

Commercial 4-ft T5 Linear Fluorescent Lighting

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

Commercial 4-ft T5 Linear Fluorescent Lighting

- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 86 lm/W for standard output T5 lamps.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		T8	T8	T8	T8
	LED	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8
Typical Wattage	36.4	80.0	55.4	24.0	22.5	21.9
Lumens	548	5040	5040	5040	5040	5040
Efficacy (lm/W)	15.1	63.0	91.0	210.0	224.0	230.0
Cost ($/klm)	$392.68	$301.00	$110.00	$10.00	$5.30	$3.60
Average Lamp Life (1000 hrs)	50	25	50	100	100	100
CRI	92	70	80	85	85	85
CCT	2700	3500	3500	3500	3500	3500
Total Installed Cost ($)	$270.44	$1,570.56	$607.92	$103.92	$80.23	$71.66
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

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

- The commercial solid-state lighting characterized is a replacement for 2 4-ft 32W T8 lamps in a troffer fixture. This represents the most common use of LED technology in the 4-ft linear fluorescent lighting market.
- Assumptions for 2011:
  - 2 F32T8 lamps equivalent: 56W LED emitting 5040 lumens
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

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

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2011			2020		2030		2040	
	Electronic HE	Typical	High Efficiency	Typical	HE	Typical	HE	Typical	HE
	60WT12	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8	59WT8	55WT8
System Wattage	119	113	106	112	104	112	104	112	104
System Lumens	7404	8379	8844	9051	9110	9258	9404	9465	9699
Lamp Efficacy (lm/W)	77.7	86.9	98.5	93.9	101.4	96.1	104.7	98.2	108.0
System Efficacy (lm/W)	62.3	73.9	83.7	81.0	87.4	82.8	90.3	84.7	93.1
Cost ($/klm)	$0.38	$0.42	$0.59	$0.58	$0.55	$0.54	$0.52	$0.51	$0.48
Cost ($/klm l/b/f)	$4.41	$6.35	$6.48	$6.19	$6.10	$5.84	$5.71	$5.51	$5.34
Average Lamp Life (1000 hrs)	12	15	18	15	19	16	19	16	20
CRI	62	75	82	82	82	82	82	82	82
Total Installed Cost ($)	$83.44	$103.93	$108.05	$106.76	$106.33	$104.84	$104.42	$102.91	$102.51
Annual Maintenance Cost ($)	$4.66	$4.40	$4.23	$4.40	$4.23	$4.40	$4.23	$4.40	$4.23
Ballast Efficiency (BLE)	88.9%	91.6%	91.6%	92.9%	92.9%	92.9%	92.9%	92.9%	92.9%

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

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

Commercial Linear Fluorescent Lighting – 8 ft. T8/T12

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 97 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE = 0.993 / (1 + 0.27 * Avg Total Lamp Arc power ^ (- 0.25)).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (NCI, 2009)

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO	86WT8HO
System Wattage	165	165	165	165	165	165	165	165	165	165
System Lumens	11488	11596	11596	12740	11951	13122	12345	13546	12740	13971
Lamp Efficacy (lm/W)	82.6	82.6	82.6	90.7	85.1	93.4	87.9	96.4	90.7	99.5
System Efficacy (lm/W)	69.6	70.3	70.3	77.2	72.4	79.5	74.8	82.1	77.2	84.6
Cost ($/klm)	$0.99	$0.51	$0.51	$0.58	$0.45	$0.51	$0.45	$0.51	$0.42	$0.47
Cost ($/klm l/b/f)	$9.29	$9.26	$9.26	$8.69	$8.15	$7.66	$8.15	$7.66	$7.62	$7.16
Average Lamp Life (1000 hrs)	24	24	24	18	26	19	26	19	26	20
CRI	78	78	78	86	78	86	78	86	78	86
Total Installed Cost ($)	$163.88	$162.76	$162.76	$166.10	$155.96	$159.09	$155.96	$159.09	$152.38	$155.40
Annual Maintenance Cost ($)	$4.64	$4.55	$4.55	$4.83	$4.55	$4.83	$4.55	$4.83	$4.55	$4.83
Ballast Efficiency (BLE)	88.9%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%	91.7%

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

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

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

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 92 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE of 0.993 / (1 + 0.38 * Avg Total Lamp Arc power ^ (- 0.25)).
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- California's Title 24 mandates the use of electronic ballasts with high-efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH	175W MH
System Wattage	208	210	211	199	170	199	170	199	170	199	170
System Lumens	5176	6669	7171	10186	11409	10645	11922	11154	12493	11663	13063
Lamp Efficacy (lm/W)	39.0	50.3	50.3	71.4	93.3	74.6	97.5	78.2	102.2	81.8	106.9
System Efficacy (lm/W)	24.9	31.8	34.0	51.2	67.2	53.5	70.3	56.1	73.6	58.7	77.0
Lamp Cost ($/klm)	$2.19	$2.75	$5.81	$5.67	$5.06	$5.26	$4.70	$4.85	$4.33	$4.47	$4.00
System Cost ($/klm)	$35.80	$26.17	$44.58	$39.92	$35.64	$37.06	$33.09	$34.15	$30.49	$31.49	$28.12
Average Lamp Life (1000 hrs)	24.0	10.0	10.0	15.0	15.0	15.7	15.7	16.4	16.4	17.2	17.2
CRI	15	65	67	69	69	69	69	69	69	69	69
Total Installed Cost ($)	$328.83	$318.18	$771.67	$858.59	$858.59	$846.39	$846.39	$832.84	$832.84	$819.28	$819.28
Annual Maintenance Cost ($)	$3.93	$4.81	$4.83	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32	$4.32

Commercial HID Low Bay Lighting (Metal Halide)

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

Commercial HID Low Bay Lighting (Metal Halide)

- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- EISA 2007 established efficiency standards for probe start magnetic ballasts (94%) and pulse start magnetic or electronic ballasts (88%) for ballasts that operate metal halide lamps between 150 and 400 watts, effective January 1, 2009. The 94% efficiency requirement effectively banned probe start magnetic ballasts.
- A DOE rulemaking is ongoing to establish new and amended energy conservation standards for metal halide lamp fixtures as directed by EISA 2007. This rulemaking is expected to be completed by June 2014.
- In the advanced case, assumed improvements could be made using improved ceramic arc tubes and better electrodes (and double arc tubes for lifetime improvement).
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

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

No change from reference case.

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	175W MV	70W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS	100W HPS
System Wattage	208	93	130	130	122	130	122	130	122	130	122
System Lumens	5176	4130	7213	7213	7213	7213	7213	7213	7213	7213	7213
Lamp Efficacy (lm/W)	39.0	77.9	94.5	94.5	94.5	94.5	94.5	94.5	94.5	94.5	94.5
System Efficacy (lm/W)	24.9	44.4	55.5	55.5	59.1	55.5	59.1	55.5	59.1	55.5	59.1
Lamp Cost ($/klm)	$2.19	$3.11	$5.37	$5.37	$5.37	$5.29	$5.29	$5.20	$5.20	$5.11	$5.11
System Cost ($/klm)	$35.80	$41.15	$43.68	$43.68	$45.58	$43.03	$44.89	$42.30	$44.13	$41.57	$43.37
Average Lamp Life (1000 hrs)	24	24	24	24	24	24	24	24	24	24	24
CRI	15	22	22	22	22	22	22	22	22	22	22
Total Installed Cost ($)	$328.83	$312.86	$767.01	$767.01	$780.68	$762.29	$775.74	$757.04	$770.27	$751.78	$764.79
Annual Maintenance Cost ($)	$3.93	$3.93	$3.93	$3.93	$4.04	$3.93	$4.04	$3.93	$4.04	$3.93	$4.04

Commercial HID Low Bay Lighting (High Pressure Sodium)

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

Commercial HID Low Bay Lighting (High Pressure Sodium)

- Assumptions for 2011:
  - Typical efficiency unit: 100W high pressure sodium lamp with magnetic ballast (ballast efficiency=76.9%)
  - High efficiency unit: 100W high pressure sodium lamp with magnetic ballast (ballast efficiency=82%)
- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- The market is moving away from HPS technology with relatively little investment going into its development. Therefore, even in an advanced case, efficacy, price and lifetime are not expected to improve faster than the reference case.
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	100W HPS LED	100W HPS LED	100W HPS LED	100W HPS LED
Typical Wattage	36	11	100	34	32	31
Lumens	548	630	7200	7200	7200	7200
Efficacy (lm/W)	15.1	55.3	72.0	210.0	224.0	230.0
Cost ($/klm)	$392.68	$160.00	$112.00	$10.00	$5.30	$3.60
Average Lamp Life (1000 hrs)	50	50	50	100	100	100
CRI	92	92	80	80	80	80
CCT	2700	2700	5500	5500	5500	5500
Total Installed Cost ($)	$270.44	$154.32	$859.92	$125.52	$91.68	$79.44
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (Low Bay Applications)

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

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	250W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH	400W MH
System Wattage	453	293	465	480	423	455	423	455	423	455	423
System Lumens	13061	12245	20607	21261	23551	22218	24610	23281	25788	24344	26965
Lamp Efficacy (lm/W)	36.0	54.0	63.0	65.0	72.0	67.9	75.2	71.2	78.8	74.4	82.4
System Efficacy (lm/W)	28.8	41.8	44.3	44.3	55.6	48.9	58.1	51.2	60.9	53.6	63.7
Lamp Cost ($/klm)	$1.16	$1.31	$2.38	$3.55	$3.21	$3.30	$2.98	$3.04	$2.74	$2.80	$2.53
System Cost ($/klm)	$11.06	$12.83	$21.54	$16.19	$22.14	$15.03	$20.55	$13.85	$18.94	$12.77	$17.47
Average Lamp Life (1000 hrs)	24.0	10.0	20.0	18.4	18.4	19.2	19.2	20.1	20.1	21.0	21.0
CRI	50	65	68	66	66	66	66	66	66	66	66
Total Installed Cost ($)	$287.32	$300.09	$926.65	$827.03	$1,004.28	$816.71	$988.63	$805.24	$971.25	$793.76	$953.87
Annual Maintenance Cost ($)	$3.93	$4.81	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13	$4.13

Commercial HID High Bay Lighting (Metal Halide)

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

Commercial HID High Bay Lighting (Metal Halide)

- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- EISA 2007 established efficiency standards for probe start magnetic ballasts (94%) and pulse start magnetic or electronic ballasts (88%) for ballasts that operate metal halide lamps between 150 and 400 watts, effective January 1, 2009. The 94% efficiency requirement effectively banned probe start magnetic ballasts.
- A DOE rulemaking is ongoing to establish new and amended energy conservation standards for metal halide lamp fixtures as directed by EISA 2007. This rulemaking is expected to be completed by June 2014.
- In the advanced case , assumed improvements could be made using improved ceramic arc tubes and better electrodes (and double arc tubes for lifetime improvement).
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

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

No change from reference case.

DATA	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS
System Wattage	453	190	190	190	171	190	171	190	171	190	171
System Lumens	13061	10754	10754	10754	10754	10754	10754	10754	10754	10754	10754
Lamp Efficacy (lm/W)	36.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
System Efficacy (lm/W)	28.8	56.6	56.6	56.6	62.9	56.6	62.9	56.6	62.9	56.6	62.9
Lamp Cost ($/klm)	$1.16	$4.65	$4.65	$4.65	$4.65	$4.51	$4.51	$4.36	$4.36	$4.20	$4.20
System Cost ($/klm)	$11.06	$30.96	$30.96	$30.96	$31.79	$30.03	$30.83	$29.00	$29.77	$27.97	$28.72
Average Lamp Life (1000 hrs)	24	24	24	24	24	24	24	24	24	24	24
CRI	50	22	22	22	22	22	22	22	22	22	22
Total Installed Cost ($)	$287.32	$815.84	$815.84	$815.84	$824.72	$805.85	$814.47	$794.75	$803.07	$783.65	$791.68
Annual Maintenance Cost ($)	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93	$3.93

Commercial HID High Bay Lighting (High Pressure Sodium)

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

Commercial HID High Bay Lighting (High Pressure Sodium)

- Assumptions for 2011:
  - Typical efficiency unit: 150W high pressure sodium lamp with magnetic ballast (ballast efficiency=78.9%)
  - High efficiency unit: 150W high pressure sodium lamp with magnetic ballast (ballast efficiency=87.7%)
- In 2010, DOE published a determination that energy conservation standards for HID lamps would be technologically feasible and economically justified. The rulemaking to establish standards for these lamps is ongoing and is expected to be completed by June 2014. No current standards exist for HID lamps.
- The market is moving away from HPS technology with relatively little investment going into its development. Therefore, even in an advanced case, efficacy, price and lifetime are not expected to improve faster than the reference case.
- Utilities in MA, NY, OR, TX, VT, WA, WI, FL and CA offer non-regulatory incentive programs to promote energy efficient HID lighting. Incentive programs favor efficient T5 high output lamps or T8 lamps for low bay applications.
- Total installed cost includes equipment and installation costs and is based on the ongoing DOE metal halide lamp fixtures rulemaking. Annual maintenance costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 lamps rule. Maintenance costs include labor only based on 3,650 operating hours per year.

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

Assumes increased rate of technology advancement (higher efficacy, lower price).

DATA	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	54WT5HO	54WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO
System Wattage	240	234	234	221	231	218	231	218	231	218
System Lumens	18060	17646	17646	17646	18175	18175	18763	18763	19351	19351
Lamp Efficacy (lm/W)	88.0	85.2	85.2	90.2	87.7	92.9	90.6	95.9	93.4	98.9
System Efficacy (lm/W)	75.2	75.5	75.5	79.9	78.6	83.3	81.2	86.0	83.7	88.7
Cost ($/klm)	$1.06	$0.26	$0.26	$0.38	$0.24	$0.36	$0.23	$0.34	$0.21	$0.32
Cost ($/klm l/b/f)	$8.50	$8.30	$8.30	$8.82	$7.82	$8.30	$7.31	$7.77	$6.84	$7.26
Average Lamp Life (1000 hrs)	20	20	20	20	21	21	21	21	22	22
CRI	85	85	85	85	85	85	85	85	85	85
Total Installed Cost ($)	$184.10	$174.12	$174.12	$183.24	$169.72	$178.58	$164.84	$173.39	$159.96	$168.20
Annual Maintenance Cost ($)	$2.81	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93	$2.93
Ballast Efficiency (BLE)	92.4%	92.4%	92.4%	92.4%	93.5%	93.5%	93.5%	93.5%	93.5%	93.5%

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

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

Commercial T5 HO Linear Fluorescent Lighting (High Bay Applications)

- Beginning July 14, 2012, DOE fluorescent lamp standards will require a minimum efficacy of 76 lm/W.
- Beginning November 14, 2014, DOE standards will require that the characterized ballasts have a minimum BLE of 0.993 / (1 + 0.51 * Avg Total Lamp Arc power ^ (- 0.25)).
- Many utilities offer rebates for T5 high output fixtures, generally to replace HID high bay fixtures. The programs include new construction incentives, customized programs, retrofit and upgrade incentives.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher. (CEC, 2005)
- Fluorescent technologies are approaching maximum technologically feasible levels. Therefore, they are assumed to be improving gradually compared to SSL lighting and ceramic metal halide technologies. While improvements can be made by using more rare-earth phosphors, additional energy savings are most likely to be captured through the use of dimming ballasts and occupancy sensors.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and 2009 lamps rulemaking. Maintenance costs include labor only based on 3,435 operating hours per year. (DOE, 2009)

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

Assumes increased rate of technology advancement (higher efficacy, longer life, lower price).

DATA	2003	2007	2011	2020	2030	2040
	Installed Base		HPS	HPS	HPS	HPS
	LED	LED	150W HPS LED	150W HPS LED	150W HPS LED	150W HPS LED
Typical Wattage	36	11	125	51	48	47
Lumens	548	630	10700	10700	10700	10700
Efficacy (lm/W)	15.1	55.3	85.4	210.0	224.0	230.0
Cost ($/klm)	$392.68	$160.00	$63.00	$10.00	$5.30	$3.60
Average Lamp Life (1000 hrs)	50	50	50	100	100	100
CRI	92	92	80	80	80	80
CCT	2700	2700	5500	5500	5500	5500
Total Installed Cost ($)	$270.44	$154.32	$727.62	$160.52	$110.23	$92.04
Annual Maintenance Cost ($)	$0.07	$0.07	$0.07	$0.07	$0.07	$0.07

Commercial Solid-State Lighting (High Bay Applications)

- The commercial solid-state lighting technology characterized is a replacement for a 150W high pressure sodium lamp. This represents the most common use of LED technology in the high bay market.
- Assumptions for 2011:
  - 150W HPS lamp equivalent: 125W LED emitting 10,700 lumens
- No federal standards exist for solid-state lighting.
- In the advanced case, projections are based on 2012 Energy Savings Forecast Model's 'high improvement' case, a scenario analyzed in the "Energy Savings Potential of Solid-State Lighting in General Illumination Applications" report, and assume LED technology advances faster than anticipated by the DOE SSL Multi-Year Program Plan.
- Total installed cost includes equipment and installation costs. Annual maintenance costs and installation costs are calculated using labor rate and labor time to install/replace equipment from RS Means and the 2009 Lamps Rule. Maintenance costs include labor only based on 3,376 operating hours per year. (DOE, 2009)

Commercial Supermarket Display Cases

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical[1]	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	20,000	20,730	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Median Store Size (ft^3)	44,000	47,500	46,000	46,000	46,000	46,000	46,000	46,000	46,000	46,000	46,000
Energy Use (kWh/yr)[2]	21,000	23,117	21,134	18,440	17,002	16,566	15,333	15,694	14,526	14,823	13,719
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$4,371	$10,094	$7,425	$7,600	$8,173	$8,763	$7,803	$8,763	$7,803	$8,763	$7,803
Total Installed Cost	$6,452	$12,176	$9,603	$9,777	$10,351	$10,937	$9,981	$10,937	$9,981	$10,937	$9,981
Annual Maintenance Cost[3]	$283	$337	$376	$376	$376	$376	$376	$376	$376	$376	$376

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

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

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

Commercial Supermarket Display Cases

- DOE set Federal energy efficiency standards for Commercial Refrigeration Equipment (CRE). These standards set maximum daily energy consumption levels, in kWh/day, for display cases manufactured and/or sold in the United States on or after January 1, 2012. The daily energy consumption is based on the total display area of the display case (TDA).
  - Vertical, open, medium temperature, remote condensing display case (VOP.RC.M) ≤ 0.82*TDA + 4.07
- The Food Marketing Institute reported the median total supermarket size in 2003 was 44,000 sq. ft., in 2007 it was 47,500 sq. ft., and in 2010, the last year that was reported by the study, it was 46,000 sq. ft. (FMI, 2012)
- The unit used to estimate energy use and installed cost is a vertical, open, medium temperature, remote condensing display case 12 ft. in length with a total display area of 53 sq. ft.
- Commercial central refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks.
- Approximately 20 percent of the total annual electricity consumption for a typical supermarket is directly attributable to display cases (this does not include the energy consumed by compressors and condensers necessary to cool the display cases). (NCI, 2009)
- As part of DOE's on-going CRE rulemaking, DOE estimates 177,000 display cases were shipped in 2005. Of those display cases 38,743 were vertical, open, medium temperature, remote condensing display cases (VOP.RC.M), which represented the most common type of remote condensing display case shipped in 2005.
- A typical commercial supermarket display case contains T8 electronic lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- The energy use decreases in the advanced case due to the use of more efficient technologies including improved evaporator coils, larger evaporators, higher efficiency evaporator fan blades, high efficiency doors, LED lighting, thicker insulation, and improved insulation.
- Assuming the use of more efficient technologies, the energy use will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Compressor Rack Systems

Assumes increased rate of technology advancement (lower energy use and power input)

DATA	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)[1]	1,050	1,077	1,077	1,077	1,077	1,077	1,077	1,077	1,077	1,077
Power Input (kW)	180	184	162	146	159	143	156	140	152	137
Energy Use (MWh/yr)	1,000	1,023	900	810	882	794	864	778	846	761
Average Life (yrs)	20	15	15	15	15	15	15	15	15	15
Total Installed Cost ($1000)[2]	$630	$630	$630	$693	$630	$693	$630	$693	$630	$693
Annual Maintenance Cost ($1000)[3]	$33	$33	$33	$33	$33	$33	$33	$33	$33	$33

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

[2] The total installed cost is based on the entire supermarket compressor rack system (two medium temperature racks and two low temperature racks). The equipment purchase price and the installation cost of a typical rack is approximately $208,130 and $20,813 per rack respectively. Therefore the total installed cost for a typical supermarket compressor rack system is approximately $913,691.

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

Commercial Compressor Rack Systems

- Commercial compressor rack systems that serve commercial supermarket display cases and walk-ins consist of a number of parallel-connected compressors located in a separate machine room. By modulating compressor capacity, these integrated systems provide higher efficiency and mechanical longevity.
- Rack integrators generally supply a packaged compressor rack for which much of the necessary piping, insulation, components, and controls are pre-assembled.
- A typical supermarket will have 10 to 20 compressors mounted in racks in the 3-hp to 15-hp size range. Usually there are 3 to 5 compressors per rack serving a series of loads with nearly identical evaporator temperature.
- The duty cycle for compressors is usually in the range 60% to 70%.
- The typical supermarket uses a reciprocating compressor system that has two medium temperature compressor racks with an overall capacity of 769 MBtu/hr and two low temperature compressor racks with an overall capacity of 308 MBtu/hr. (NCI, 2009)
- Approximately 34 percent of the total annual electricity consumption for a typical supermarket is attributable to compressors. (NCI, 2009)
- There are an estimated 140,000 compressor rack systems installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- The energy use and power input decreases in the advanced case due to the use of more efficient technologies including higher efficiency compressors, improved compressor configurations, and improved controls.
- Assuming the use of more efficient technologies, the energy use and power input will decrease by 2% in 2020, 4% in 2030, and 6% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Condensers

Assumes increased rate of technology advancement (lower energy use and power input)

DATA	2003	2007	2011		2020		2030		2040	
	Typical	Typical	Typical	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)[1]	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520
Power Input (kW)	25	25	22	20	21	19	20	18	19	17
Energy Use (MWh/yr)	138	138	120	108	114	103	108	97	102	92
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10
Total Installed Cost ($1000)	$47	$54	$54	$60	$54	$60	$54	$60	$54	$60
Annual Maintenance Cost[2]	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090	$817 - $1,090

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

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

Commercial Condensers

- Condensers are designed with multiple methods of cooling: air-cooled, water-cooled, and evaporative. These units can be single-circuit or a multiple circuit.
- Commercial condensers are remotely located, typically installed on the roof of a supermarket.
- For use with parallel compressors in supermarkets, air-cooled units are the most commonly used condensers. This analysis is based on multiple air-cooled condensers connected to a supermarket refrigeration system comprised of two low temperature condensers and two medium temperature condensers, using R-404A refrigerant.
- Each compressor rack has a dedicated condenser or a separate circuit of a single common condenser. Condenser temperatures of multiple racks are often different.
- The duty cycle for condensers is usually in the range 50 - 70%.
- Approximately 5 percent of the total annual electricity consumption for a typical supermarket is attributable to condensers. (NCI, 2009)
- There are an estimated 140,000 condensers installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- The energy use and power input decreases in the advanced case due to the use of more efficient fan motors.
- Assuming the use of more efficient technologies, the energy use and power input will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Walk-In Refrigerators

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011[1]			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	44,970	44,970	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Size (ft^2)[2]	240	240	96	96	96	96	96	96	96	96	96
Energy Use (kWh/yr)	42,300	42,182	12,337	6,329	4,822	6,013	4,581	5,696	4,339	5,380	4,098
Insulated Box Average Life (yrs)	18	18	15	15	15	15	15	15	15	15	15
Compressor Average Life (yrs)	10	10	11	11	11	11	11	11	11	11	11
Retail Equipment Cost	$19,252	$33,821	$13,026	$15,087	$18,821	$15,087	$18,821	$15,087	$18,821	$15,087	$18,821
Total Installed Cost[3]	$23,415	$38,712	$14,080	$16,141	$19,875	$16,141	$19,875	$16,141	$19,875	$16,141	$19,875
Annual Maintenance Cost[4]	$817 - $1,090	$817 - $1,090	$2,755	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970

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

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

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

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

Commercial Walk-In Refrigerators

- The commercial walk-in refrigerator characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going Walk-In rulemaking, is a small non-display cooler with a footprint of 96 sq. ft. and includes a floor and a single door. The typical size of 240 sq. ft. was used for 2003 and 2007 because that was the typical size reported in the ADL, 1996 and NCI, 2009 reports respectively.
- A typical walk-in refrigerator includes: insulated floor and wall panels, merchandising doors, shelving, lighting (not included in cost estimate), semi-hermetic reciprocating compressor, refrigerant (R404A), condenser, and evaporator.
- The high efficiency unit is based on the energy savings potential and cost premiums of several advanced refrigeration technologies identified in the preliminary analysis of DOE's ongoing Walk-In rulemaking. These include:
  - ECM (electronically commutated motor) evaporator and condenser fan motors
  - floating heat pressure
  - ambient sub-cooling
  - evaporator fan shutdown
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- DOE is currently working on a Federal energy consumption standard for commercial walk-in refrigerators. The estimated effective date is 2016.
- As part of DOE's on-going Walk-In rulemaking, DOE estimates 85,333 walk-in coolers will be shipped in 2015. Of those walk-in coolers, 41,403 will be small non-display coolers, which represents the most common type of walk-in cooler estimated to ship in 2015.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Walk-In Refrigerators

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

Commercial Walk-In Freezers

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011[1]			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,929	4,929	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
Size (ft^2)[2]	80	80	64	64	64	64	64	64	64	64	64
Energy Use (kWh/yr)	15,600	15,524	28,455	13,844	12,319	13,637	12,134	13,429	11,949	13,152	11,703
Insulated Box Average Life (yrs)	18	18	15	15	15	15	15	15	15	15	15
Compressor Average Life (yrs)	10	10	11	11	11	11	11	11	11	11	11
Retail Equipment Cost	$7,597	$13,008	$12,068	$14,070	$20,637	$14,070	$20,637	$14,070	$20,637	$14,070	$20,637
Total Installed Cost[3]	$8,637	$14,049	$12,920	$14,921	$21,489	$14,921	$21,489	$14,921	$21,489	$14,921	$21,489
Annual Maintenance Cost[4]	$545	$545	$2,755	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970	$2,970

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

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

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

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

Commercial Walk-In Freezers

- The commercial walk-in freezer characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going Walk-In rulemaking, is a small non-display freezer with a footprint of 64 sq. ft. and includes a floor and a single door. The typical size of 80 sq. ft. was used for 2003 and 2007 because that was the typical size reported in the ADL, 1996 and NCI, 2009 reports respectively.
- A typical walk-in freezer includes: insulated floor, door, and wall panels, semi-hermetic reciprocating compressor, refrigerant (R404A), condenser, and evaporator.
- The high efficiency unit is based on the energy savings potential and cost premiums of several advanced refrigeration technologies determined by the preliminary analysis from DOE's ongoing Walk-In standard rulemaking. These include:
  - ECM (electronically commutated motor) evaporator and condenser fan motors
  - external heat rejection
  - hot gas defrost
  - evaporator fan shutdown
- DOE is currently working on a Federal energy consumption standard for commercial walk-in freezers. The estimated effective date is 2016.
- As part of DOE's on-going Walk-In rulemaking, DOE estimates 34,985 walk-in freezers will be shipped in 2015. Of those walk-in freezers, 17,291 will be small non-display freezers, which represents the most common type of walk-in freezers estimated to ship in 2015.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, defrost, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 1.5% in 2020, 3% in 2030, and 5% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Walk-In Freezers

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

Commercial Reach-In Refrigerators

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	3,000	2,700	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Size (ft^3)	48	48	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	3,800	2,477	2,533	1,598	993	1,439	894	1,359	844	1,279	794
Energy Use (kWh/yr/ft^3)	79	52	52	33	20	29	18	28	17	26	16
Average Life (yrs)	8	9	15	15	15	15	15	15	15	15	15
Retail Equipment Cost	$2,810	$2,988	$3,131	$3,146	$3,191	$3,146	$3,191	$3,146	$3,191	$3,146	$3,191
Total Installed Cost[3]	$2,966	$3,144	$3,948	$3,963	$4,008	$3,963	$4,008	$3,963	$4,008	$3,963	$4,008
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

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

Commercial Reach-In Refrigerators

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

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

- The commercial reach-in refrigerator characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 49 cubic ft. solid two-door unit with a cooling capacity of 1,000 Btu/hr. The typical size of 48 cubic ft. solid two-door unit with a cooling capacity of 3,000 Btu/hr and 2,700 Btu/hr was used for 2003 and 2007 because that was the typical size and capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- Annual shipments of reach-in refrigerators in the U.S. in 2008 are estimated to be 263,000 with an estimated installed base of 1,556,000. (NCI, 2009)
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls..
- Assuming the use of more efficient technologies, the energy use will decrease by 10% in 2020, 15% in 2030, and 20% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Reach-In Freezers

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	2,200	2,200	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Size (ft^3)	24	24	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	4,600	3,960	7,658	5,151	3,037	4,636	2,733	4,378	2,581	4,121	2,429
Energy Use (kWh/yr/ft^3)	192	165	156	105	62	95	56	89	53	84	50
Average Life (yrs)	8	9	15	15	15	15	15	15	15	15	15
Retail Equipment Cost	$2,498	$2,905	$3,277	$3,290	$3,353	$3,290	$3,353	$3,290	$3,353	$3,290	$3,353
Total Installed Cost[3]	$2,654	$3,061	$4,093	$4,107	$4,170	$4,107	$4,170	$4,107	$4,170	$4,107	$4,170
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

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

Commercial Reach-In Freezers

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

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

- The commercial reach-in freezer characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 49 cubic ft. solid two-door unit with a cooling capacity of 1,800 Btu/hr. The typical size of 24 cubit ft. solid one-door unit with a cooling capacity of 2,200 Btu/hr was used for 2003 and 2007 because that was the typical size and capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- Annual shipments of reach-in freezers in the U.S. in 2008 are estimated to be 52,000 with an estimated installed base of 1,156,000. (NCI, 2009)
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, defrost, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 10% in 2020, 15% in 2030, and 20% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Ice Machines

Assumes increased rate of technology advancement (lower energy use and water use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Output (lbs/day)[3]	500	500	300	300	300	300	300	300	300	300	300
Water Use (gal/100 lbs)	24.0	27.5	22.0	19.8	17.6	19.6	17.4	19.4	17.3	19.2	17.2
Energy Use (kWh/100 lbs)	7.0	5.5	7.7	6.9	6.1	6.7	6.0	6.6	5.8	6.4	5.7
Energy Use (kWh/yr)[4]	6,388	5,019	4,249	3,833	3,408	3,719	3,307	3,643	3,239	3,529	3,139
Average Life (yrs)	8.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Retail Equipment Cost	$2,289	$3,954	$4,059	$4,077	$4,152	$4,077	$4,152	$4,077	$4,152	$4,077	$4,152
Total Installed Cost (with Bin)[5]	$2,498	$4,475	$4,431	$4,449	$4,524	$4,449	$4,524	$4,449	$4,524	$4,449	$4,524
Annual Maintenance Cost[6]	$218 - $327	$218 - $327	$110	$110	$110	$110	$110	$110	$110	$110	$110

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

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

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

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

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

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

Commercial Ice Machines

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

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

- Commercial ice machine maintenance includes periodic cleaning (every 2 to 6 weeks) to remove lime and scale, and sanitizing to kill bacteria. Some ice machines are self-cleaning/sanitizing.
- As part of DOE's on-going Automatic Ice Makers rulemaking, DOE estimates 263,552 ice machines will be shipped in 2016. Of those ice-machines 71,357 will be air cooled, ice making head units with a harvest capacity rate between 50 lbs/24 hr. and 450 lbs/24 hrs., which represents the most common type of ice maker estimated to ship in 2016.
- The energy use and water use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, evaporators, condensers, compressors, insulation, water circulation pumps, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 3% in 2020, 5% in 2030, and 8% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Ice Machines: EPACT 2005

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

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

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

Commercial Beverage Merchandisers

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low[1]	Typical[2]	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	1,200	2,500	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27
Energy Use (kWh/yr)	3,900	2,527	2,523	1,763	996	1,587	897	1,499	847	1,410	797
Average Life (yrs)	8.0	8.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Retail Equipment Cost	$1,457	$2,706	$2,662	$2,810	$2,935	$2,810	$2,935	$2,810	$2,935	$2,810	$2,935
Total Installed Cost[3]	$1,613	$2,862	$3,479	$3,626	$3,752	$3,626	$3,752	$3,626	$3,752	$3,626	$3,752
Annual Maintenance Cost[4]	Negligible	Negligible	$36	$36	$36	$36	$36	$36	$36	$36	$36

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

Commercial Beverage Merchandisers

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

Beverage Merchandiser Size	0 < V < 15	15 ≤ 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

- The beverage merchandiser characterized in this report from 2011 and beyond, which is the typical unit according to DOE's on-going CRE rulemaking, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a cooling capacity of 2,100 Btu/hr. A similar beverage merchandiser with a cooling capacity of 1,200 Btu/hr and 2,500 Btu/hr was used for 2003 and 2007 because that was the typical capacity reported in the ADL, 1996 and NCI, 2009 reports respectively.
- Beverage merchandisers have an estimated installed base of 920,000 units in 2008. Of those beverage merchandisers 460,000 are one-door units, which represents the most common type of beverage merchandiser.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 10% in 2020, 15% in 2030, and 20% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Refrigerated Vending Machines

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical[1]	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	700	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Can Capacity	500	650	650	650	650	650	650	650	650	650	650
Energy Use (kWh/yr)[2]	3,000	2,913	2,383	2,029	1,821	1,653	1,487	1,566	1,409	1,479	1,331
Average Life (yrs)	14	14	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$1,769	$1,907	$1,742	$2,046	$2,096	$2,137	$2,632	$2,137	$2,632	$2,137	$2,632
Total Installed Cost[3]	$1,844	$2,011	$1,826	$2,130	$2,180	$2,221	$2,716	$2,221	$2,716	$2,221	$2,716
Annual Maintenance Cost[4]	$180	$177	$159	$159	$159	$159	$159	$159	$159	$159	$159

[1] DOE's Federal energy standards for Refrigerated Beverage Vending Machines will go into effect on August 31, 2012. The 2020 Typical values are based on this standard.

[2] Energy use is based on a zone-cooled machine tested in 75°F steady state ambient conditions.

[3] Installation cost for 2003 and 2007 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $75 and $104 respectively. Installation cost for 2011 and beyond is based on DOE's Refrigerated Beverage Vending Machine rulemaking which assumes a cost of $84.

[4] Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils and also includes an annualized cost for refurbishments/remanufacturing.

Commercial Refrigerated Vending Machines

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

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

- The annual maintenance cost is consists of preventive maintenance including checking and maintaining refrigerant charge levels, cleaning heat exchanger coils, and replacement of lighting and the annualized value of a single refurbishment at approximately the mid-point of the machine's useful life. The preventative annual maintenance cost is approximately $98 and the annualize value of a one-time refurbishment cost of $599 over the lifetime of the machine is $61. Therefore, the annual maintenance cost is $159 for refrigerated vending machines.
- As part of DOE's Refrigerated Beverage Vending Machine rulemaking, DOE estimates 190,200 refrigerated vending machines will be shipped in 2012. Of those refrigerated vending machines 63,700 will be zone-cooled, medium size units, which represents the most common type of refrigerated vending machine estimated to ship in 2012.
- The energy use decreases in the advanced case due to the use of more efficient technologies including higher efficiency fan motors, lighting, evaporators, condensers, compressors, insulation, and controls.
- Assuming the use of more efficient technologies, the energy use will decrease by 5% in 2020, 10% in 2030, and 15% in 2040 in the advanced case. Equipment costs will stay the same as the reference case assuming constant market volumes.

Commercial Constant Air Volume Ventilation

Assumes increased rate of technology advancement (lower energy use)

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

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

Commercial Constant Air Volume Ventilation

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

Commercial Variable Air Volume Ventilation

Assumes increased rate of technology advancement (lower energy use)

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

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

Commercial Variable Air Volume Ventilation

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

Commercial Fan Coil Unit

Assumes increased rate of technology advancement (lower energy use)

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

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

Commercial Fan Coil Unit

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

Appendix A
Data Sources

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

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

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

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

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

DATA SOURCES	2005	2009	2011			2013*		2020**	
	Installed Base		Low	Typical	High	Typical	High	Typical	High
	75W	75W	75W	75W	75W	75W	75W	75W	75W
Lamp Wattage	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Lumens	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Efficacy (lm/W)	2008 EIA Reference Case		Calculated			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Price	2008 EIA Reference Case		Distributor Websites			EISA 2007; NCI, 2012		EISA, 2007	
Lamp Cost ($/klm)	2008 EIA Reference Case		Calculated			EISA 2007; NCI, 2012		EISA, 2007	
Average Lamp Life (1000 hrs)	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	
CRI	2008 EIA Reference Case		Product Catalogs			EISA 2007; NCI, 2012		EISA, 2007	

Data Sources » Residential Reflector Lamps

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

Data Sources » Residential Reflector Lamps

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

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

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

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

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

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

Data Sources » Residential Linear Fluorescent Lamps (T5)

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

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

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

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

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

Data Sources » Commercial General Service Incandescent Lighting

DATA SOURCES	2003	2007	2011			2020	
	Installed Base		Low	Typical	High	Typical	High
	Typical	Typical	Low	Typical	High	72W Inc	72W Inc
System Wattage	2008 EIA Reference Case		Distributor Websites; Calculated			NCI, 2012	
System Lumens							
Lamp Efficacy (lm/W)			Distributor Websites; Calculated				
System Efficacy (lm/W)							
Lamp Cost ($/klm)							
System Cost ($/klm)							
Average Lamp Life (1000 hrs)			Distributor Websites				
CRI							
Total Installed Cost ($)			Distributor Websites; NCI 2012; RSMeans 2007; Calculated				
Annual Maintenance Cost ($)							

Data Sources » Commercial Compact Fluorescent Lamps

DATA SOURCES	2003	2007	2011			2020		2030		2040	
	Installed Base		Low	Typical	High	Typical	High	Typical	High	Typical	High
	26W	26W	23W	23W	23W	23W	23W	23W	23W	23W	23W
System Wattage	2008 EIA Reference Case		Distributor Websites; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Distributor Websites; Calculated								
System Efficacy (lm/W)											
Lamp Cost ($/klm)											
System Cost ($/klm)											
Average Lamp Life (1000 hrs)			Distributor Websites								
CRI											
Total Installed Cost ($)			Distributor Websites; NCI 2012; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

Data Sources » Commercial Halogen Lighting (PAR 38)

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

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

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

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

Data Sources » Commercial 4-ft T8 Linear Fluorescent Lighting

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

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

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

Data Sources » Commercial 4-ft T5 Linear Fluorescent Lighting

DATA SOURCES	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	28WT5	28WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5	28WT5	26WT5
System Wattage	2008 EIA Reference Case	DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated			NCI, 2012					
System Lumens										
Lamp Efficacy (lm/W)		Calculated								
System Efficacy (lm/W)										
Cost ($/klm)										
Cost ($/klm l/b/f)										
Average Lamp Life (1000 hrs)		DOE GSFL and IRL Energy Conservation Standard, 2009								
CRI										
Total Installed Cost ($)		DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)										
Ballast Efficiency (BLE)		DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011								

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

DATA SOURCES	2003	2007	2011	2020	2030	2040
	Installed Base		Typical	Typical	Typical	Typical
	LED	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8	LED 32W T8
Wattage	2008 EIA Reference Case	Calculated				
Lumens		Product Catalogs				
Efficacy (lm/W)		Product Catalogs		2012 SSL MYPP		
Cost ($/klm)				2012 Energy Savings Forecast Model		
Life (1000 hrs)						
CRI				NCI, 2012		
CCT						
Total Installed Cost ($)				RSMeans 2007; Calculated		
Annual Maintenance Cost ($)						

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

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

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

Data Sources » Commercial 8-ft Linear Fluorescent Lighting (High Output)

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

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

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

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

<table>
<tr><th rowspan="3">DATA SOURCES</th><th colspan="2">2003</th><th>2007</th><th colspan="2">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="3">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>175W MV</th><th>70W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3">DOE Energy Conservation Standards, 2010</td></tr>
<tr><td>CRI</td><td colspan="3">Product Catalogs</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th>2011</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>HPS</th><th>HPS</th><th>HPS</th><th>HPS</th></tr>
<tr><th>LED</th><th>LED</th><th>100W HPS LED</th><th>100W HPS LED</th><th>100W HPS LED</th><th>100W HPS LED</th></tr>
<tr><td>Typical Wattage</td><td rowspan="9" colspan="2">2008 EIA Reference Case</td><td colspan="4">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="4">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td rowspan="2" colspan="3">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td rowspan="2" colspan="3">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2" colspan="3">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

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

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

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

DATA SOURCES	2003		2007	2011		2020		2030		2040	
	Installed Base			Typical	High	Typical	High	Typical	High	Typical	High
	400W MV	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS	150W HPS
System Wattage	2008 EIA Reference Case		DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated			NCI, 2012					
System Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Efficacy (lm/W)											
Cost ($/klm)											
Cost ($/klm l/b/f)											
Average Lamp Life (1000 hrs)			DOE Energy Conservation Standards, 2010								
CRI			Product Catalogs								
Total Installed Cost ($)			DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)											

Data Sources » Commercial T5 HO Lighting (High Bay Applications)

DATA SOURCES	2003	2007	2011		2020		2030		2040	
	Installed Base		Typical	High	Typical	High	Typical	High	Typical	High
	54WT5HO	54WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO	54WT5HO	51WT5HO
System Wattage	2008 EIA Reference Case	DOE GSFL and IRL Energy Conservation Standard, 2009; DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011; Product Catalogs; Calculated			NCI, 2012					
System Lumens										
Lamp Efficacy (lm/W)		Calculated								
System Efficacy (lm/W)										
Cost ($/klm)										
Cost ($/klm l/b/f)										
Average Lamp Life (1000 hrs)		DOE GSFL and IRL Energy Conservation Standard, 2009								
CRI										
Total Installed Cost ($)		DOE GSFL and IRL Energy Conservation Standard, 2009; Distributor Websites; RSMeans 2007; Calculated								
Annual Maintenance Cost ($)										
Ballast Efficiency (BLE)		DOE Ballast Energy Conservation Standard, 2011								

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

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th>2011</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>HPS</th><th>HPS</th><th>HPS</th><th>HPS</th></tr>
<tr><th>LED</th><th>LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th></tr>
<tr><td>Typical Wattage</td><td colspan="2" rowspan="9">2008 EIA Reference Case</td><td colspan="4">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="4">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td colspan="3" rowspan="2">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="2">NCI, 2012</td></tr>
<tr><td>CCT</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Commercial Supermarket Display Cases

DATA SOURCES	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2007 / NCI Analysis, 2008	NCI, 2009	NCI Analysis, 2012			DOE, 2009 / DOE, 2011 / FMI, 2012 / NCI Analysis 2012					
Median Store Size (ft^3)	Food Marketing Institute (FMI), 2012										
Energy Use (kWh/yr)	DOE, 2007 / NCI Analysis, 2008	NCI, 2009 / NCI Analysis, 2012	DOE, 2011								
Average Life (yrs)		NCI, 2009									
Retail Equipment Cost											
Total Installed Cost											
Annual Maintenance Cost											

Data Sources » Commercial Compressor Rack Systems

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="2">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Typical</th><th>Typical</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Total Capacity (MBtu/hr)</td><td>ADL, 1996</td><td rowspan="5">NCI, 2009 / NCI Analysis, 2012</td><td rowspan="6" colspan="8">NCI, 2009 / NCI Analysis, 2012 / ADL, 1996</td></tr>
<tr><td>Power Input (kW)</td><td>Copeland, 2008</td></tr>
<tr><td>Energy Use (MWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td></tr>
<tr><td>Average Life (yrs)</td><td>Kysor-Warren, 2008</td></tr>
<tr><td>Total Installed Cost ($1000)</td><td>NCI, 2009 / NCI Analysis, 2012</td></tr>
<tr><td>Annual Maintenance Cost ($1000)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td>ADL, 1996 / NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Condensers

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

Data Sources » Commercial Walk-In Refrigerators

DATA SOURCES	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	NCI, 2009	DOE, 2011			DOE, 2011 / NCI Analysis, 2012					
Size (ft²)											
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008										
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004										
Compressor Average Life (yrs)											
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008										
Total Installed Cost											
Annual Maintenance Cost	ADL, 1996 / FMI, 2005 / NCI Analysis, 2008	DOE, 2011 / NCI Analysis, 2012									

Data Sources » Commercial Walk-In Freezers

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td rowspan="2">ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009</td><td rowspan="8" colspan="3">DOE, 2011</td><td rowspan="8" colspan="6">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^2)</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008</td></tr>
<tr><td>Insulated Box Average Life (yrs)</td><td rowspan="2">ADL, 1996 / PG&E, 2004</td></tr>
<tr><td>Compressor Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost</td><td rowspan="2">ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td><td>ADL, 1996 / FMI, 2005 / NCI Analysis, 2008</td><td>DOE, 2011 / NCI Analysis, 2012</td></tr>
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<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="7">NCI, 2009 / NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft^3)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Energy Use (kWh/yr/ft^3)</td><td>NCI Analysis, 2012</td><td colspan="3">NCI Analysis, 2012</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
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Data Sources » Commercial Reach-In Freezers

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

Data Sources » Commercial Beverage Merchandisers

<table>
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<tr><th>Typical</th><th>Typical</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td rowspan="6">NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="7">DOE, 2011 / NCI Analysis, 2012</td></tr>
<tr><td>Size (ft³)</td><td>ADL, 1996 / Distributor Web Sites</td><td colspan="3">DOE, 2011</td></tr>
<tr><td>Energy Use (kWh/yr)</td><td>ADL, 1996 / NCI Analysis, 2008</td><td colspan="3">DOE, 2011 / ENERGY STAR, 2012 / EPACT, 2005</td></tr>
<tr><td>Average Life (yrs)</td><td>ACEEE, 2002</td><td colspan="3" rowspan="4">DOE, 2011</td></tr>
<tr><td>Retail Equipment Cost</td><td>ADL, 1996 / Distributor Web Sites</td></tr>
<tr><td>Total Installed Cost</td><td>Distributor Web Sites / NCI Analysis, 2008</td></tr>
<tr><td>Annual Maintenance Cost</td><td>NCI Analysis, 2008</td><td>NCI Analysis, 2012</td></tr>
</table>

Data Sources » Commercial Refrigerated Vending Machines

DATA SOURCES	2003	2007	2011			2020		2030		2040	
	Typical	Typical	Low	Typical	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2008 / NCI Analysis, 2008	NCI, 2009 / NCI Analysis, 2012	DOE, 2009			DOE, 2009 / NCI Analysis, 2012					
Can Capacity	CEC, 2005 / NREL, 2003 / FEMP, 2004										
Energy Use (kWh/yr)	ADL, 1996 / CEC, 2008 / NREL, 2003		DOE, 2009 / ENERGY STAR, 2012								
Average Life (yrs)	DOE, 2008		DOE, 2009								
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008										
Annual Maintenance Cost	DOE, 2008										

Data Sources » Commercial Constant Air Volume Ventilation

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

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

Data Sources » Commercial Variable Air Volume Ventilation

<table>
<tr><th rowspan="2">DATA</th><th>2003</th><th>2007</th><th colspan="3">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Minimum[3]</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>System Airflow (CFM)</td><td colspan="11">Assumed based on average 15,000 square foot commercial building (CBECS 2003 and BED 2007)</td></tr>
<tr><td>System Fan Power (kW)</td><td colspan="2" rowspan="2">eQUEST/DOE-2</td><td rowspan="2">ASHRAE 90.1-2007</td><td colspan="8" rowspan="2">SAIC & Mfrs</td></tr>
<tr><td>Specific Fan Power (W/CFM)</td></tr>
<tr><td>Annual Fan Energy Use (kWh/yr)[1]</td><td colspan="11">Calculated – see note 1</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="11">2011 ASHRAE Handbook: HVAC Applications</td></tr>
<tr><td>Total Installed Cost ($)[2]</td><td colspan="11">RS Means 2012</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="11">Jones Lang LaSalle</td></tr>
</table>

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

Data Sources » Commercial Fan Coil Unit

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

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

Appendix B
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1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

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