APPENDIX D

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

Presented to:

U.S. Energy Information Administration

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Table of Contents

Objective

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

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

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

Methodology

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Residential General Service Incandescent Lamps (60 and 75 Watts)

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

Performance/Cost Characteristics » Residential Reflector Lighting

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

Performance/Cost Characteristics » Residential Reflector Lighting

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

Residential Reflector Lamps

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

Performance/Cost Characteristics » Residential Compact Fluorescent Lighting

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

Residential Compact Florescent Lamps

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

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

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

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

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

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

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

Residential Linear Fluorescent Lighting (T12/T8)

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

Residential Linear Fluorescent Lighting (T12/T8)

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

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

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

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

Residential Linear Fluorescent Lighting (T5)

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

Residential Linear Fluorescent Lighting (T5)

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

Performance/Cost Characteristics » Residential Torchieres

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

Performance/Cost Characteristics » Residential Torchieres

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

Residential Torchieres

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

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

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

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

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.

Advanced Case

Final

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)

Advanced Case

Final

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)

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2005</th><th>2009</th><th colspan="3">2011</th><th colspan="2">2014*</th><th colspan="2">2020**</th></tr>
<tr><th colspan="2">Installed Base</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>60W</th><th>60W</th><th>60W</th><th>60W</th><th>60W</th><th>60W</th><th>60W</th><th>60W</th><th>60W</th></tr>
<tr><td>Lamp Wattage</td><td colspan="2" rowspan="7">2008 EIA Reference Case</td><td colspan="3" rowspan="2">Product Catalogs</td><td colspan="2" rowspan="7">EISA 2007;
NCI, 2012</td><td colspan="2" rowspan="7">EISA, 2007</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td></tr>
<tr><td>Lamp Price</td><td colspan="3">Distributor Websites</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3" rowspan="2">Product Catalogs</td></tr>
<tr><td>CRI</td></tr>
</table>

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

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

Data Sources » 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									

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="6">2011</th></tr>
<tr><th colspan="3">Installed Base</th><th>Current Standard</th><th>Mid-Level T12</th><th>High T12</th><th>Baseline T8</th><th>Mid-Level T8</th><th>High T8</th></tr>
<tr><th>32WT8</th><th>40WT12</th><th>32WT8</th><th>40WT12</th><th>40WT12</th><th>34WT12</th><th>32WT8</th><th>32WT8</th><th>28WT8</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="12">2008 EIA Reference Case</td><td colspan="8" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>System Wattage</td><td colspan="8" rowspan="4">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Lamp Price ($)</td><td colspan="8">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>Ballast Price ($)</td><td colspan="8">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="8">Calculated</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="8" rowspan="2">DOE GSFL and IRL Energy Conservation Standard, 2009</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="8">DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011</td></tr>
</table>

Data Sources » 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 ($)			Distributor Websites; NCI 2012; RSMeans 2007; Calculated				
Annual Maintenance Cost ($)							

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

Data Sources » Commercial Halogen Lighting (PAR 38)

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

Data Sources » Commercial Halogen Lighting (Edison)

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

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

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

Data Sources » Commercial 4-ft T8 Linear Fluorescent Lighting

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

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

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

Data Sources » Commercial 4-ft T5 Linear Fluorescent Lighting

<table>
<tr><th rowspan="3">DATA SOURCES</th><th>2003</th><th>2007</th><th colspan="2">2011</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>28WT5</th><th>28WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th><th>28WT5</th><th>26WT5</th></tr>
<tr><td>System Wattage</td><td rowspan="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)

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

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

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

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

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

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)

<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>175W MH</th><th>175W MH</th><th>175W MH</th><th>175W MH</th><th>175W MH</th><th>175W MH</th><th>175W MH</th><th>175W MH</th><th>175W MH</th><th>175W MH</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated</td><td colspan="6" rowspan="10">NCI, 2012</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Cost ($/klm)</td></tr>
<tr><td>Cost ($/klm l/b/f)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="3">DOE Energy Conservation Standards, 2010</td></tr>
<tr><td>CRI</td><td colspan="3">Product Catalogs</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial Low Bay HID Lighting (High Pressure Sodium)

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<tr><th colspan="3">Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><th>175W MV</th><th>70W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th><th>100W HPS</th></tr>
<tr><td>System Wattage</td><td colspan="2" rowspan="10">2008 EIA Reference Case</td><td colspan="3" rowspan="2">DOE Energy Conservation Standards, 2010; Product Catalogs; Calculated</td><td colspan="8" 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 Solid State Lighting (Low Bay Applications)

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

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

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

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

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<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 rowspan="10" colspan="2">2008 EIA Reference Case</td><td rowspan="2" colspan="3">DOE Energy Conservation Standards, 2010; Product Catalogs; 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="3">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 ($)</td><td rowspan="2" colspan="3">DOE Energy Conservation Standards, 2010; Distributor Websites; RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

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

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)

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<tr><th colspan="2">Installed Base</th><th>HPS</th><th>HPS</th><th>HPS</th><th>HPS</th></tr>
<tr><th>LED</th><th>LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th><th>150W HPS LED</th></tr>
<tr><td>Typical Wattage</td><td rowspan="9" colspan="2">2008 EIA Reference Case</td><td colspan="4">Calculated</td></tr>
<tr><td>Lumens</td><td colspan="4">Product Catalogs</td></tr>
<tr><td>Efficacy (lm/W)</td><td rowspan="7">Product Catalogs</td><td colspan="3">2012 SSL MYPP</td></tr>
<tr><td>Cost ($/klm)</td><td rowspan="2" colspan="3">2012 Energy Savings Forecast Model</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>CRI</td><td rowspan="2" colspan="3">NCI, 2012</td></tr>
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<tr><td>Total Installed Cost ($)</td><td rowspan="2" colspan="3">RSMeans 2007; Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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Data Sources » Commercial Supermarket Display Cases

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<tr><td>Cooling Capacity (Btu/hr)</td><td>DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009</td><td colspan="3">NCI Analysis, 2012</td><td colspan="6" rowspan="8">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="6">DOE, 2007 / NCI Analysis, 2008</td><td>NCI, 2009 / NCI Analysis, 2012</td><td colspan="3" rowspan="6">DOE, 2011</td></tr>
<tr><td>Average Life (yrs)</td><td rowspan="5">NCI, 2009</td></tr>
<tr><td>Retail Equipment Cost</td></tr>
<tr><td>Total Installed Cost</td></tr>
<tr><td>Annual Maintenance Cost</td></tr>
</table>

Data Sources » Commercial Compressor Rack Systems

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

Data Sources » Commercial Condensers

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

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

Data Sources » Commercial Walk-In Freezers

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

<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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Data Sources » Commercial Reach-In Freezers

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

Data Sources » Commercial Constant Air Volume Ventilation

DATA	2003	2007	2011			2020		2030		2040	
	Installed Base		Minimum[3]	Typical	High	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	Assumed based on average 15,000 square foot commercial building (CBECS 2003 and BED 2007)										
System Fan Power (kW) / **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

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
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And

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McLean, VA 22102

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