APPENDIX B

FINAL

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

Presented to:

U.S. Energy Information Administration

Prepared by

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

With

SAIC
8301 Greensboro Drive
McLean, VA 22102

March 2014

DISCLAIMER

March 2014

Final

Table of Contents

Table of Contents

Objective

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

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

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

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

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

Definitions

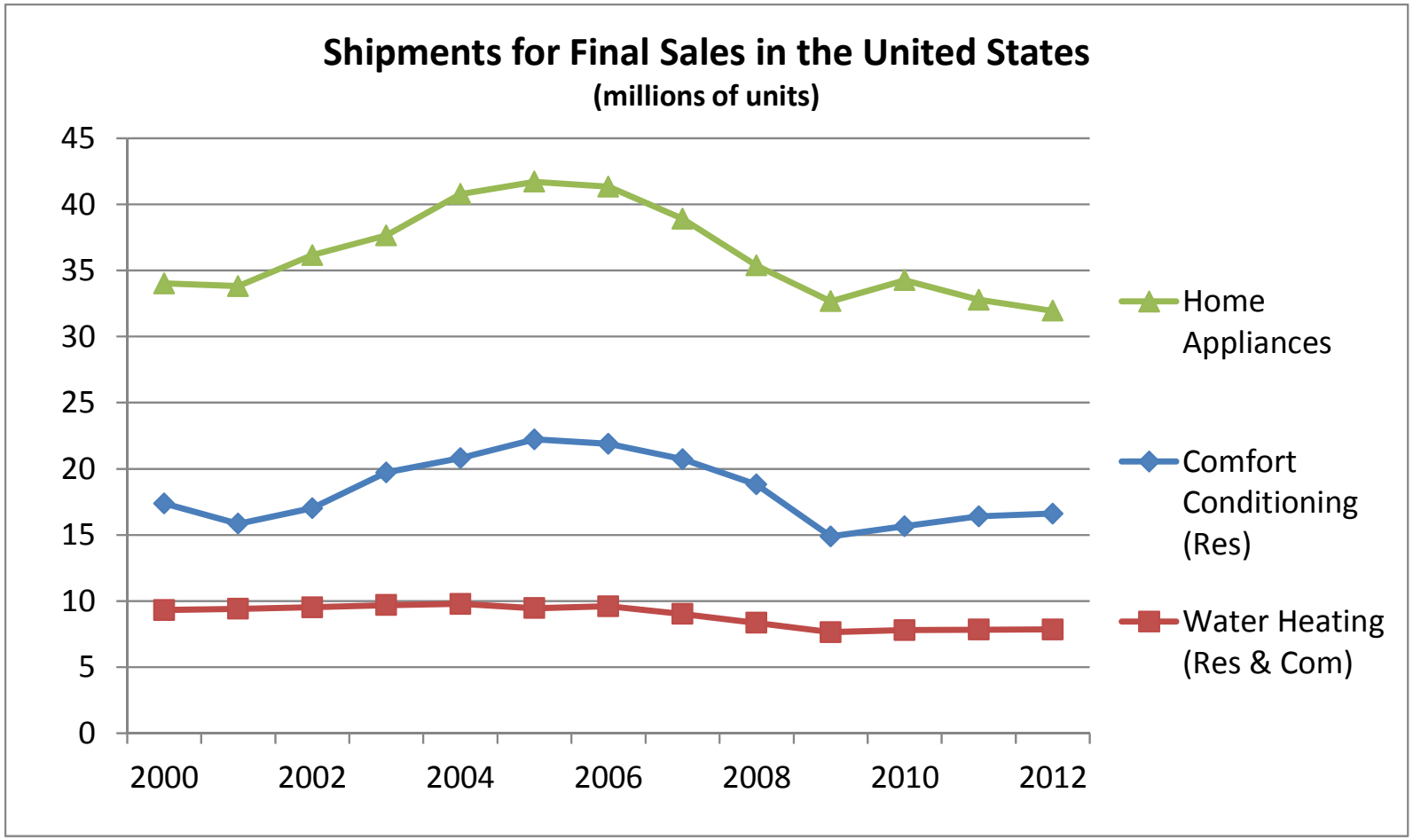
The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (or 2009 for residential products) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming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

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

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

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

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



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

Residential Gas-Fired Water Heaters

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

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

Residential Gas-Fired Water Heaters

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

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

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

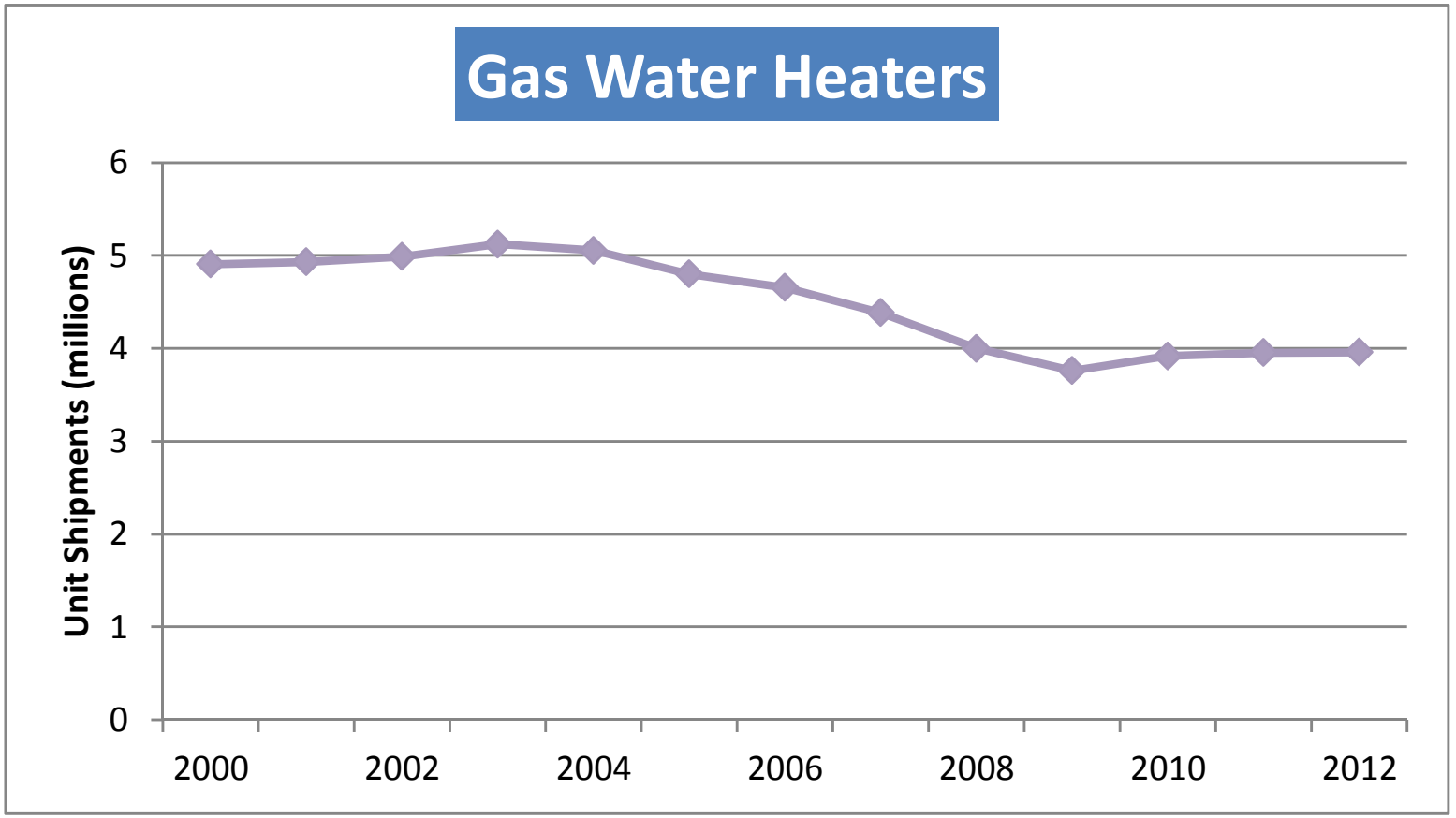
  EF=0.675-(0.0015*Gal) for a volume ≤ 55 gallons and

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

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

Residential Gas-Fired Water Heaters

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



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

Residential Oil–Fired Water Heaters

Higher typical efficiencies than ref. case

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

Residential Oil-Fired Water Heaters

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

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

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

  EF=0.68-(0.0019*Gal)

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

Residential Electric Resistance Water Heaters

Higher efficiencies than ref. case

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

Residential Electric Resistance Water Heaters

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

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

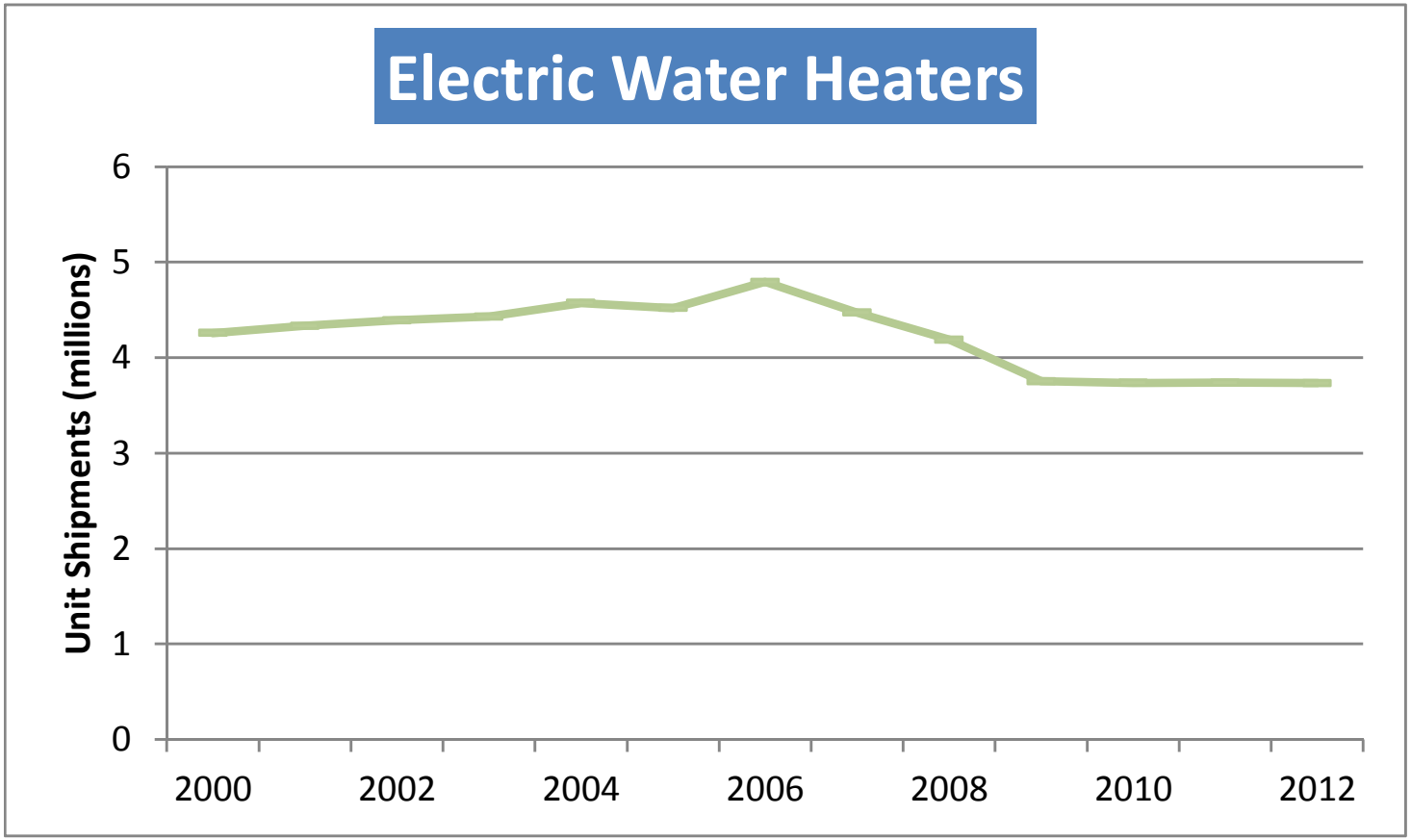
- An updated Federal standard will go into effect on April 16, 2015. The equation for the Federal standard is:

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

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

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

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



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

Residential Heat Pump Water Heaters

Higher typical efficiencies than ref. case

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

Residential Heat Pump Water Heaters

- The minimum EF for ENERGY STAR qualification is 2.0 for heat pump water heaters (HPWH). All HPWH products on the market meet ENERGY STAR minimums and no HPWH products are being offered below the ENERGY STAR efficiency level.
- There is no unique Federal standard HPWH, but integrated HPWHs are in the same product class as electric resistance water heaters, so the Federal electric resistance water heaters standard also applies to HPWH.
- Technology improvements have advanced efficiency and reliability, but the high first-cost still precludes high-volume market penetration. Although there is an installed base listed for 2009, the market penetration of HPWHs was quite low at that time.
- Several major water heater manufacturers have an integrated HPWH model on the market, and other competitors offer integrated or retrofit units (for existing electric or indirect storage water heaters).
- Stiebel Eltron has an 80 gallon, 2.51 EF HPWH. This unit was not included in this analysis because it has a significantly larger capacity than the units included on the previous slide.
- Sales are estimated to be driven partly by rebates and tax credits at the utility, local, state, and Federal level.
- Resistive heating elements are virtually 100% efficient, but there is a jump in efficiency when heat pump technology is adopted because heat pumps' COP are usually between 2 and 3.
- Heat pumps raise the water temperature at a slow rate, so it is usual for these systems to use resistive heat for some of the water heating process. All HPWH systems examined by DOE allow the consumer to adjust the HPWH behavior.
- First-hour ratings range from 57 to 68 gallons.[18]

Residential Instantaneous Water Heaters

Higher typical efficiencies than ref. case

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

Residential Instantaneous Water Heaters

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

Residential Solar Water Heaters

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

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

Residential Solar Water Heaters

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

Residential Gas-Fired Furnaces

Higher typical efficiencies and lower costs for a given efficiency level

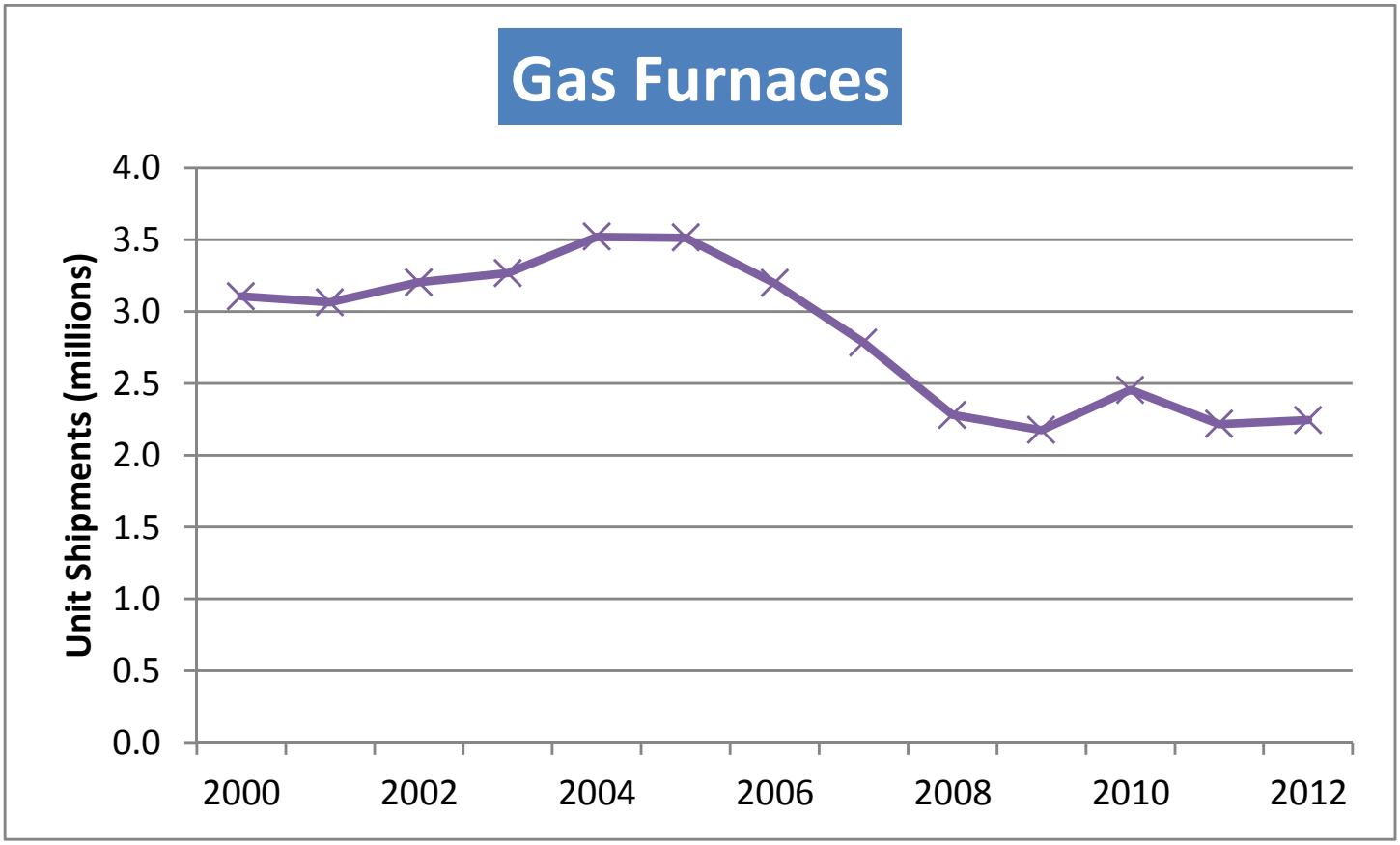
DATA	2009	2013					2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR (South)	ENERGY STAR (North)	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	75	75	75	75	75	75	75	75	75	75	75	75
AFUE (%)	80	80	80	90	95	98	90	98	94	98	96	98
Electric Consumption (kWh/yr)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

Residential Gas-Fired Furnaces

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

Residential Gas-Fired Furnaces

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



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

Residential Oil-Fired Furnaces

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

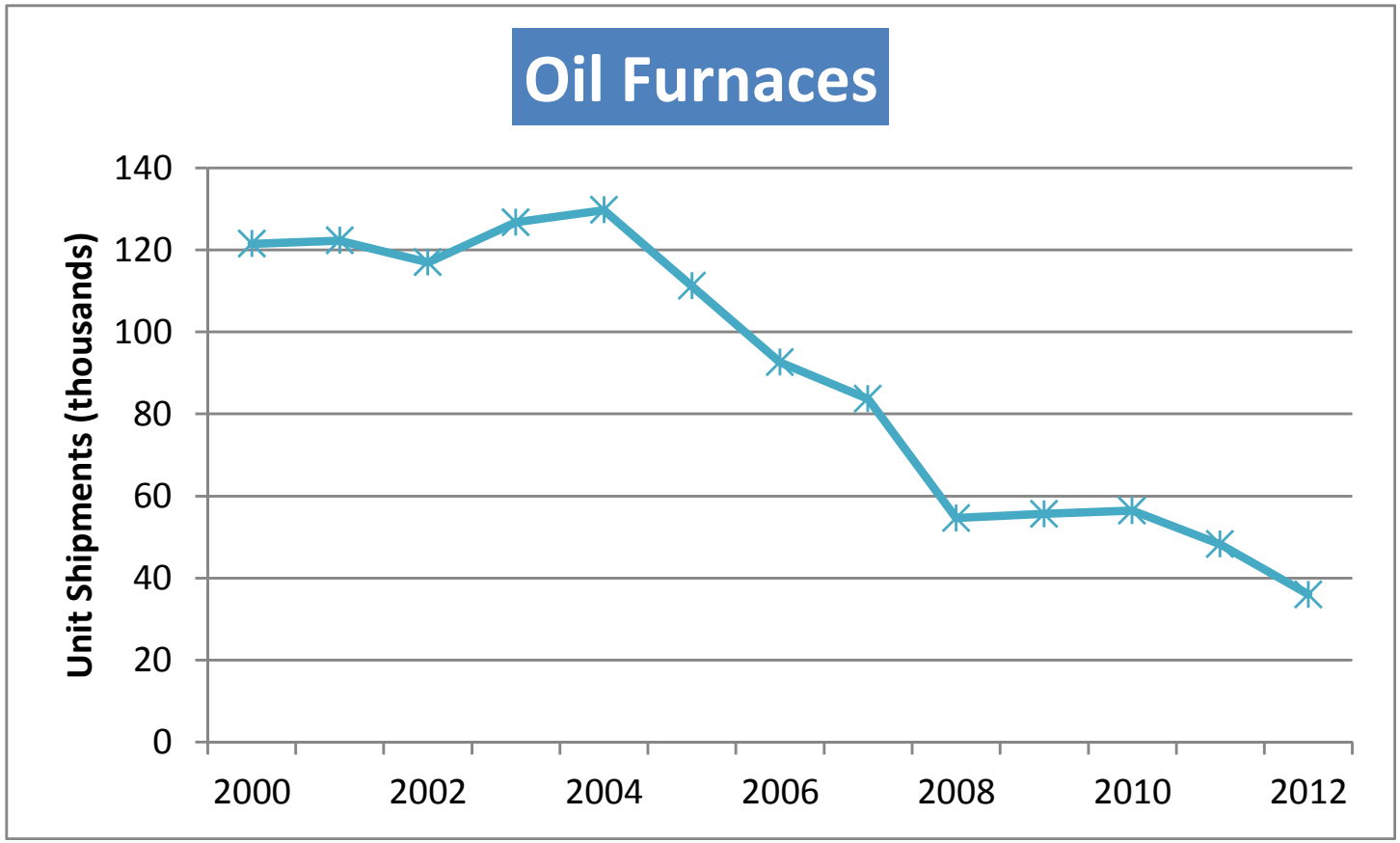
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	83	83	85	97	84	97	84	97	85	97
Electric Consumption (kWh/yr)	490	477	477	460	410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

Residential Oil-Fired Furnaces

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

Residential Oil-Fired Furnaces

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



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

Residential Gas-Fired Boilers

Higher typical efficiencies and lower costs for a given efficiency level

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

Residential Gas-Fired Boilers

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

Residential Oil-Fired Boilers

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

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

Residential Oil-Fired Boilers

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

Residential Room Air Conditioners

Higher typical efficiencies and lower costs for a given efficiency level

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

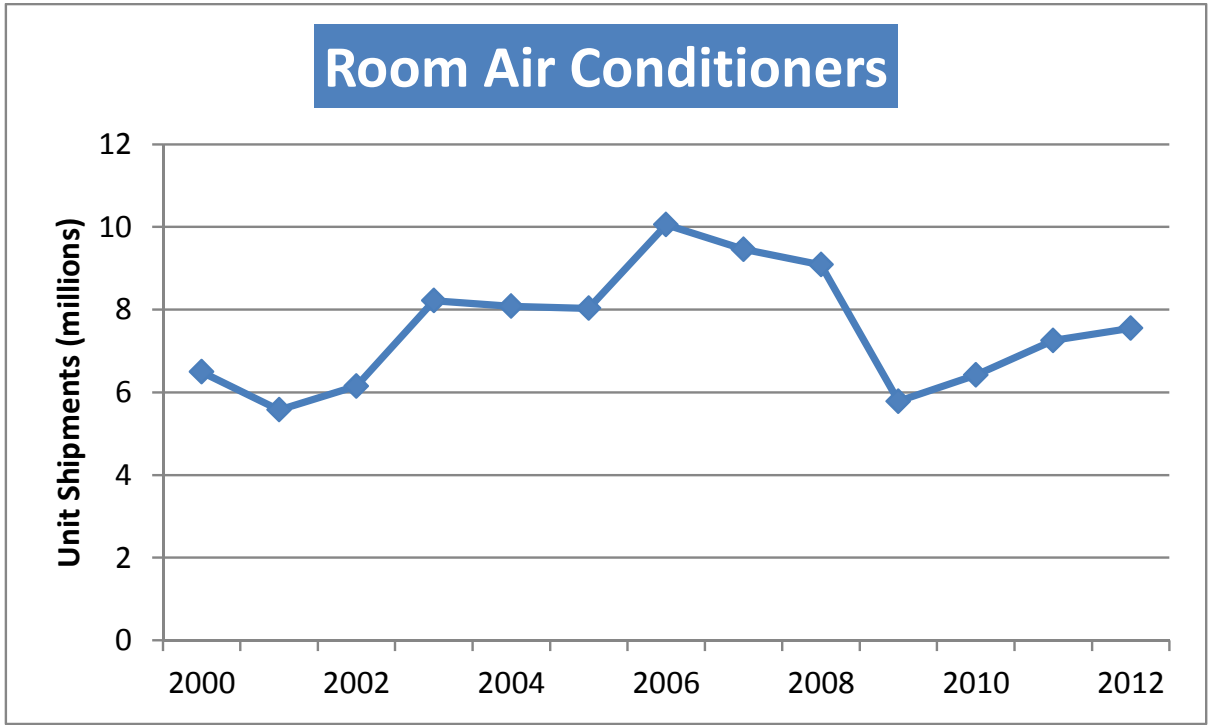
* All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).
** Italicized values are estimated. The federal standard is expressed in EER, but will be expressed in CEER beginning in 2014. The two metrics are not strictly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

Residential Room Air Conditioners

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

Residential Room Air Conditioners

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



Source: *Appliance Magazine.*

South (Hot-Dry and Hot-Humid)

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

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

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

North (Rest of Country)

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

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

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

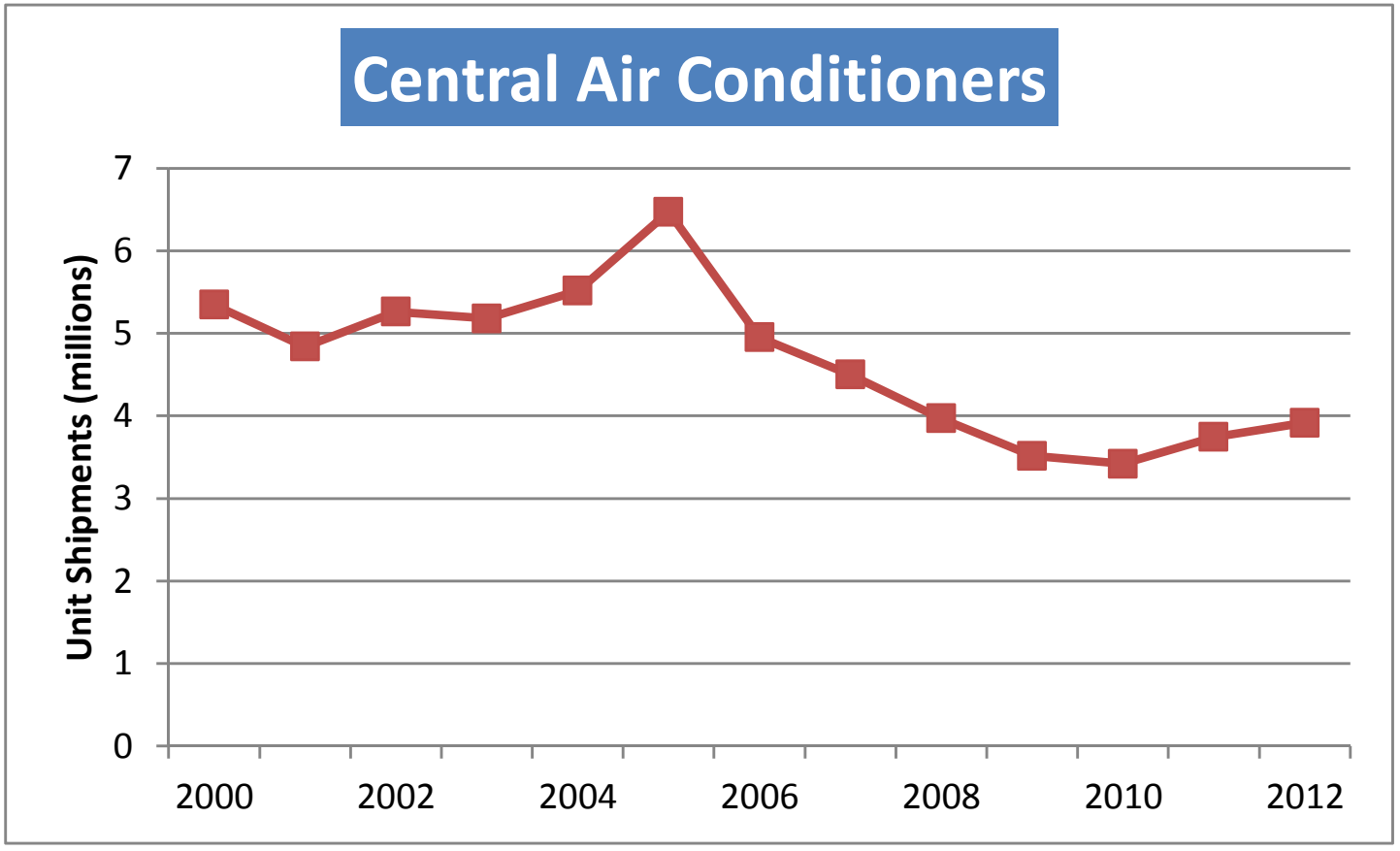
Final

Residential Central Air Conditioners

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

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

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



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

Residential Air Source Heat Pumps

Same as reference case

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

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

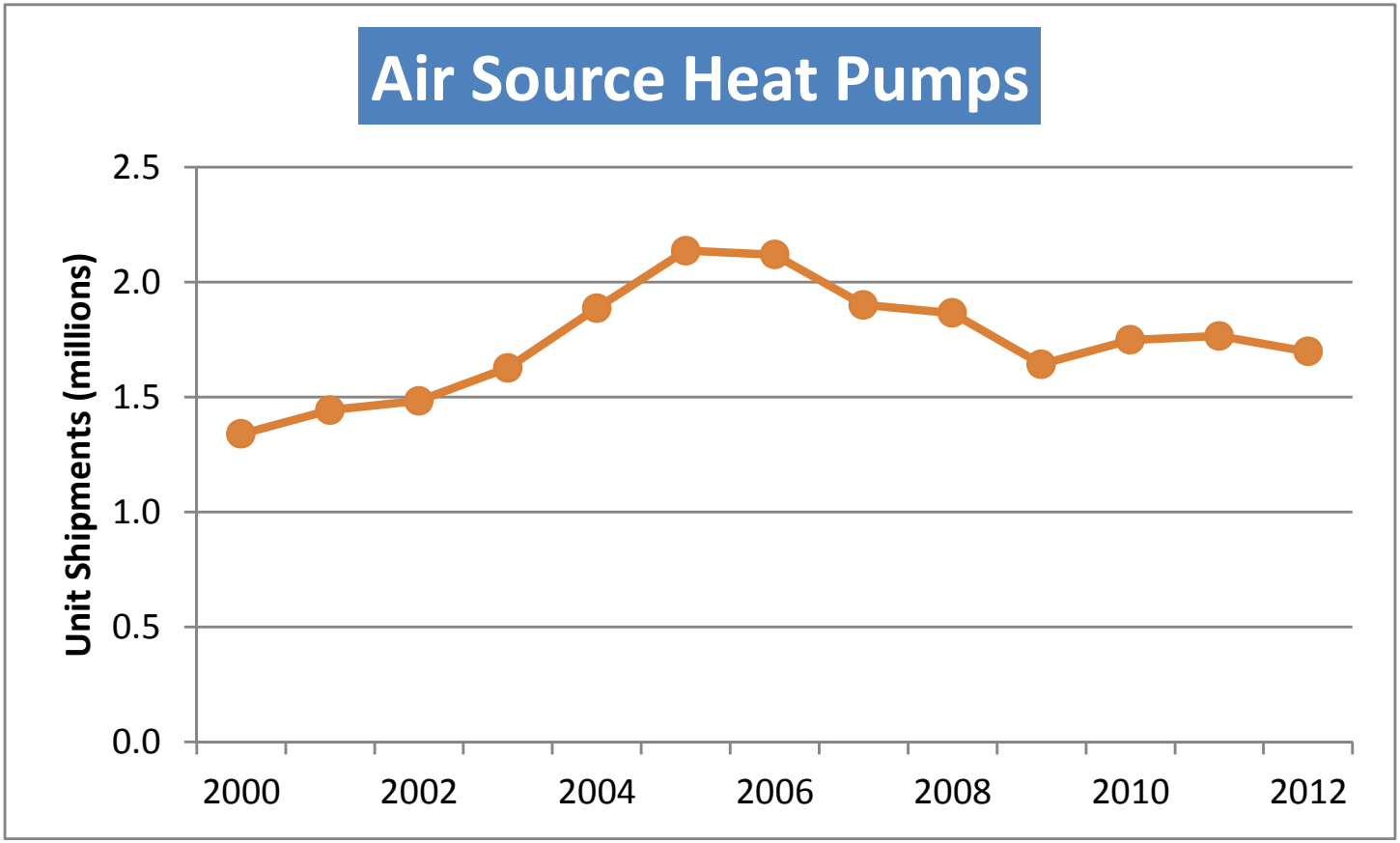
Residential Air Source Heat Pumps

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

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

Residential Air Source Heat Pumps

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



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

Residential Central Air Conditioners and Air Source Heat Pumps

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

Residential Ground Source Heat Pumps

Higher typical efficiencies and lower costs than reference case

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

Residential Ground Source Heat Pumps

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

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

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

Residential Gas Heat Pumps

Higher efficiencies and lower costs than reference case

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

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

Residential Gas Heat Pumps

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

Residential Electric Resistance Furnaces

Same as reference case

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

Residential Electric Resistance Furnaces

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

Residential Electric Resistance Unit Heaters

Same as reference case

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

* Annual Maintenance Cost is negligible

Residential Electric Resistance Unit Heaters

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

Residential Cordwood Stoves

Same as reference case

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

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

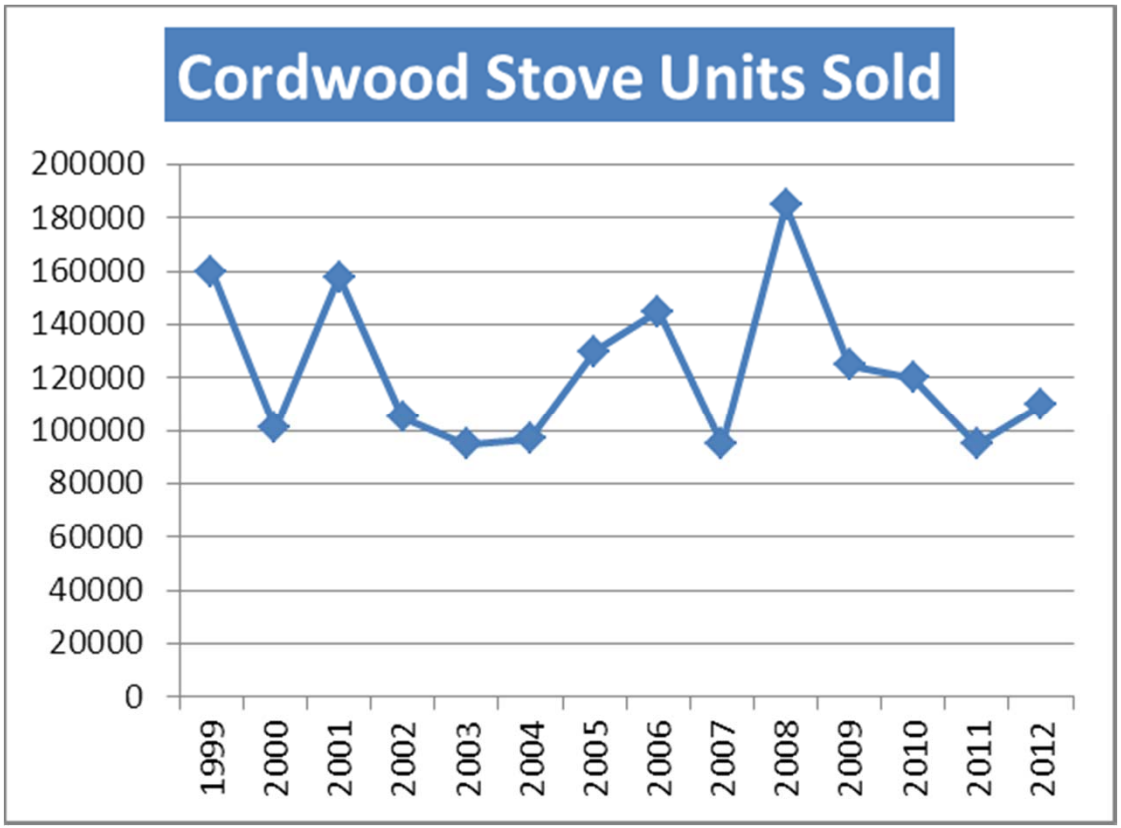
Residential Cordwood Stoves

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

Residential Cordwood Stoves

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

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



Source: HPBA

Final

Residential Wood Pellet Stoves

Same as reference case

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

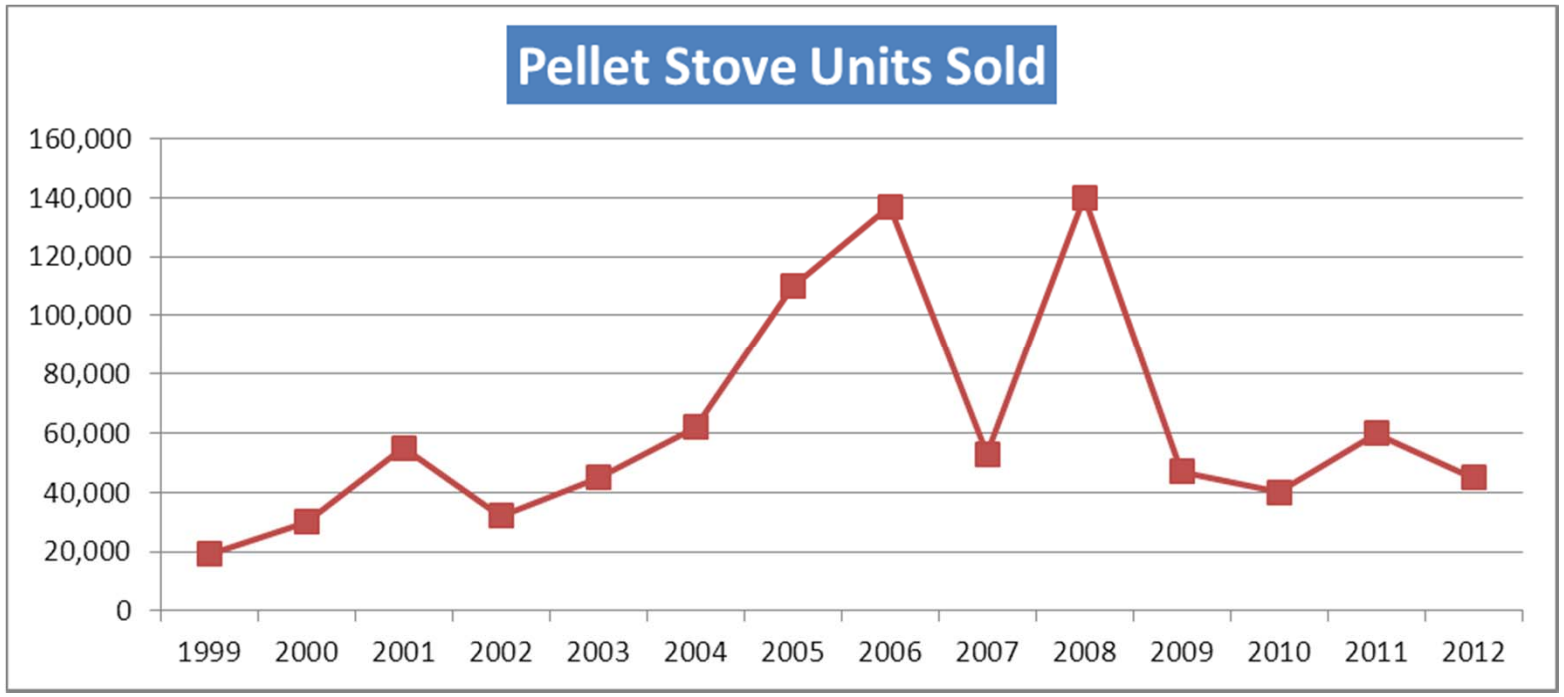
*Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
**Electricity consumption is for combustion air fan, distribution blower, and pellet feeder.
***Installed cost includes cost of hearth and vent pipe - materials and labor.

Residential Wood Pellet Stoves

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

Residential Wood Pellet Stoves

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



Source: HPBA

Top-Mount (Product Class 3)

Higher typical efficiencies than ref. case

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

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

Bottom-Mount (Product Class 5)

Higher typical efficiencies than ref. case

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

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

Side-Mount (Product Class 7)

Higher typical efficiencies than ref. case

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

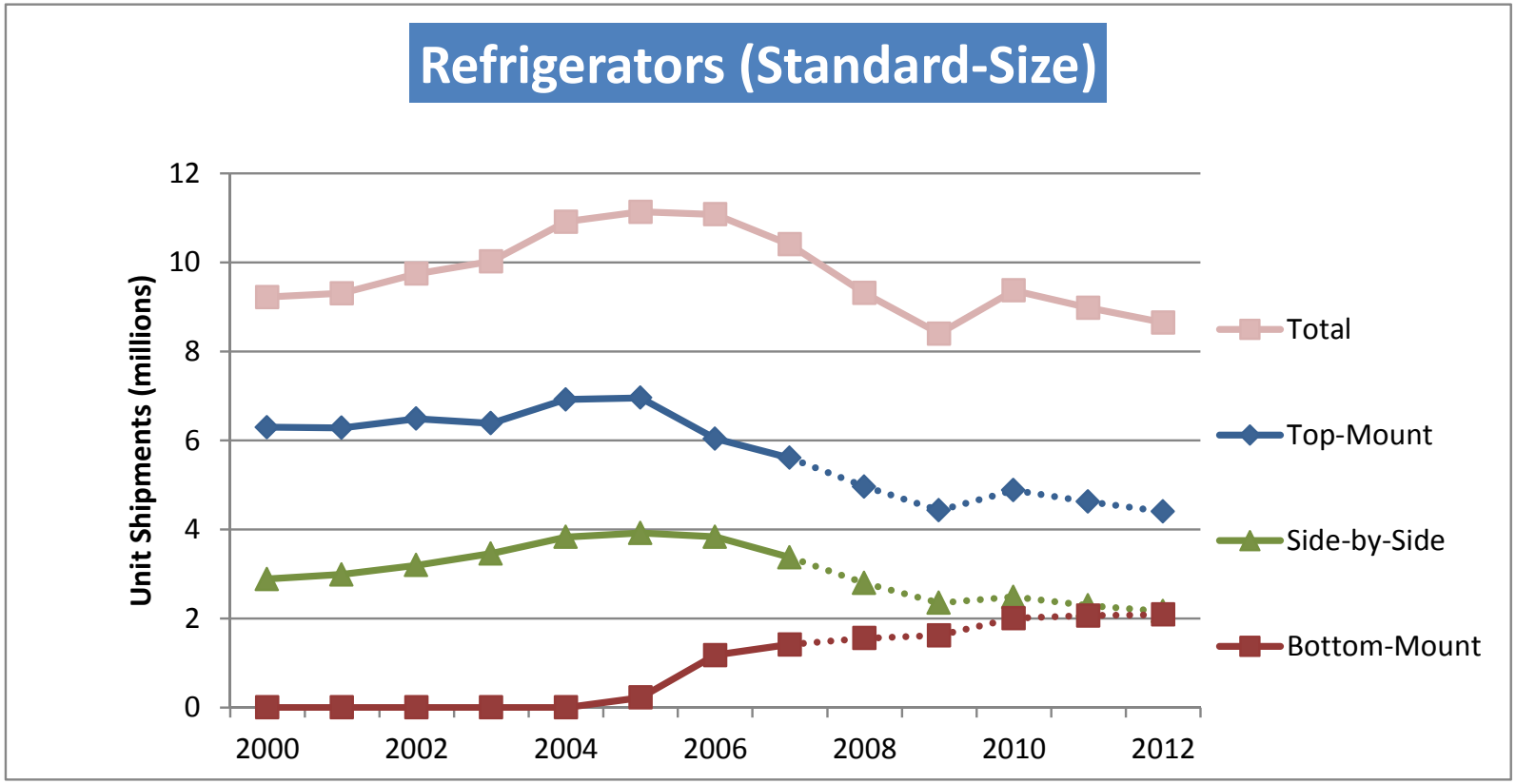
* The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards.
** Based on an adjusted volume of 32 ft3.

Residential Refrigerator-Freezers

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

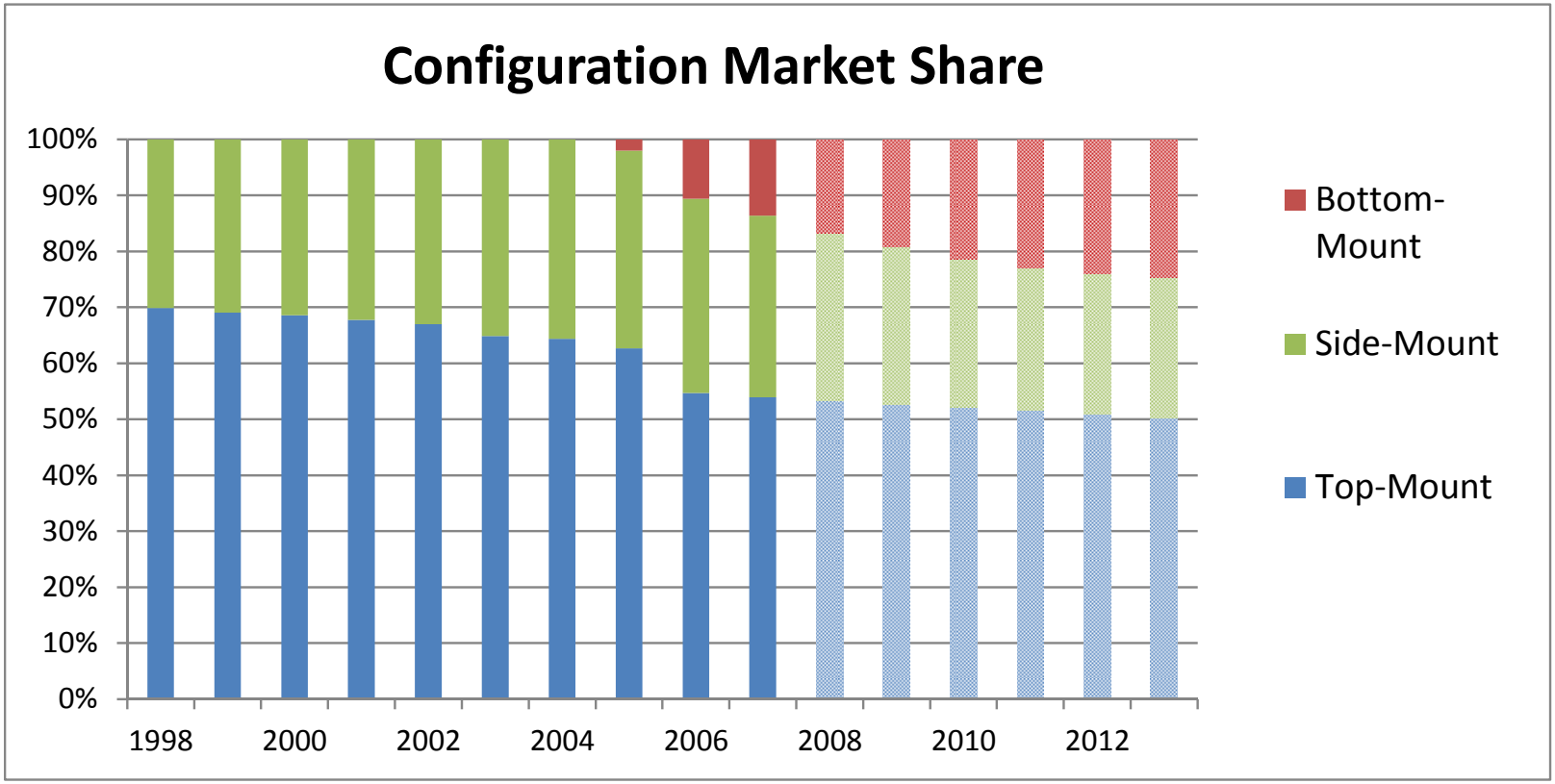
[1]Adjusted Volume (AV) = (Fresh Volume) + 1.63 × (Freezer Volume). Beginning in 2004, the 1.63 coefficient will change to 1.76.

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



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

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



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

Upright Freezers (Product Class 9)

Same as reference case

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

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

Chest Freezers (Product Class 10)

Same as reference case

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

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

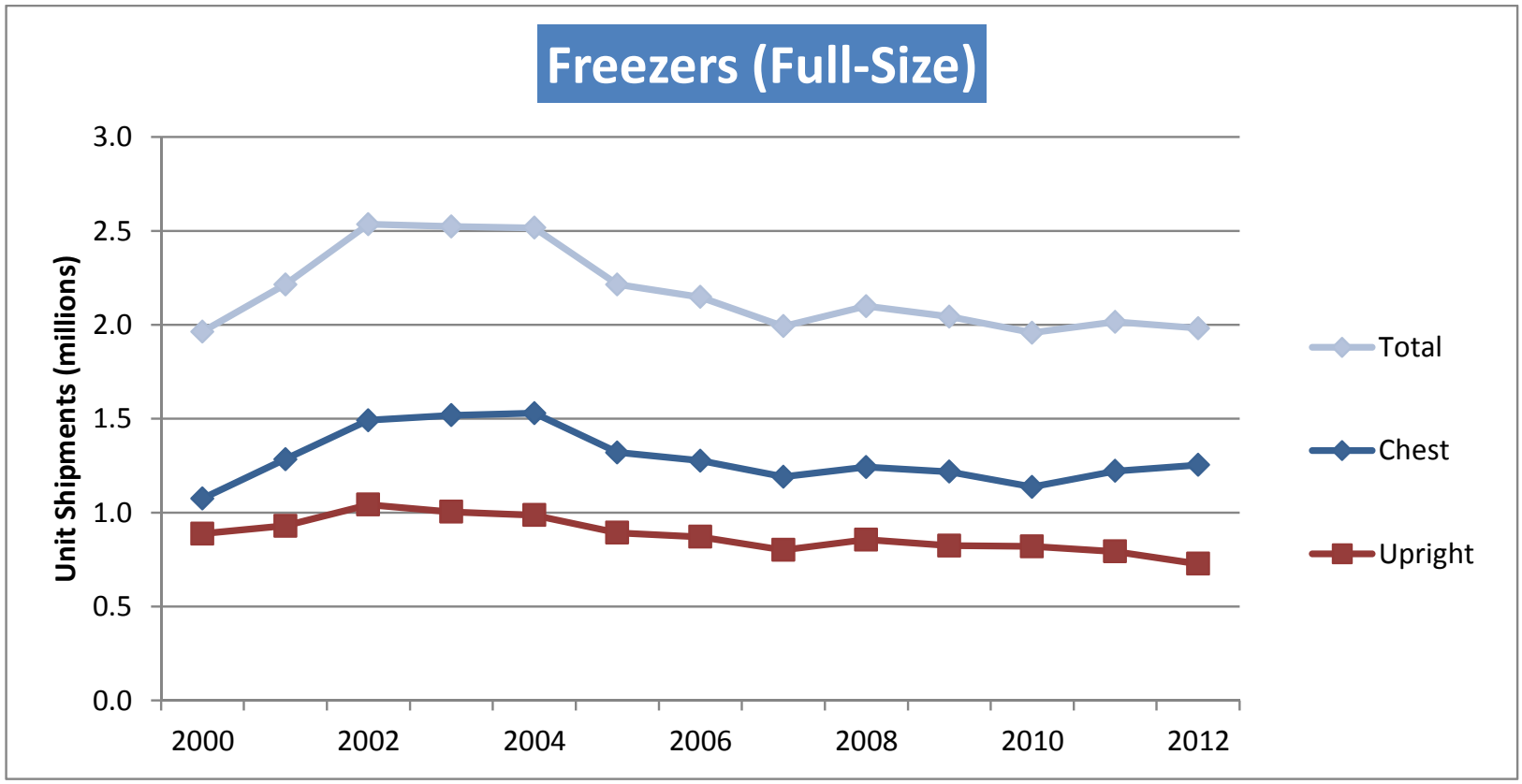
Residential Freezers

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

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

Residential Freezers

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



Source: *Appliance Magazine.*

Residential Natural Gas Cooktops and Stoves

Same as reference case

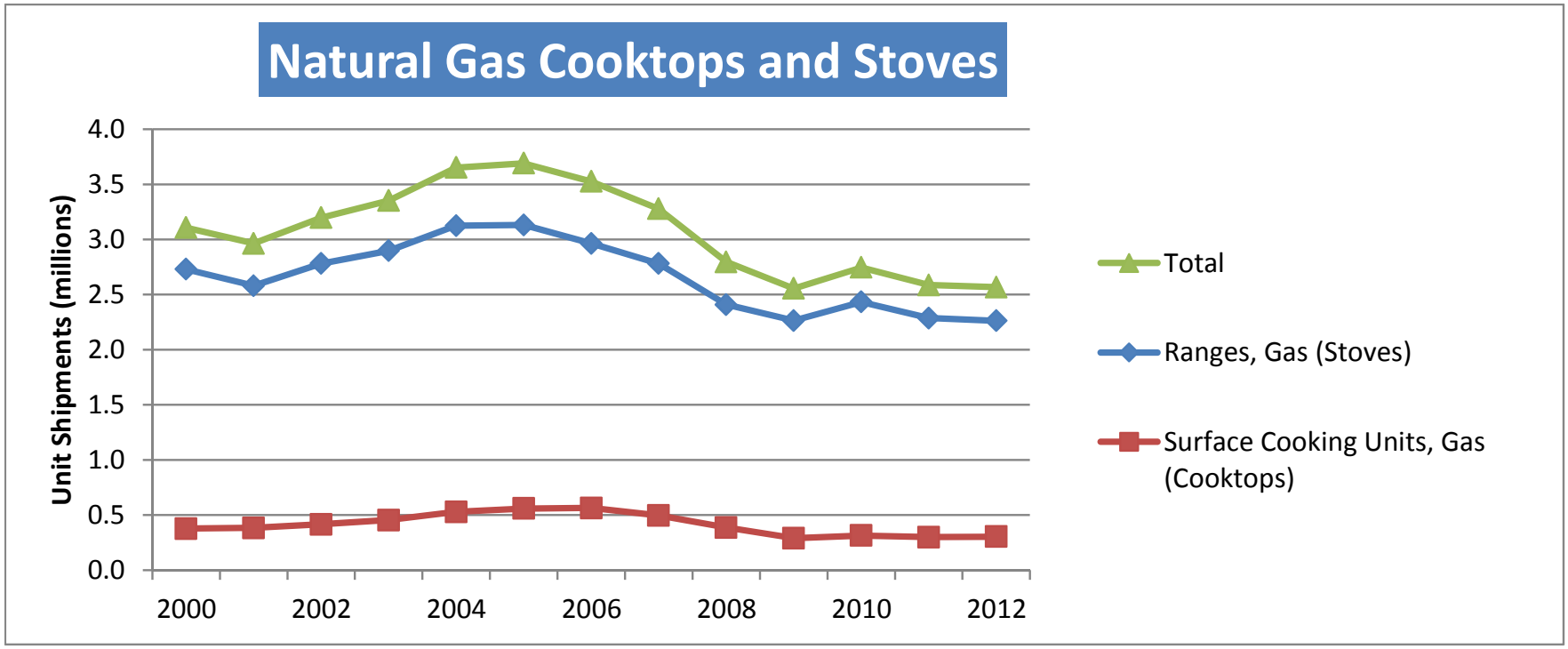
DATA	2009	2013		2020		2030		2040	
	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9
	12	12	12	12	12	12	12	12	12
Cooking Efficiency (%)	38.5	39.9	42	39.9	42	39.9	42	39.9	42
Average Life (yrs)	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22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

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

Residential Natural Gas Cooktops and Stoves

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

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



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

Residential Clothes Washers – Front-Loading

Same as reference case

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

* Maintenance costs are negligible.

Residential Clothes Washers – Top-Loading

Same as reference case

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

* Maintenance costs are negligible.

Residential Clothes Washers

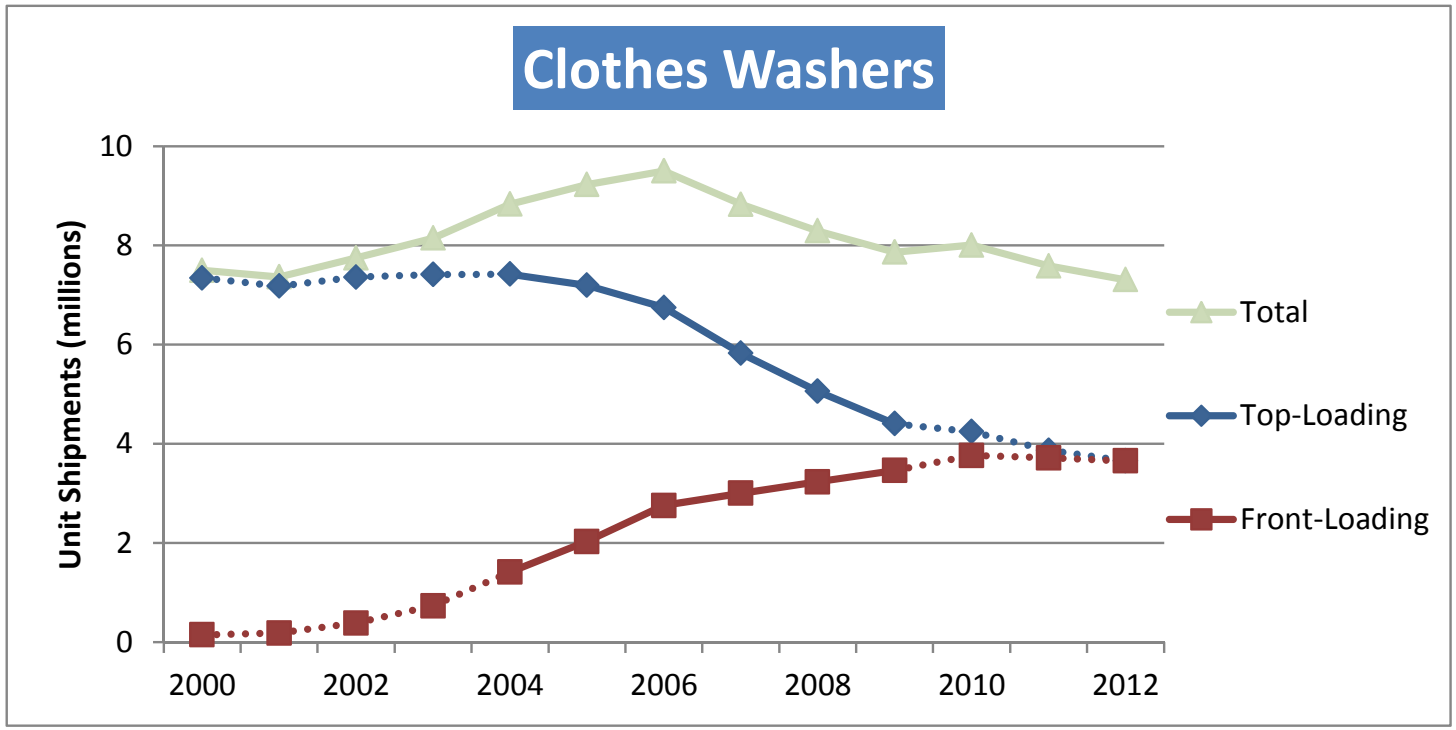
- Present analysis treats front- and top-loading models separately. Past analyses did not consider the two types separately.
- Federal standards for standard-capacity clothes washers (≥ 1.6 cubic feet):

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

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

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

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



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

Electric

Same as reference case

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

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

Natural Gas

Same as reference case

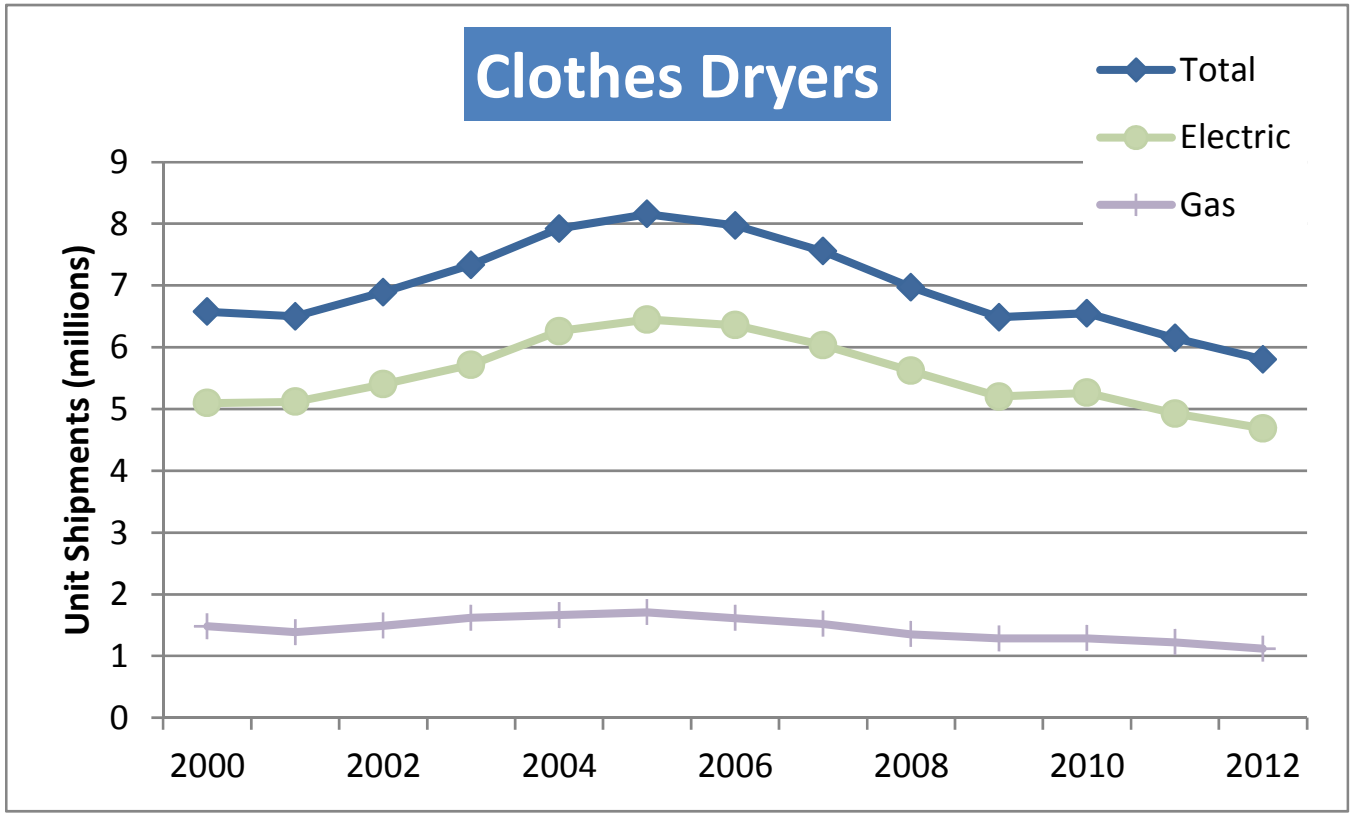
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	Mid-Level	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7
EF (lb/kWh)*	2.67	2.67	2.75	2.85	3.02	*2.81*	*3.02*	*2.81*	*3.02*	*2.81*	*3.02*
CEF (lb/kWh)*	*3.14*	*3.14*	*3.24*	*3.35*	*3.61*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

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

Residential Clothes Dryers

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

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



Source: *Appliance Magazine.*

Residential Dishwashers

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

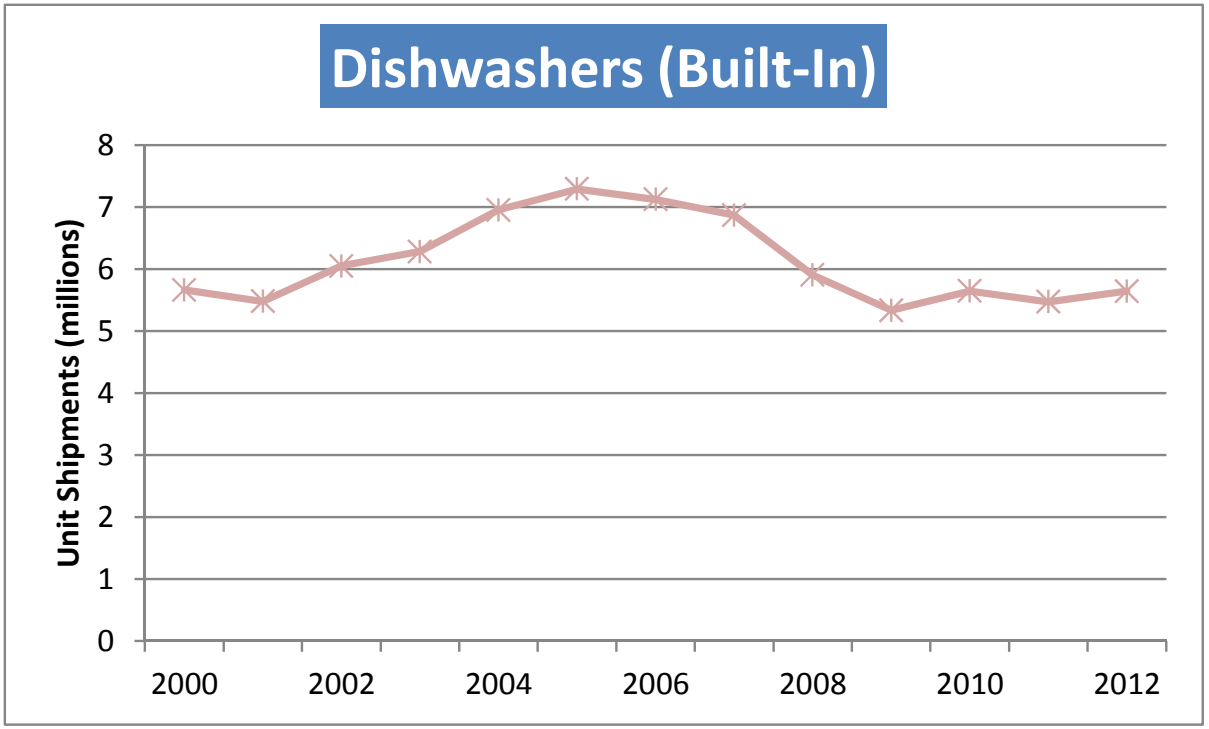
DATA	2009	2013				2020		2030		2040	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/yr)	312	307	295	295	180	275	180	275	180	275	180
Water Consumption (gal/cycle)	4.50	5.00	4.25	4.25	2.22	4.00	2.22	4.00	2.22	4.00	2.22
Water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

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

Residential Dishwashers

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

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



Source: *Appliance Magazine*

Commercial Gas-Fired Furnaces

Higher typical efficiencies than ref. case

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

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

Commercial Gas-Fired Furnaces

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

Commercial Oil-Fired Furnaces

Same as reference case

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

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

Commercial Oil-Fired Furnaces

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

Commercial Electric Boilers

Same as reference case

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

* Capacity is *output*

Commercial Electric Boilers

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

Commercial Gas-Fired Boilers

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

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

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

Commercial Gas-Fired Boilers

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

Commercial Oil-Fired Boilers

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

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

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

Commercial Oil-Fired Boilers

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

Commercial Gas-Fired Chillers[1]

Higher efficiencies and costs than reference case

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

* Capacity is *output*

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

Commercial Gas-Fired Chillers

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

Commercial Centrifugal Chillers

Higher typical efficiencies than reference case

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

* Capacity is *output*

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

Commercial Centrifugal Chillers

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

Commercial Reciprocating Chillers

Same as reference case

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

* Capacity is *output*

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

Commercial Reciprocating Chillers

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

Commercial Screw Chillers

Higher typical efficiencies than reference case

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

* Capacity is *output*

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

Commercial Screw Chillers

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

Commercial Scroll Chillers

Same as reference case

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

* Capacity is *output*

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

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

Commercial Scroll Chillers

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

Commercial Rooftop Air Conditioners

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

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

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

Air-Cooled Commercial Packaged Air Conditioners

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

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

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners

Same as reference case

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

* Capacity is *output*

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

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

Commercial Rooftop Heat Pumps

Higher typical efficiencies and lower costs for a given efficiency level

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

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

Air-Cooled Commercial Packaged Heat Pumps

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

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

Commercial Ground Source Heat Pumps

Higher typical efficiencies and lower costs than ref. case

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

Commercial Ground Source Heat Pumps

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

Commercial Electric Resistance Heaters

Same as reference case

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

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

Commercial Electric Resistance Heaters

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

Commercial Gas Storage Water Heaters

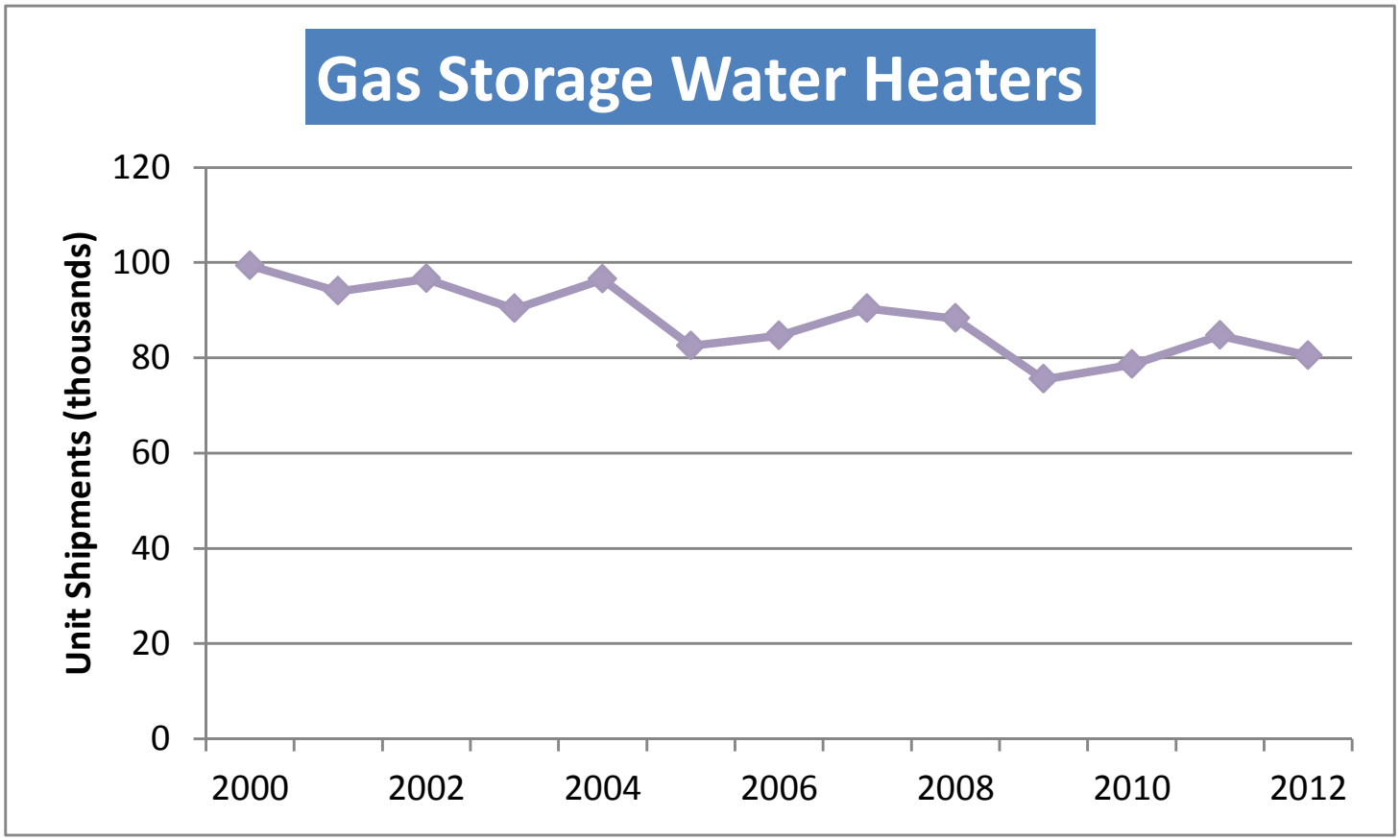
Higher typical efficiencies than ref. case

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

Commercial Gas Storage Water Heaters

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

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



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

Commercial Electric Resistance Water Heaters

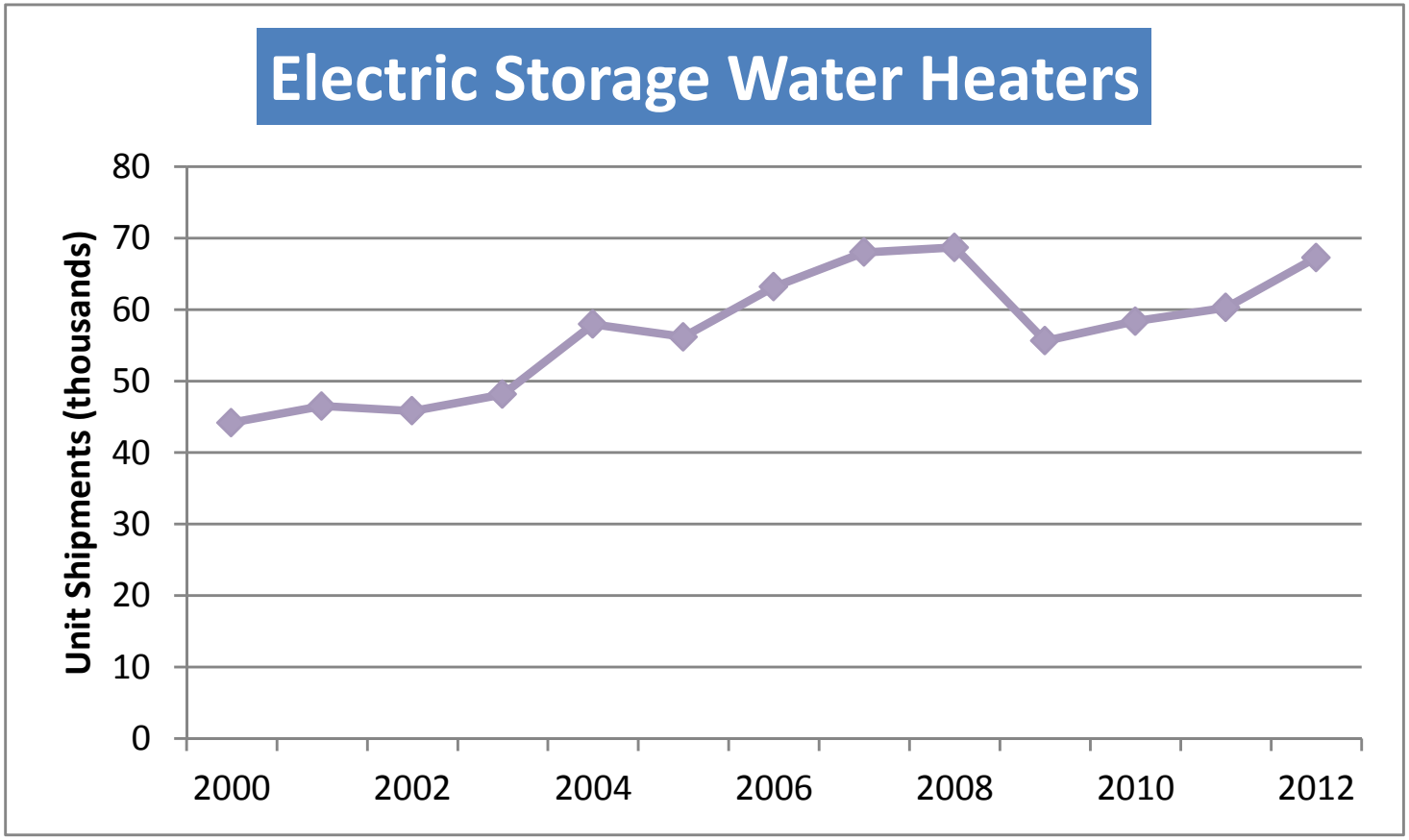
Same as reference case

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

Commercial Electric Resistance Water Heaters

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

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



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

Commercial Oil-Fired Water Heaters

Higher typical efficiencies than ref. case

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

Commercial Oil-Fired Water Heaters

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

Commercial Gas-Fired Instantaneous Water Heaters

Higher typical efficiencies than ref. case

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

* Maintenance costs are negligible.

Commercial Gas-Fired Instantaneous Water Heaters

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

Commercial Electric Booster Water Heaters

Same as reference case

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

* Annual Maintenance Cost is negligible

Final

Commercial Gas Booster Water Heaters

Same as reference case

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

Commercial Booster Water Heaters

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

Commercial Gas Griddles

Higher typical efficiencies than ref. case

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

* Maintenance costs are negligible.

Commercial Electric Griddles

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

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

* Maintenance costs are negligible.

Commercial Gas and Electric Griddles

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

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

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

Commercial Hot Food Holding Cabinets

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

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

* Maintenance costs are negligible.

Commercial Hot Food Holding Cabinets

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

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

Appendix A
Data Sources

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

www.navigantconsulting.com

Data Sources » Residential Gas-Fired Water Heaters

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

Data Sources » Residential Oil Water Heaters

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

Data Sources » Residential Electric Resistance Water Heaters

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

Data Sources » Residential Heat Pump Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th colspan="2">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI</td><td>EERE</td><td>ENERGY STAR</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Energy Factor</td><td>AHRI</td><td colspan="2">ENERGY STAR</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>RS Means 2010 / ACEEE, 2007</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>RS Means 2010 / ACEEE, 2007</td><td colspan="2">Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td></td><td colspan="2">EERE</td></tr>
</table>

Data Sources » Residential Instantaneous Water Heaters

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

Data Sources » Residential Solar Water Heaters

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

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

Data Sources » Residential Gas-Fired Furnaces

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

Data Sources » Residential Oil-Fired Furnaces

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

Data Sources » Residential Gas-Fired Boilers

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

Data Sources » Residential Oil-Fired Boilers

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

Data Sources » Residential Room Air Conditioners

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

South (Hot-Dry and Hot-Humid)

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

North (Rest of Country)

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

Data Sources » Residential Air Source Heat Pumps

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

Data Sources » Residential Ground Source Heat Pumps

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

Data Sources » Residential Gas Heat Pumps

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

Data Sources » Residential Electric Resistance Furnaces

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

Data Sources » Residential Electric Resistance Heaters

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

Data Sources » Residential Cord Wood Stoves

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

Data Sources » Residential Wood Pellet Stoves

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

Data Sources » Residential Refrigerator-Freezers and Freezers

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

Data Sources » Residential Natural Gas Cooktops

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

Front-Loading

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

Top-Loading

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

Data Sources » Residential Clothes Dryers

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

Data Sources » Residential Dishwashers

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

Data Sources » Commercial Gas-Fired Furnaces

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

Data Sources » Commercial Oil-Fired Furnaces

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

Data Sources » Commercial Electric Boilers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th>2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><td colspan="2">Installed Base</td><td>Typical</td><td colspan="3">Typical</td></tr>
<tr><td>Typical Capacity (kW)</td><td colspan="3">BSRIA</td><td colspan="3" rowspan="6">SAIC</td></tr>
<tr><td>Efficiency (%)</td><td colspan="3">DOE/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3">ASHRAE 2007 HVAC Applications</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>RS Means 2010/SAIC</td><td colspan="2">RS Means 2013/SAIC</td></tr>
<tr><td>Total Installed Cost ($)</td><td>RS Means 2010/SAIC</td><td colspan="2">RS Means 2013/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>RS Means 2010/SAIC</td><td colspan="2">RS Means 2013/SAIC</td></tr>
</table>

Data Sources » Commercial Gas-Fired Boilers

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

Data Sources » Commercial Oil-Fired Boilers

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

Data Sources » Commercial Gas-Fired Chillers

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

Data Sources » Commercial Centrifugal Chillers

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

Data Sources » Commercial Reciprocating Chillers

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

Data Sources » Commercial Screw Chillers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>Mid</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">SAIC</td><td colspan="3" rowspan="8">SAIC</td></tr>
<tr><td>Efficiency (kW/ton)</td><td>DEER/FEMP/ Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>COP</td><td>DEER/FEMP/ Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">Manufacturers</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="6">RS Means 2013/Distributors/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td><td colspan="6">RS Means 2013/Distributors/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="6">SAIC</td></tr>
</table>

Data Sources » Commercial Scroll Chillers

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>Mid</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">SAIC/Manufacturers</td><td colspan="3" rowspan="7">SAIC</td></tr>
<tr><td>Efficiency [full-load/IPLV] (kW/ton)</td><td>Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>COP [full-load/IPLV]</td><td>Product Literature</td><td>SAIC</td><td>ASHRAE 90.1-2010</td><td colspan="3">Product Literature/SAIC</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">Manufacturers</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="6">Manufacturers/RS Means 2013/SAIC</td></tr>
<tr><td>Total Installed Cost ($/ton)</td><td colspan="6">Manufacturers/RS Means 2013/SAIC</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="6">SAIC</td></tr>
</table>

Data Sources » Commercial Rooftop Air Conditioners

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Output Capacity (kBtu/h)</td><td colspan="6">AHRI / Navigant</td><td colspan="3" rowspan="6">Navigant</td></tr>
<tr><td>Efficiency (EER)</td><td>ASHRAE Standard 90.1-2004</td><td>Distributors/ Navigant</td><td colspan="2">EERE</td><td>ENERGY STAR</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost $)</td><td>Navigant / LBNL, 2003</td><td>Distributors/ Navigant / DEER, 2008</td><td colspan="2">EERE</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Navigant / LBNL, 2003</td><td>Distributors/ Navigant / DEER, 2008</td><td colspan="2">EERE</td><td colspan="2">Distributors</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">EERE</td></tr>
</table>

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

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

Data Sources » Commercial Rooftop Heat Pumps

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

Data Sources » Commercial Ground Source Heat Pumps

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

Data Sources » Commercial Electric Resistance Heaters

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

Data Sources » Commercial Gas-Fired Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="3">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="3">Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td colspan="4">Arthur D. Little / Distributors / AHRI</td><td colspan="2">AHRI</td><td colspan="3" rowspan="8">Navigant</td></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>Arthur D. Little / AHRI</td><td colspan="2">AHRI</td><td colspan="3">AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="3">EERE / ASHRAE Standard 90.1-2004 / Navigant</td><td>EERE</td><td>AHRI</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="4">Distributors / CEC / Navigant</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="6">Distributors / CEC / Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="6">Navigant</td></tr>
</table>

Data Sources » Commercial Electric Resistance Water Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th>2003</th><th>2012</th><th colspan="2">2013</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><th colspan="2">Installed Base</th><th>Current Standard</th><th>Typical</th><th colspan="3">Typical</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td colspan="2">Navigant / Product Literature</td><td colspan="2">AHRI</td><td colspan="3" rowspan="8">Navigant</td></tr>
<tr><td>Typical Input Capacity (kW)</td><td colspan="2">Product Literature</td><td colspan="2">AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>Product Literature</td><td>ASHRAE Standard 90.1-2004</td><td colspan="2">AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors/ Navigant</td><td>Distributors</td><td colspan="2">Distributors</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors/ Navigant</td><td>Navigant</td><td colspan="2">Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="3">Navigant</td></tr>
</table>

Data Sources » Commercial Oil-Fired Water Heaters

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

Data Sources » Commercial Gas-Fired Instantaneous Water Heaters

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

Data Sources » Commercial Electric Booster Water Heaters

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

Data Sources » Commercial Gas Booster Water Heaters

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

Data Sources » Commercial Gas Griddles

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

Data Sources » Commercial Electric Griddles

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

Data Sources » Commercial Hot Food Holding Cabinets

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

Appendix B
References

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

www.navigantconsulting.com

References

- ACEEE. (2007). *Top Rated Energy-Efficient Appliances.* American Council for an Energy-Efficient Economy.
- AHAM. (n.d.). *Directory of Certified Products*. Retrieved September 2010 from: http://www.ahamdir.com/dirsvc/aham.nsf/fraRAC?OpenFrameset&pgm=Room%20Air%20Conditioners
- AHRI. (n.d.). *Directory of Certified Product Performance.* Retrieved September 2010 and June 2013 from: http://www.ahridirectory.org/ahridirectory/pages/home.aspx
- Appliance Magazine. (2012). "The U.S. Appliance Industry: Market Value, Life Expectancy & Replacement Picture 2012." UBM Canon.
- Appliance Magazine. (n.d.).
  - "U.S. Appliance Industry Statistical Review: 2000 to YTD 2010." Canon Data Products Group. July 2010.
  - "U.S. Appliance Shipment Statistics Monthly: January 2011." Canon Data Products Group. January 2011.
  - "2011 Full-Year Appliance Industry Shipment Statistics." UBM Canon. March 2012.
  - "2012 Full-Year Appliance Industry Shipment Statistics and Year-In-Review." UBM Canon. March 2013.
- Arthur D. Little. (1997). *Massachusetts Market Transformation Scoping Study; Final Report.* Massachusetts Gas DSM / Market Transformation Collaborative.

References

- ASHRAE. (2003). *2003 ASHRAE Handbook - HVAC Applications.* ASHRAE, Inc.
- ASHRAE. (1999). *ASHRAE Standard 90.1-1999.* ASHRAE, Inc.
- ASHRAE. (2004). *ASHRAE Standard 90.1-2004.* ASHRAE, Inc.
- ASHRAE. (2007). *ANSI/ASHRAE/IESNA Standard 90.1-2007.* ASHRAE, Inc.
- Building Services Research and Information Association & Ducker Research Company. (1997, 1998). *U.S. Market for Central Plant Air Conditioning; Market for Ducted Warm Air Central Heating; U.S. Market for Hydronic Heating and Burners; U.S. Water Heating Market; U.S. Unitary and Close Control Air Conditioning.*
- California Air Resources Board (CARB). (2009). *Inventory of Direct and Indirect GHG Emissions from Stationary Air Conditioning and Refrigeration Sources, with Special Emphasis on Retail Food Refrigeration and Unitary Air Conditioning*
- CCMS. (n.d.). U.S. DOE *Compliance Certification Database*. Retrieved June 2013 from: http://www.regulations.doe.gov/certification-data/
- CEC. (n.d.). California Energy Commission *Appliance Efficiency Database*. Retrieved 2004, September 2010, and June 2013 from: http://www.appliances.energy.ca.gov/AdvancedSearch.aspx
- CEE. (2009). "Commercial Hot Food Holding Cabinets Program Guide." Consortium for Energy Efficiency. April 2009.

References

- CFR. (n.d.). National energy conservation standards authorized under the Energy Policy and Conservation Act of 1975 (EPCA) and codified in the Code of Federal Regulations (CFR).
- DEER. (2008, June). *Database for Energy Efficiency Resources*. Retrieved June 2013, from California Energy Commission: www.energy.ca.gov/deer
- DOE. (2012, June). *Energy Saver: Geothermal Heat Pumps.* Retrieved June 2013, from ENERGY.GOV: http://energy.gov/energysaver/articles/geothermal-heat-pumps
- Distributors. (n.d.). Navigant and SAIC online research and discussions with distributors (e.g., Grainger, Home Depot, Lowe's, Sears, and others).
- EERE. (2006). *Appliance Standards Framework, Rulemaking Framework for Residential Water Heaters, Direct Heating Equipment and Pool Heaters.*
- EERE. (2006). *Buildings Energy Data Book.*
- EERE. (2009). *Commercial Heating, Air Conditioning and Water Heating Equipment (i.e. ASHRAE Equipment).*
- EERE. (2001). *Energy Conservation Program for Consumer Products: Central Air Conditioners and Heat Pumps Energy Conservation Standards; Final Rule.*
- EERE. (2010). *Energy Conservation Program for Appliance Standards: Residential Central Air Conditioners and Heat Pumps.*

References

- EERE. (2007). *Energy Conservation Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers; Final Rule.*
- EERE. (2009). *Energy Conservation Program: Energy Conservation Standards for Certain Consumer Products and for Certain Commercial and Industrial Equipment; Final Rule.*
- EERE. (2009). *Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards and Test Procedures for Commercial Heating, Air-Conditioning, and Water-Heating Equipment; Proposed Rule*.
- EERE. (2011). *Energy Conservation Program: Energy Conservation Standards for Residential Clothes Dryers and Room Air Conditioners; Direct Final Rule.*
- EERE. (2012). *Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers; Direct Final Rule.*
- EERE. (2012). *Energy Conservation Program: Energy Conservation Standards for Residential Dishwashers; Direct Final Rule*.
- EERE. (2011). *Energy Conservation Program: Energy Conservation Standards for Residential Furnaces and Residential Central Air Conditioners and Heat Pumps; Direct Final Rule*.

References

- EERE. (2010). *Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters; Final Rule.*
- EERE. (2011). *Energy Conservation Program: Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers; Final Rule.*
- EERE. (2009). *Energy Conservation Program: Energy Conservation Standards for Certain Consumer Products (Dishwashers, Dehumidifiers, Microwave Ovens, and Electric and Gas Kitchen Ranges and Ovens) and for Certain Commercial and Industrial Equipment (Commercial Clothes Washers); Final Rule.*
- EERE. (2004). *Joint Stakeholders Comments on Standards for Commercial Package Air Conditioners and Heat Pumps.*
- EERE. (2009). *Ground-Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers.*
- EERE. (2011). *Technical Support Document: Energy Efficiency Program for Commercial And Industrial Equipment: Efficiency Standards for Commercial Heating, Air-Conditioning, and Water-Heating Equipment.*

References

- ENERGY STAR Savings Calculator (n.d.). "Savings Calculator for ENERGY STAR Qualified Commercial Kitchen Equipment." U.S. EPA and DOE. Retrieved June 2013 from http://www.energystar.gov/index.cfm?c=bulk_purchasing.bus_purchasing
- ENERGY STAR. (n.d.). Retrieved June 2013, from ENERGY STAR Products: http://www.energystar.gov/index.cfm?c=products.pr_find_es_products
- EPA. (2013, March) *List of Certified Wood Stoves.* *ww.**epa**.gov/compliance/resources/.../**woodstoves**/**certifiedwood**.pdf*
- eSource. (n.d.). *Centrifugal and Screw Chillers.* Retrieved June 2013, from Business Energy Advisor: http://www.esource.com/escrc/0013000000DP22YAAT/BEA1/PA/PA_Cooling/PA-14
- FEMP. (2012, December). *Covered Product Category: Air-Cooled Electric Chillers.* Retrieved June 2013, from FEMP Technologies: https://www1.eere.energy.gov/femp/technologies/eep_ac_chillers.html
- FEMP. (2012). "Federal Energy Management Program: Covered Product Category: Hot Food Holding Cabinets." Retrieved June 2013 from: http://www1.eere.energy.gov/femp/technologies/printable_versions/eep_hot_food.html
- FEMP. (2012, December). *Covered Product Category: Water-Cooled Electric Chillers.* Retrieved June 2013, from FEMP Technologies: https://www1.eere.energy.gov/femp/technologies/eep_wc_chillers.html

References

- FSTC. (2002). Food Service Technology Center. *Commercial Cooking Appliance Technology Assessment.* Fisher Nickel, Inc.
- FSTC. (2013). Personal communication with Yung Lin of the Food Service Technology Center. June 21, 2013.
- GeoExchange. *GeoExchange Heating and Cooling Systems: Fascinating Facts.*
- GHPC. (n.d.). *Geothermal Heat Pump Consortium*. Retrieved 2007 from www.geoexchange.org
- Georgia Institute of Technology (GIT). (1998). *Analysis And Performance Of Gas-Electric Hybrid Chiller Systems*
- IGSPHA. (n.d.). *International Ground Source Heat Pump Association*. Retrieved 2007 from www.igshpa.okstate.edu
- International Ground Source Heat Pump Association (IGSHPA) Conference Proceedings. (2012, October). *Measuring the Costs & Benefits of Nationwide Geothermal Heat Pump (GHP) Deployment – A Progress Report.* Retrieved June 2013, from IGSHPA: http://www.igshpa.okstate.edu/membership/members_only/proceedings/2012/10-3-2012-0130-Session-C-Measuring-the-Costs-&-Benefits-of-Nationwide-Geothermal-Heat-Pump-(GHP)-Deployment-A-Progress-Report.pdf

References

- LBNL. (2003). *Commercial Unitary Air Conditioning and Heat Pumps - Life Cycle Cost Analysis: Inputs and Results.* Lawrence Berkeley National Laboratory.
- Manufacturers. (n.d.). SAIC and Navigant discussions with product manufacturers.
- Max Neubauer, A. d. (2009). *Ka-BOOM! The Power of Appliance Standards.* ACEEE, ASAP.
- Navien America Inc. (n.d.). *Navien Condensing 98%.* Retrieved September 2010 from http://www.navienamerica.com/PDS/ftp/NavienCondensingTankless/DownLoad_Brochure_Manual/NavienCodensing98_Brochure.pdf
- Navigant Consulting, Inc. (n.d.). In-House Expertise.
- Product Literature. (n.d.). Literature from manufacturers and experts on specific products.
- Propane Education and Research Council (PERC). (2007). *Assessment of Propane Fired Gas Air Conditioning, Heat Pumping and Dehumidification Technologies, Products, Markets and Economics*

References

- *RS Means Mechanical Cost Data.* (2007). Means Construction Information Network.
- *RS Means Mechanical Cost Data.* (2010). Means Construction Information Network.
- *RS Means Mechanical Cost Data.* (2011). Means Construction Information Network.
- *RS Means Mechanical Cost Data.* (2013). Means Construction Information Network.
- SAIC. (n.d.). In-House Expertise.
- Technology Cost and Performance File for Commercial Model for AEO2010. (2009). (E. Boedecker, Compiler)
- Technology and Economic Assessment Panel (TEAP). (2004). *Report of the TEAP Chiller Task Force.*