Technology Collaboration Programme on
Heat Pumping Technologies (HPT TCP)

Annex 42

Heat Pumps in Smart Grids

Market overview: Country report for the United States

Appendix to the Final report

Operating Agent: The Netherlands

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Market overview

Country report for UNITED STATES

Report compiled by

Oak Ridge National Laboratory

Abstract
This appendix provides the detailed summary report discussing the market overview for United States.

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1 Overview of the U.S. Energy Sector

1.1 Overview of Main Challenges in the United States

As a result of the American Recovery and Reinvestment Act of 2009 (ARRA), rapid deployment of smart meters occurred between 2009 and 2012 in the United States. Now that this large amount of advanced metering infrastructure is installed, utilities are revisiting how to best incorporate them into operations to enhanced power distribution through the following functions:

- Outage Management
- Restoration verification
- Power quality alarming
- Load monitoring and profiling
- Asset and condition monitoring
- Adaptive conservation voltage reduction
- Integrated Volt/VAR control
- Fault location, isolation, and restoration
- Distributed generation integration

Smart grid infrastructure enhancements have created a wealth of data for utilities. While this presents great opportunity for efficiency improvements, it can be counterproductive and expensive if no intelligent information technology is in place to analyse the data and, in turn, make smart (in some cases, autonomous) operating decisions. In response, the introduction of more sophisticated utility information technology (IT) solutions (e.g., advanced distributions management systems capable of integrating individual operations and departments) are on the rise at a rapid rate [1].

Another growing challenge for the U.S. grid is how to appropriately accommodate an increased presence of distributed generation and microgrids. While these help to increase the level of grid flexibility and reduce dependence on a single grid, they are, in some cases, contributing to increased losses of revenue for utilities since they often pay customers a generous rate for power sold back to the grid. As a result, a push for net metering and residential feed-in tariff (FIT) reform is rising in the United States as the number of independent power generators (primarily through solar) continue to increase. Requests by the utilities to lower FIT rates, however, can carry with it the impression that they do not support growth in renewable generation (aka “green power” solutions). This situation is exacerbated since net metering regulations and compensation schemes vary by state. Proposed changes in utility business models to accommodate this market trend are in the works [1].

1.2 U.S. Electricity Generation

U.S. electricity generation, by fuel type (incl. renewables & import/export balance if available), historic trend and outlook

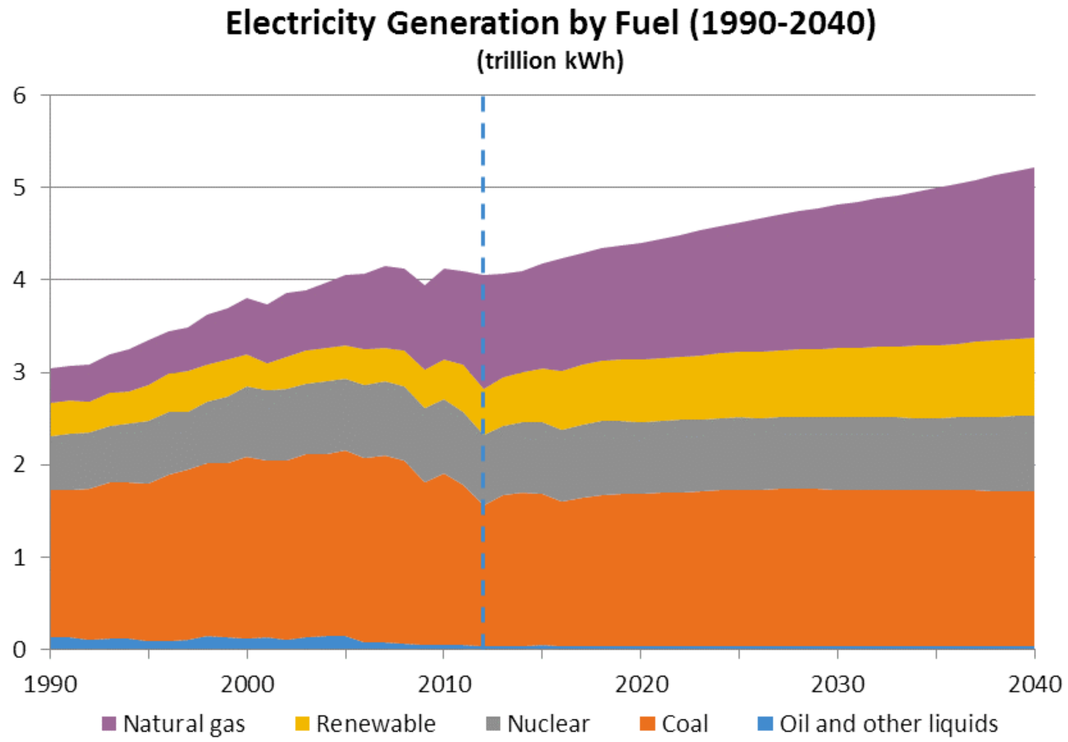
The electricity generation mix in the United States has historically been dominated by coal, comprising about 50-55% of total generation between 1990 and 2005, as shown in Figure 1. Coal-fired electricity is supplemented by large contributions from nuclear, natural gas, and renewable resources (primarily conventional hydro) [2].

Since 2005 coal’s share of total electricity generation has fallen steadily reaching 37% in 2012. Increased electric power generation from natural gas and, to a lesser extent, renewable energy plants has made up the difference. This change in the U. S. generation fuel mix has been driven by more competitively priced natural gas, programs that promote renewable generation and stricter environmental regulations that require coal plants to further limit CO_2 and other emissions. Emission reduction technologies and systems tend to increase the cost for new coal-fired power plants, so as coal plants retire, natural gas plants offer a less expensive option to meet new capacity needs.

According to the *Annual Energy Outlook 2014 Early Release* (AEO 2014ER), coal generation is projected to slow in upcoming years, then flatten out through 2040 (total generating capacity dropping from 310 GW in 2012 to 262 GW in 2040), as a result of the factors above. Meanwhile, natural gas generation is projected to steadily grow and eventually match coal generation by 2035, each representing 34% of total generation, and exceed

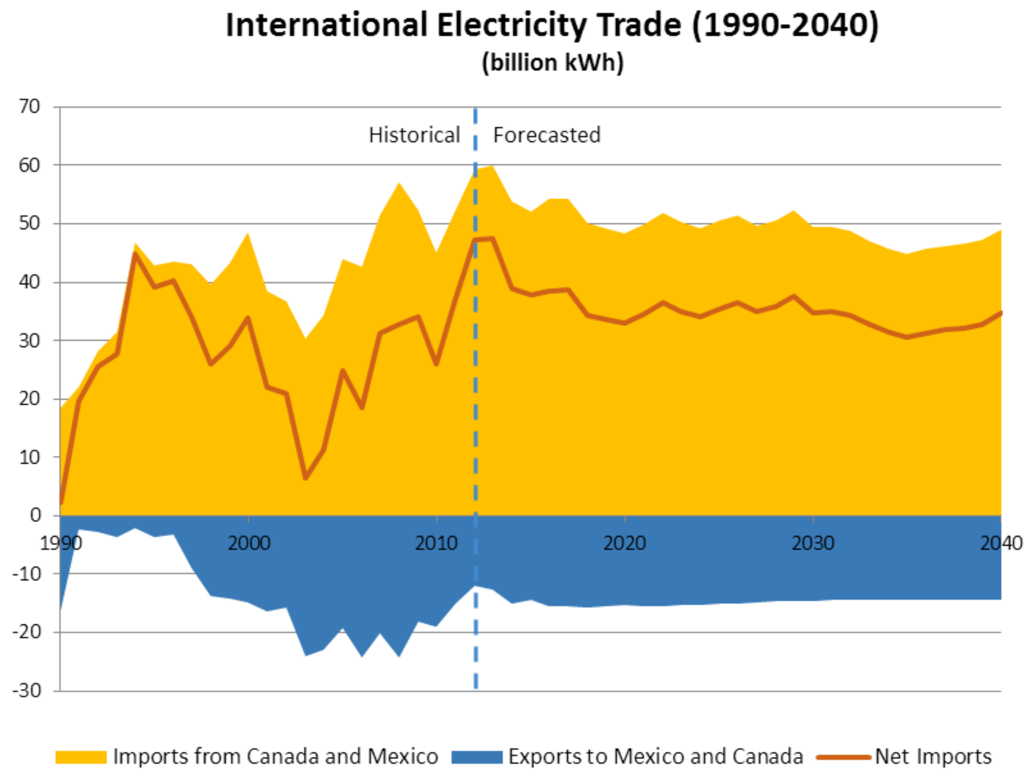
coal by 2040. Electricity generation from nuclear power plants is projected to increase by 5%, from 769 billion kWh in 2012 to 811 billion kWh in 2040, but drop in total generation from 19% in 2012 to 16% in 2040.
AEO 2014ER also forecasts a 28% overall growth in renewable energy (excluding hydropower) between 2012 and 2040. Through 2030, this growth is primarily a result of supportive federal incentives and regulation, as well as state-level policies. Beyond 2030, however, renewable generation growth is expected to be more cost competitive with traditional electric generation methods.

Figure 1 – Electricity generation by fuel, 1990 – 2012 with forecasts through 2040.



To a small extent, the United States participates in international electricity trade with neighbouring Mexico and Canada, as shown in Figure 2. In 2012, the United States exported 12 billion kWh and imported 60 billion kWh, resulting in a net import of over 47 billion kWh. Much of these imports are hydropower originating from Canada [3][4].

Figure 2 – US historical and projected international electricity trade.



Historic development and outlook of renewable generation capacities, production and market share

Of the 4 trillion kWh of electricity generated in 2012, renewables accounted for 12% of the mix (following nuclear, 19%; natural gas, 30%, and coal, 37%). As shown in Figure 3, in 2012 56% of the renewable energy generated in the U.S. was by conventional hydropower, followed by wind (28%), biomass wood (8%), biomass waste (4%), geothermal (3%), and solar (1%). By 2040, renewable generation is projected to climb to 16% of the total generation mix as capacity increases [5].

Generation capacity for renewables has gained significant traction since 2000. Wind power demonstrates the largest penetration in installed capacity during this time, as shown in Figure 4, with growth highly impacted by Federal financial incentives and State government mandates (e.g., Renewable Portfolio Standards or RPS) [6]. Solar power capacity is projected to increase as small-scale, customer-sited installations continue to be integrated and used, in some cases, for distributed generation. Hydropower generating capacity has remained and is projected to remain stable through 2040 since nearly all hydroelectric plants were built prior to mid-1970s and are operated by the federal government [7].

Figure 3 – US renewable net energy generation.

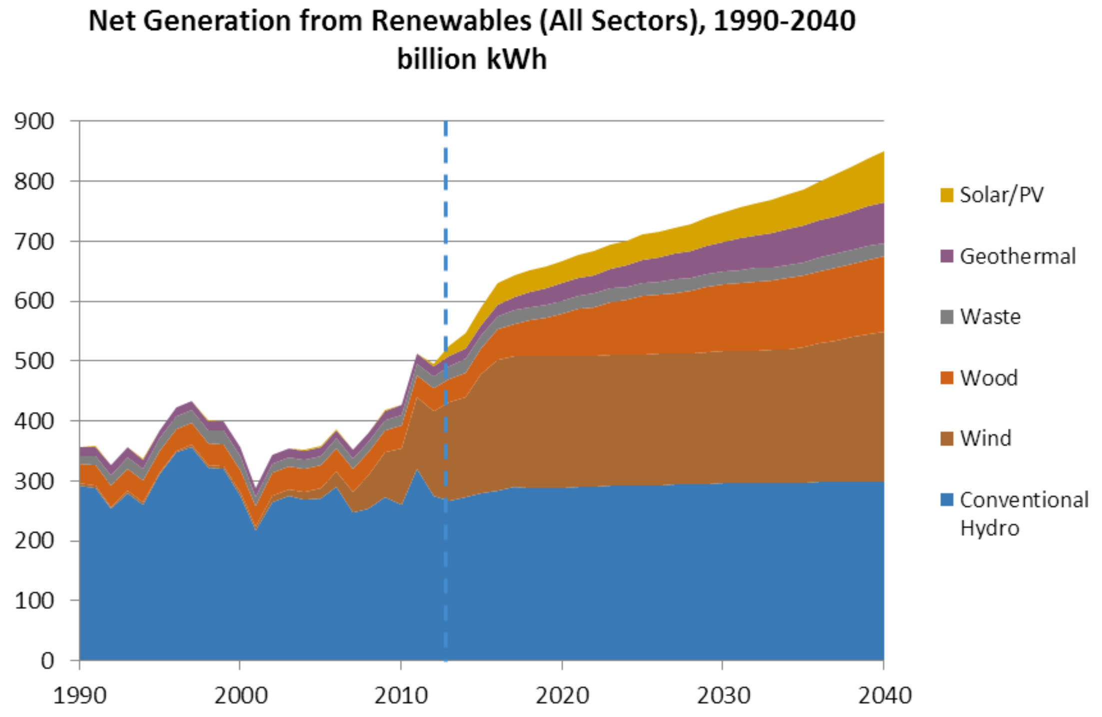
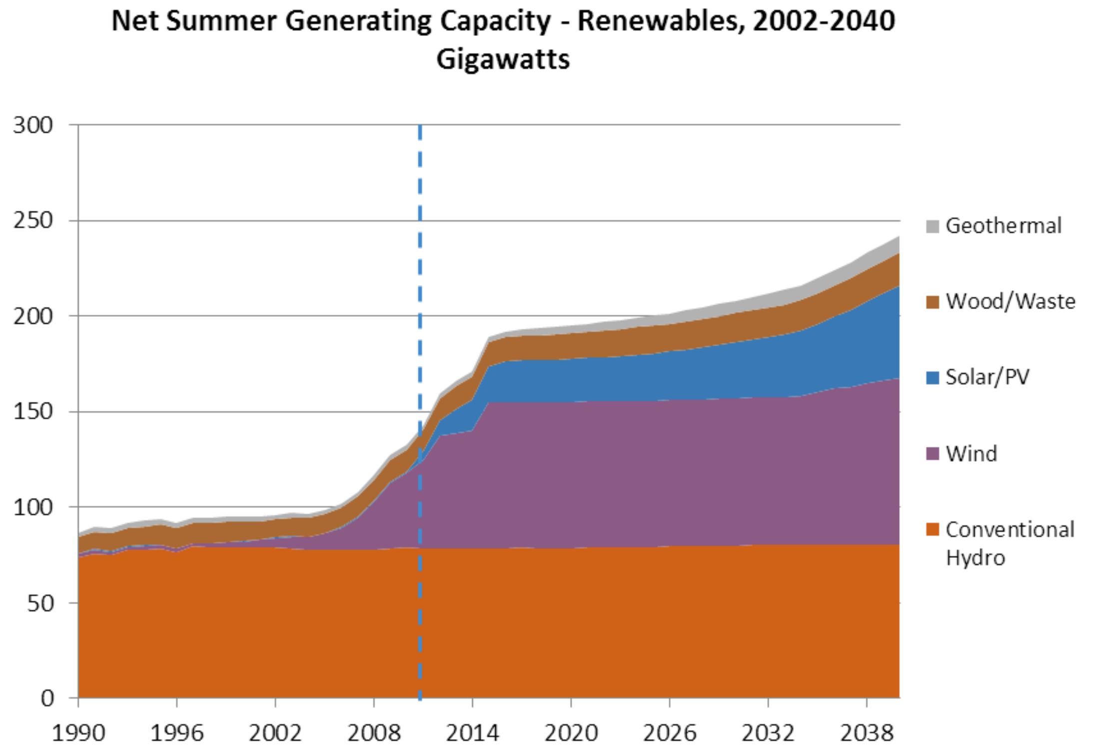


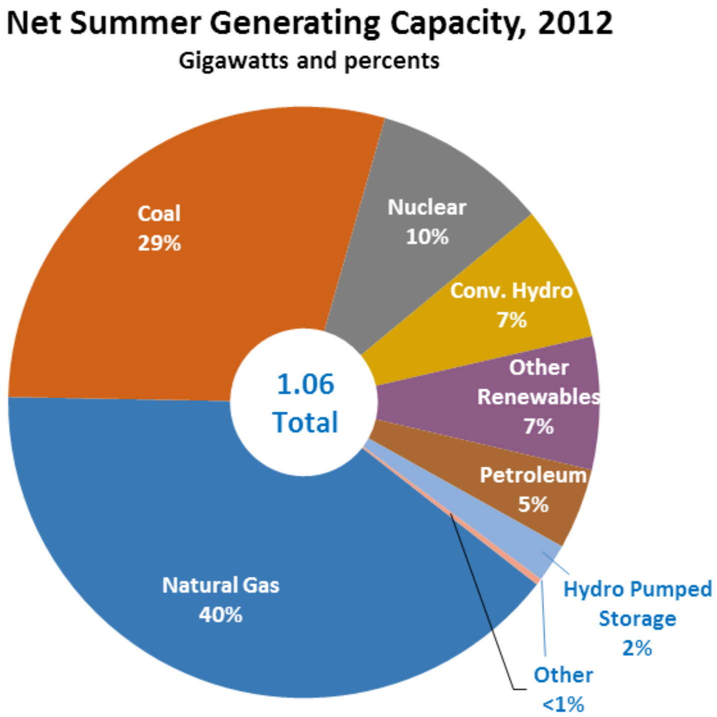
Figure 4 – US net summer renewable energy generating capacity.



Total available generation capacity

In 2012, natural gas plants constituted the highest amount of net summer generating capacity with 422 GW, or 40% of total capacity (Figure 5). Coal accounted for 29% with 310 GW, followed by renewables with about 14% (156 GW), nuclear with 10% (102 GW), petroleum with 5% (47.2 GW), hydro pumped storage with 2% (22.4 GW) and other sources with less than 1% (3.7 GW) [8]. Much of the natural gas generation assets are used primarily to meet peak electric demands as discussed in the following section.

Figure 5 – Total US generating capacity.

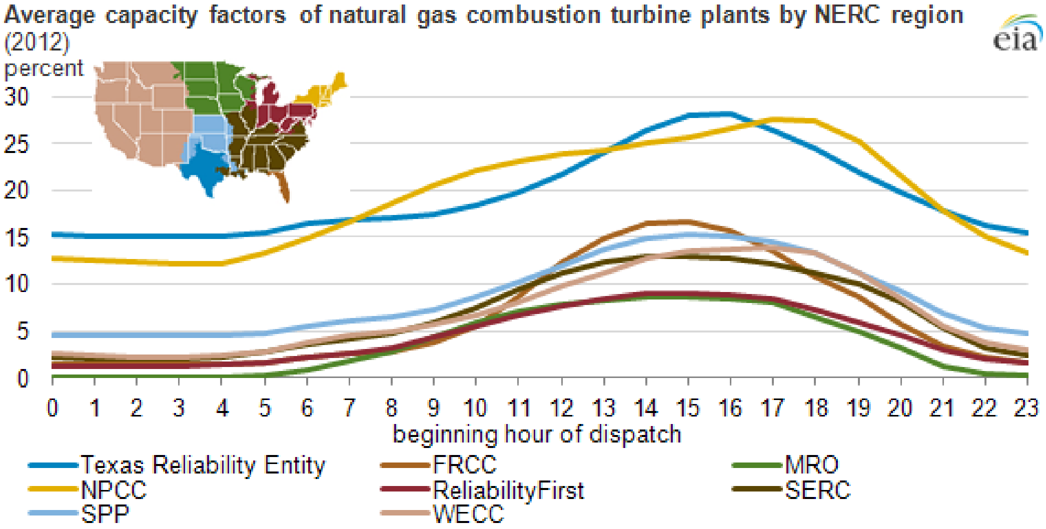


How is peak demand met?

In the United States, peak demand is addressed domestically and is most commonly met with natural gas-fired power stations. While the natural gas combustion turbines used for peak generation are more costly to operate than other types of power plants, they can fire up quickly in response to short-term increases in electricity demand during peak hours (3:00 p.m. to 6:00 p.m.), which typically coincide with higher peak prices. The turbines are most often dispatched in response to price signals of real-time wholesale hourly electricity prices. Figure 6 demonstrates how average generation of the natural gas combustion turbine fleet ramps up and down in response to the price signals, ranging significantly in average capacity factors across the eight North American Electric Reliability Corporation (NERC) regional entities:

- Florida Reliability Coordinating Council (FRCC)
- Midwest Reliability Organization (MRO)
- Northeast Power Coordinating Council (NPCC)
- ReliabilityFirst Corporation (RFC)
- SERC Reliability Corporation (SERC)
- Southwest Power Pool, RE (SPP)
- Texas Reliability Entity (TRE)
- Western Electricity Coordinating Council (WECC) [9]

Figure 6 – Hourly average natural gas plant generation capacity factors in US.



In some cases, pumped storage hydroelectricity facilities are also used to meet peak demand coincidentally increasing load on the electric grid during periods of low demand.

1.3 U.S. Energy Demand

Final energy demand in the domestic heating sector (& cooling sector where appropriate) divided by fuel type

Table 1 provides 2010 data on energy demand (in quadrillion Btus, or quads) for the domestic heating and cooling sectors, in addition to other common residential loads, by fuel type. Furthermore, the data is broken down into site and primary electric amounts. With 5.23 quads (5.52 EJ), space heating required the greatest share of site energy consumption, followed by water heating and space cooling with 1.92 and 1.08 quads (2.03 and 1.14 EJ), respectively [10].

Table 1 – 2010 residential energy end-use demand, by fuel type.

2.1.5 2010 Residential Energy End-Use Splits, by Fuel Type (Quadrillion Btu)

	Natural Gas	Fuel Oil	LPG	Other Fuel(1)	Renw. En.(2)	*Site* Electric	*Site* Total	*Site* Percent	Primary Electric (3)	Primary Total	Primary Percent
Space Heating (4)	3.50	0.53	0.30	0.04	0.43	0.44	5.23	44.7%	1.35	6.15	27.8%
Water Heating	1.29	0.10	0.07		0.01	0.45	1.92	16.4%	1.38	2.86	12.9%
Space Cooling	0.00					1.08	1.08	9.2%	3.34	3.34	15.1%
Lighting						0.69	0.69	5.9%	2.13	2.13	9.7%
Refrigeration (6)						0.45	0.45	3.9%	1.41	1.41	6.4%
Electronics (5)						0.54	0.54	4.7%	1.68	1.68	7.6%
Wet Cleaning (7)	0.06					0.33	0.38	3.3%	1.01	1.06	4.8%
Cooking	0.22		0.03			0.18	0.43	3.7%	0.57	0.81	3.7%
Computers						0.17	0.17	1.5%	0.53	0.53	2.4%
Other (8)	0.00		0.16		0.01	0.20	0.37	3.2%	0.63	0.80	3.6%
Adjust to SEDS (9)						0.42	0.42	3.6%	1.29	1.29	5.8%
Total	**5.06**	**0.63**	**0.56**	**0.04**	**0.45**	**4.95**	**11.69**	100%	**15.34**	**22.07**	100%

Note(s): 1) Kerosene and coal are assumed attributable to space heating. 2) Comprised of wood space heating (0.42 quad), solar water heating (0.01 quad), geothermal space heating (less than 0.01 quad), and solar PV (0.01 quad). 3) Site-to-source electricity conversion (due to generation and transmission losses) = 3.10. 4) Includes furnace fans (0.13 quad). 5) Includes color television (0.33 quad). 6) Includes refrigerators (0.37 quad) and freezers (0.08 quad). 7) Includes clothes washers (0.03 quad), natural gas clothes dryers (0.06 quad), electric clothes dryers (0.19 quad), and dishwashers (0.10 quad). Does not include water heating energy. 8) Includes small electric devices, heating elements, motors, swimming pool heaters, hot tub heaters, outdoor grills, and natural gas outdoor lighting. 9) Energy adjustment that EIA uses to relieve discrepancies between data sources. Refers to energy attributable to the residential buildings sector, but not directly to specific end-uses.

Source(s): EIA, Annual Energy Outlook 2012 Early Release, Jan. 2012, Table A2, p. 2-5 and Table A4, p. 9-12; BTS/A.D. Little, Electricity Consumption by Small End-Uses in Residential Buildings, Aug. 1998, Appendix A, for residential electric end-uses.

Typical heating / cooling / electricity demand in households

The average demand breakdown by end use on the household level is similar to that for the entire sector shown above, although proportions will vary depending on the region of the country. As shown in Figure 7, space heating accounts for the largest percentage at 42% and air conditioning at 7%. For many years, heating and cooling demand comprised more than half of the average household's energy demand (58% in 1993). But the most recent Residential Energy Consumption Survey (RECS, released in 2011 and 2012) data indicates that fraction has dropped to 48%. Underlying causes for this shift include installation of more efficient equipment, improved insulation, more efficient windows, people migrating to warmer climates, and the increased use of non-weather-related appliances and electronics (included in the "Other" category in Figure 7) [11].

1.4 U.S. Energy Infrastructure

Electricity networks – current status & outlook

The United States power grid, Figure 8, is comprised of three major electrical systems that are interlinked to enable transmission and distribution of electricity between utilities for use by millions of customers across the country (Figure 8). Today, the interlinked grid consists of more than 3,200 electric distribution utilities, more than 10,000 generating units, and hundreds of thousands of miles of transmission and distribution lines [12].

Figure 7 – Site energy consumption.

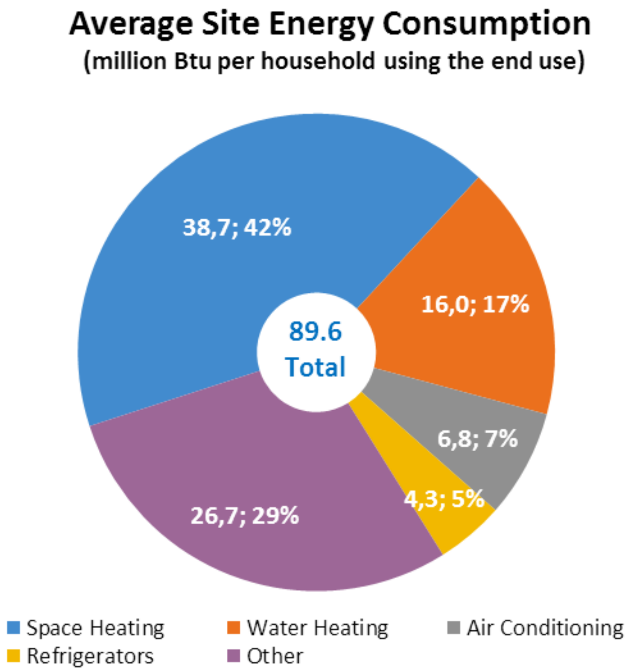
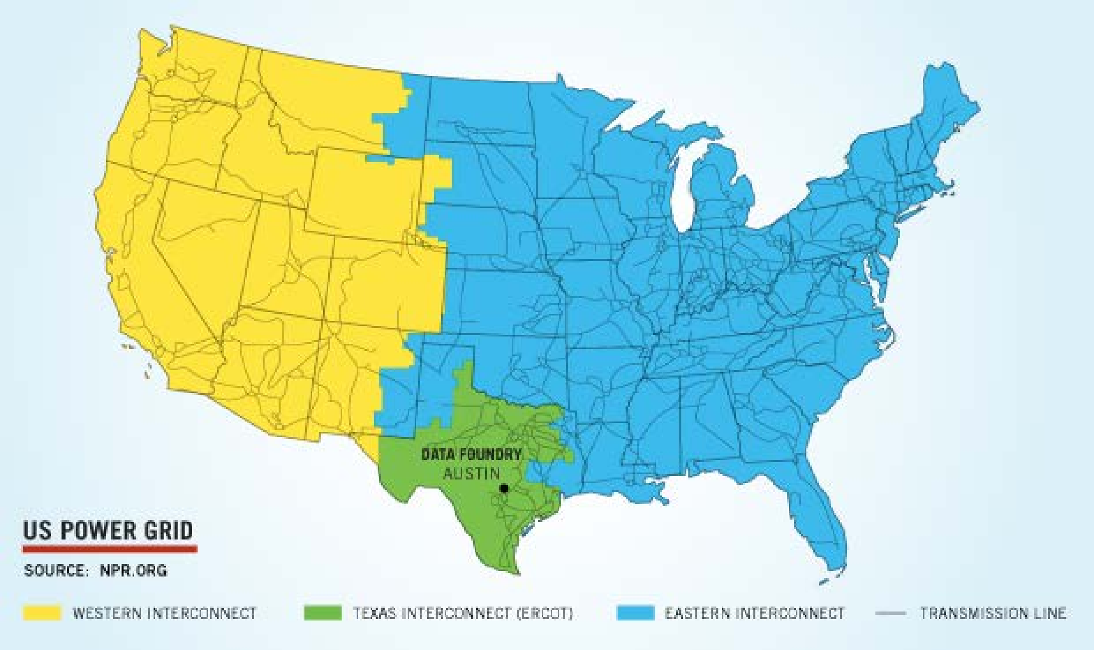


Figure 8 – The US power grid, showing the three major interconnects [13].

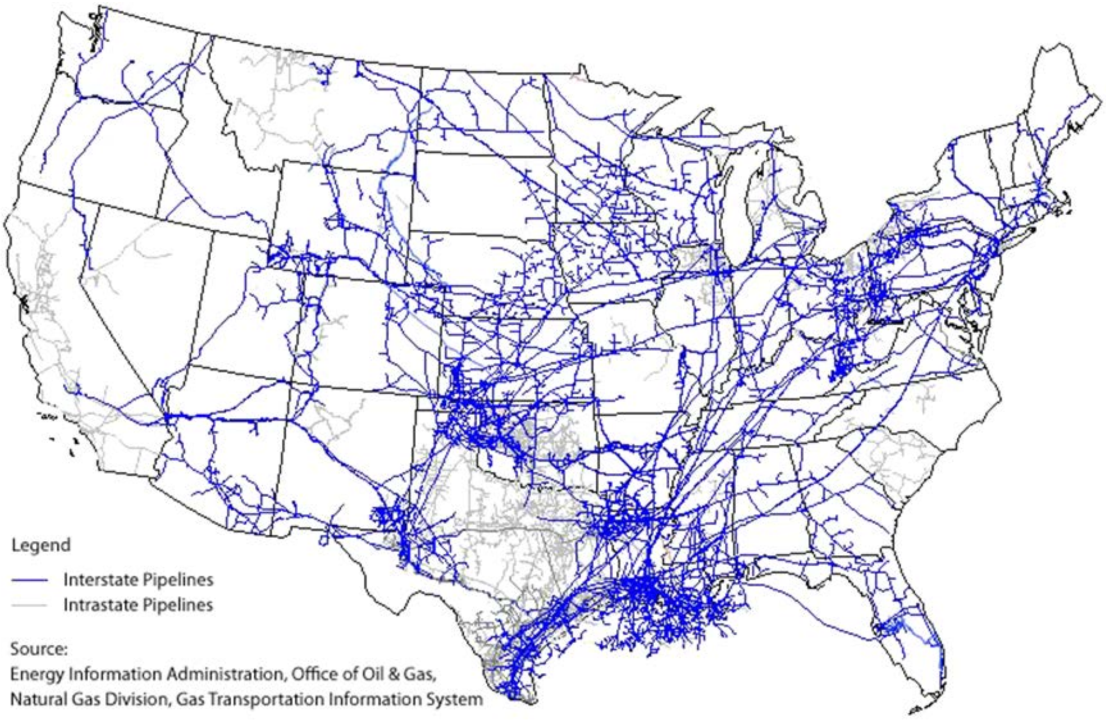


Before the systems were interconnected, each utility was responsible for building, planning and maintaining a reliable power supply for their customers, but this setup was eventually broadened through voluntary standards to allow for linked interconnection operations. By doing so, utilities had more flexibility in operations, therefore, reducing risk of blackouts within their service region. Today, mandatory procedures have been set up by NERC to ensure proper levels of supply, to establish and oversee formal operational standards for operating bulk power systems, and to address any national security concerns related to grid infrastructure. Oversight is provided by the Federal Energy Regulatory Commission and the U.S. Department of Energy (DOE) [12].

Gas network + heat network - current extent and future outlook:

The natural gas distribution system in the United States, shown in Figure 9, is extensive and well established, enabling quick and cost-effective delivery of natural gas among the contiguous 48 states. The network is made up of 300,000 miles of transmission pipes, plus 1.9 million miles of distribution pipes that transport gas throughout utility service areas. Thousands of delivery, receipt, and interconnection points have been incorporated into the system, as well as hundreds of storage facilities and many import/export connection points [14].

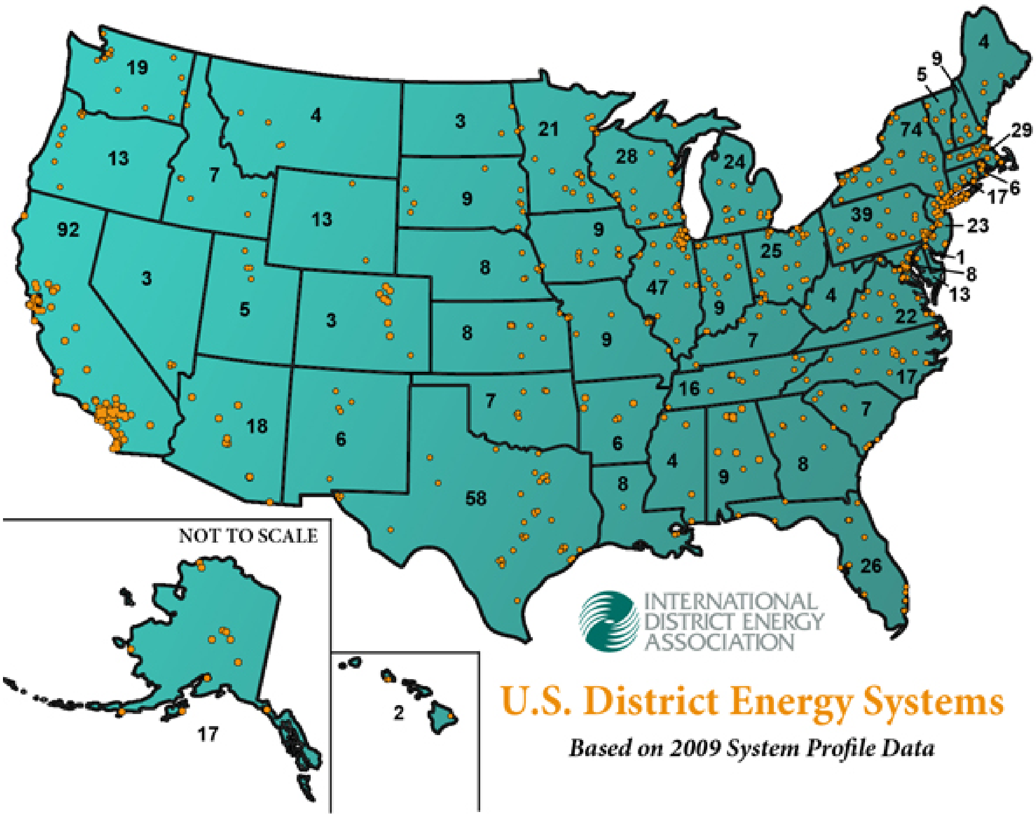
Figure 9 – US natural gas pipeline network [15].



District and local heating networks in the United States are small in scope compared to Europe and generally limited to larger cities. The New York City steam system, run by Consolidated Edison of New York, is the largest commercial district heating system in the country. Other major U.S. cities with district heating include Denver, San Francisco, Harrisburg, Minneapolis, Pittsburgh, Seattle, and San Diego. Some college campuses and hospitals have also incorporated district heating, which is often integrated with district cooling and power supply. Figure 10**Error! Reference source not found.** shows the location of all district energy systems in the United States, as of 2009. Of the 837 systems identified:

- 400 are located at colleges and universities,
- 119 are community utilities,
- 251 are healthcare installations,
- 41 are military/government installations,
- 10 are located at airports,
- 13 are located at industrial settings, and
- 3 are designated as other [16]

Figure 10 – US district energy systems map, 2009 (Source: IDEA).



1.5 U.S. Energy Policy

Major policies affecting the electricity sector, including renewable energy/CO_2 reduction targets

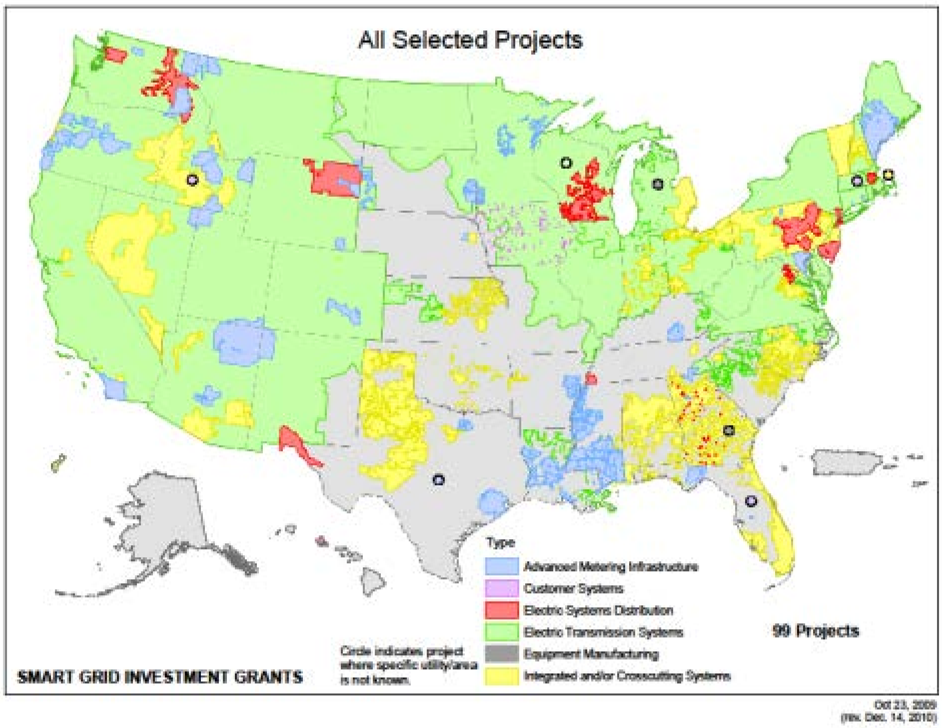
Policies have been enacted to help the energy, including electricity, sector produce and consume energy more efficiently and with less impact on the environment. To achieve this, policies tend to focus on promoting increased use of renewable sources, decreased use of fossil fuels (particularly coal) often through standards and implementation of end user incentives. The goal of these measures is to help reduce the total U.S. carbon emissions.

The Energy Policy Act (EPAct), for example, was enacted in 1992 (and revised in 2005 and 2007) to facilitate the introduction of energy efficiency and conservation measures, such as the ENERGY STAR program, and clean energy development through grants and tax incentives for both renewable energy and non-renewable energy production and use. Loan guarantees were initiated for organizations developing and/or using innovative technologies that mitigated or avoided the production of greenhouse gases.

The EPAct of 2005 and the Energy Independence and Security Act of 2007 (EISA 2007) both included amendments to establish federal policy that expands the use of smart meters, smart grid, and access to time-based pricing if requested by the customer. Federal funding was authorized through these amendments for smart meter and smart grid projects. EISA 2007 also included language in support of the decoupling and changing of rate structures to improve efficiency and conservation [17].

Most recently, the largest single grid modernization investment in U.S. history was made possible through ARRA funds, which provided $3.4 billion in funding to accelerate the nation’s transition to a smarter, more reliable, and more efficient electric system. This funding was matched by industry to achieve over $8 billion in total public-private investment. The map in Figure 11 geographically shows the type and location of these projects [18].

Figure 11 – ARRA grid modernization projects.



While policies have been enacted to mandate specific levels of renewable energy to be used in Federal government facilities (e.g., EPAct of 2005, EISA 2007, and Executive Order 13423) [19], no national-level renewable portfolio standard has been established for the electric power sector. On a state level, however, 29 of the 50 U.S. states (in addition to the District of Columbia and Puerto Rico) have set requirements for utility companies to deliver a specified amount of electricity from renewable sources by a certain date. The most stringent of these RPS programs is found in California, requiring 33 percent of its electricity to be renewable by 2020.

RPS programs generally support the increased utilization of renewable resources like wind, solar, geothermal, biomass, and hydroelectricity, and in some cases, landfill gas, municipal solid waste, and marine energy. Certain states also allot credits for space and water heating from renewables, fuel cells, energy efficiency improvements, and advanced fossil-fuel operations [20].

Major policies affecting the heating sector, including building regulations and renewable energy/CO_2 reduction targets

Combined heat and power (CHP) technologies have been incorporated into policies to help entities reduce energy costs, increase energy efficiency, improve power reliability, and establish output-based emissions regulations. For example, CHP/waste-to-heat power has been integrated into many state RPS, Energy Efficiency Resource Standards, and energy/climate plans. Financial incentives are also available for CHP in the United States, ranging from direct financial grants, tax incentives, low-interest loans, rebate programs, and FITs [21].

Heat pump related incentives/policies etc.

Residential consumers have benefited from heat pump incentives in recent years through federal financial incentives that support renewables and efficiency measures in new or existing houses (e.g., heating, cooling, and insulating system improvements). Recently expired on December 31, 2013, the Residential Energy Efficiency Tax Credit provided up to a $300 credit toward the cost of electric air-source heat pumps that meet the following requirements [22]:

- Split Systems: HSPF ≥ 8.5, EER ≥ 12.5, SEER ≥ 15, Btu/Wh
    - (heating SPF ≥ 2.5, cooling COP ≥ 3.7, cooling SPF ≥ 4.4, W/W)
- Package Systems: HSPF ≥ 8, EER ≥ 12, SEER ≥ 14, Btu/Wh
    - (heating SPF ≥ 2.3, cooling COP ≥ 3.5, cooling SPF ≥ 4.1, W/W)

Note that the cooling EER or COP rating is for operation at 95 °F (35 °C) outdoor temperature.
The Residential Renewable Energy Tax Credit, available through December 31, 2016, covers 30% of the total cost of various renewable technologies, including geothermal heat pumps. To qualify for this credit, geothermal heat pumps must meet the requirements of the ENERGY STAR program that are in effect at the time of the expenditure. According to ENERGY STAR, the current requirements are [22]:

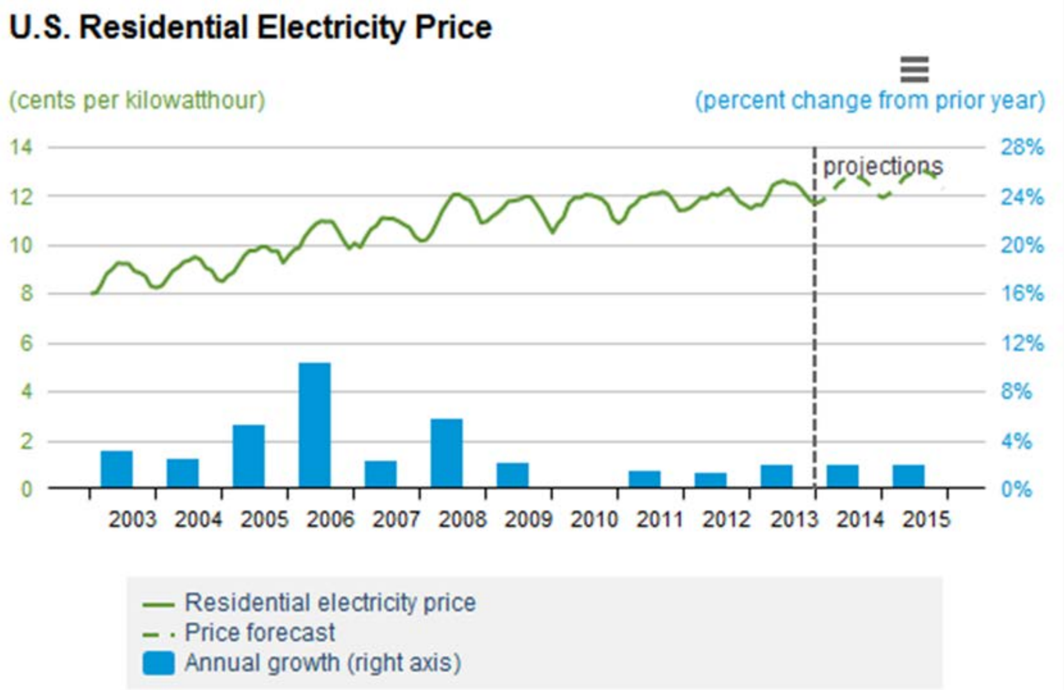
- Water-to-Air:
  - Closed Loop: cooling EER ≥ 17.1 Btu/Wh (5.0 W/W),
    - heating COP ≥ 3.6 W/W
  - Open Loop: cooling EER ≥ 21.1 Btu/Wh (6.2 W/W),
    - heating COP ≥ 4.1 W/W
- Water-to-Water:
  - Closed Loop: cooling EER ≥ 16.1 Btu/Wh (4.72 W/W),
    - heating COP ≥ 3.1 W/W
  - Open Loop: cooling EER ≥ 20.1 Btu/Wh (5.9 W/W),
    - heating COP ≥ 3.5 W/W
- Direct Expansion: cooling EER ≥ 16 Btu/Wh (4.7 W/W),
    - heating COP ≥ 3.6 W/W

1.6 Energy Prices, Tariffs & Structures

Electricity prices, including price structure (generation costs, network charges, taxes & levies):

The national average electricity price for residences in the United States has steadily risen over the past decade from approximately 8 cents/kWh to 12 cents per kWh, and is anticipated to follow a similar trend in 2014. Figure 12**Error! Reference source not found.** demonstrates this trend, along with annual growth percentages [23].

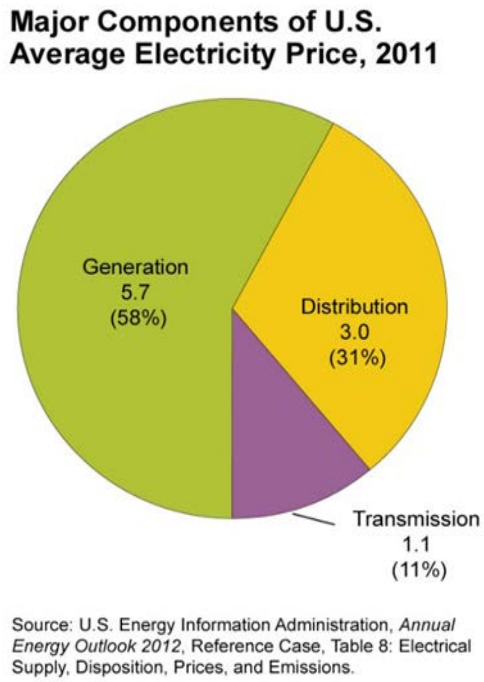
Figure 12 – Historical residential electricity prices (national average).



As shown in Figure 13, generation of electricity accounts for over half of the total average electricity price, followed by distribution and transmission. Key factors that affect electricity price include the availability of power plants and fuels, local fuel costs, and pricing regulation and structures. These factors often vary seasonally, with prices typically higher in the summer due to increased generation needed to meet higher demand. For example, in 2010, average state electricity prices ranged from 6.2 cents/kWh in Wyoming to 25.1

cents/kWh in Hawaii. Furthermore, utilities that are for-profit will add return for owners and shareholders into their electricity prices [24].

Figure 13 – Major components of US average electricity price.



Residential and commercial prices are generally higher than those for industrial customers. Industrial customers are able to accept electricity at higher voltages and, therefore, do not require the voltages to be stepped down like residential and commercial customers. Therefore, industrial customers receive an electricity rate closer to wholesale price [24].

Gas prices / prices of other competing heating technologies

Below are the national average residential prices for the most common fuels used for heating in the United States, as of October 2013, according to the U.S. Energy Information Administration:

- 12.31 cents per kWh of electricity
- $12.48 per thousand cubic feet ($0.44/m^3) of natural gas
- $3.832 per gallon ($1012/m^3) of heating oil (aka distillate fuel)
- $2.370 per gallon ($626/m^3) of liquid propane

When converted to a common basis (price per million Btu or per kWh), natural gas is the least expensive residential heating fuel, when compared to electricity and common petroleum products:

- $36.08 per million Btu ($0.123/kWh) of electricity[1]
- $12.15 per million Btu ($0.041/kWh) of natural gas[2]
- $27.63 per million Btu ($0.094/kWh) of heating oil[3]
- $25.95 per million Btu ($0.089/kWh) of liquid propane[4]

What types of tariffs are available? How will this change in the future?

Aside from standard rates, certain time-based rate programs have been implemented in the United States to promote flexibility on the demand side, although not to a large extent. These include [25]:

1. **Time of Use Prices (TOU)** is a program in which customers pay different prices at different times of the day. On-peak prices are higher and off-peak prices are lower than a "standard" rate. Price schedule is fixed and predefined, based on season, day of week, and time of day.

[1] 1 kWh = 3,412 Btu
[2] 1 MCF = 1.027 million Btu
[3] Assumes 138,690 Btu per gallon of heating oil
[4] Assumes 91,333 Btu per gallon of liquid propane

2 **Real Time Pricing (RT)** is a program of rate and price structure in which the retail price for electricity typically fluctuates hourly or more often, to reflect changes in the wholesale price of electricity on either a day-ahead or hour-ahead basis.

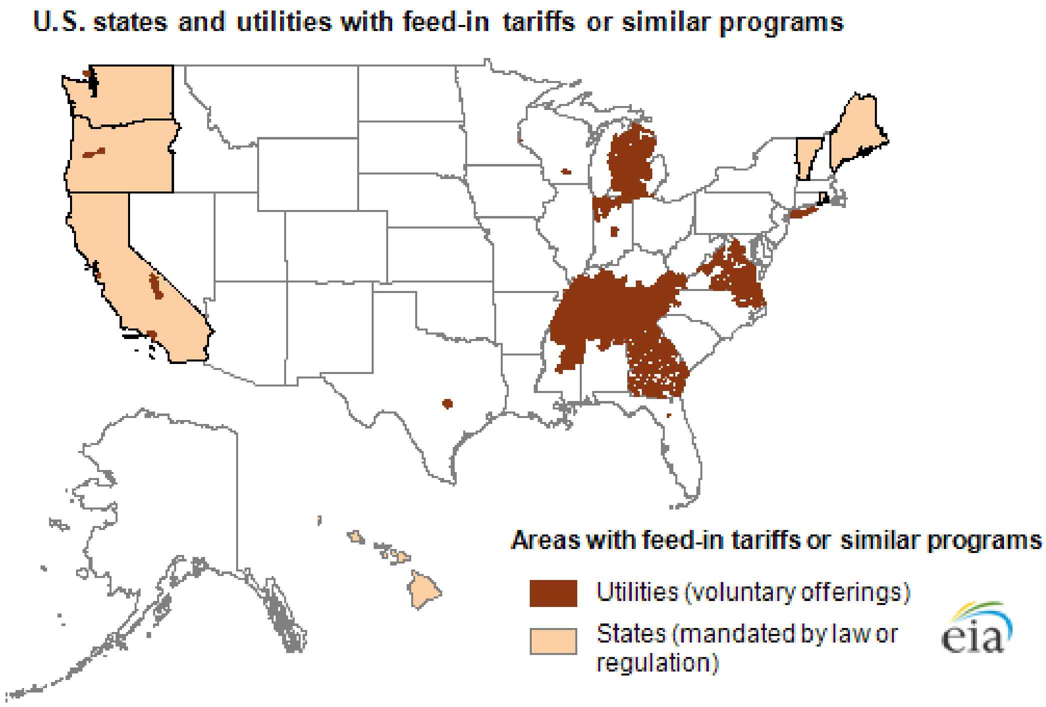
3 **Variable Peak Pricing (VPP)** is a program in which a form of Time-Of-Day (TOD) pricing allows customers to purchase their generation supply at prices set on a daily basis. Standard on-peak and off-peak TOD rates are in effect throughout the month. Under the VPP program, the on-peak price for each weekday becomes available the previous day (typically late afternoon) and the customer gets billed for actual consumption during the billing cycle at these prices.

4 **Critical Peak Pricing (CPP)** is a program in which rate and/or price structure is designed to encourage reduced consumption during periods of high wholesale market prices or system contingencies, by imposing a pre-specified high rate or price for a limited number of days or hours. Very high “critical peak” prices are assessed for certain hours on event days (often limited to 10-15 per year). Prices can be 3-10 times as much during these few hours. Typically, CPP is combined with a TOU rate, but not always.

5 **Critical Peak Rebate (CPR)** is a program in which rate and/or price structure is designed to encourage reduced consumption during periods of high wholesale market prices or system contingencies, by providing a rebate to the customer on a limited number of days and for a limited number of hours, at the request of the energy provider. Under this structure the energy provider can call event days (often limited to 10-15 per year) and provide a rebate typically several times the average price for certain hours in the day. The rebate is based on the actual customer usage compared to its baseline to determine the amount of the demand reduction each hour.

Non-time-based pricing schedules include inverted block rate structures, where higher usage customers pay a higher marginal rate than lower usage customers. Such a schedule encourages energy efficiency practices. Also, to a small extent, feed-in tariffs (FIT) are also used in the United States to encourage deployment of renewable energy. FITs set a rate that utilities pay (either voluntarily or government-mandated) to customers that generate renewable energy on site using an eligible facility (e.g., solar photovoltaic system) and sell electricity back to the grid [26]. Figure 14 provides an overview or which states and utilities participate in FIT programs.

Figure 14 – Areas with FIT programs in the US.



2 Analysis of the U.S. Housing Stock & Heating Market

2.1 Overview of Main Challenges in the United States

In addition to benefits to the utilities, the surge of smart meter installations over the past five years provides customers with more opportunity to become engaged through enhanced home energy management (HEM) services. Such services could interface with utility “smart grid” programs and allow homeowners to reduce their electricity costs via participation in residential demand response programs or response to dynamic pricing signals.

One challenge to implementing HEM services is getting consumers to adopt smart-controls devices that could benefit from such features. Smart thermostats are increasing in popularity but the availability of other appliances (e.g., heat pumps and other HVAC equipment) with smart features is still rather limited. A few major utilities (e.g., Oklahoma Gas & Electric, NV Energy, and Baltimore Gas and Electric) are attempting to address this challenge by offering HEM products or services as part of their residential demand response services [27].

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) has established a working group called the Smart or Connected Equipment Ad Hoc Committee (Ad Hoc Committee). This group was formed in late 2011 following the U.S. Department of Energy’s (DOE) August 5, 2011 request for information (RFI) regarding the treatment of smart appliances and equipment in future energy conservation standards and test procedures within DOE’s appliance standards program, as well as in the test procedures for the ENERGY STAR Program. They have noted a number of critical requirements for “smart” systems and equipment manufactured by AHRI member companies. Among these are 1) system owners must have capability to override and demand response request received from the grid; and 2) grid/equipment communication standards will be need to enable the equipment to communicate its demand response capabilities to the utility and to enable utilities to design meaningful DR programs [28].

2.2 U.S. Housing Stock Characteristics

Total number of dwellings as far as possible broken down by:

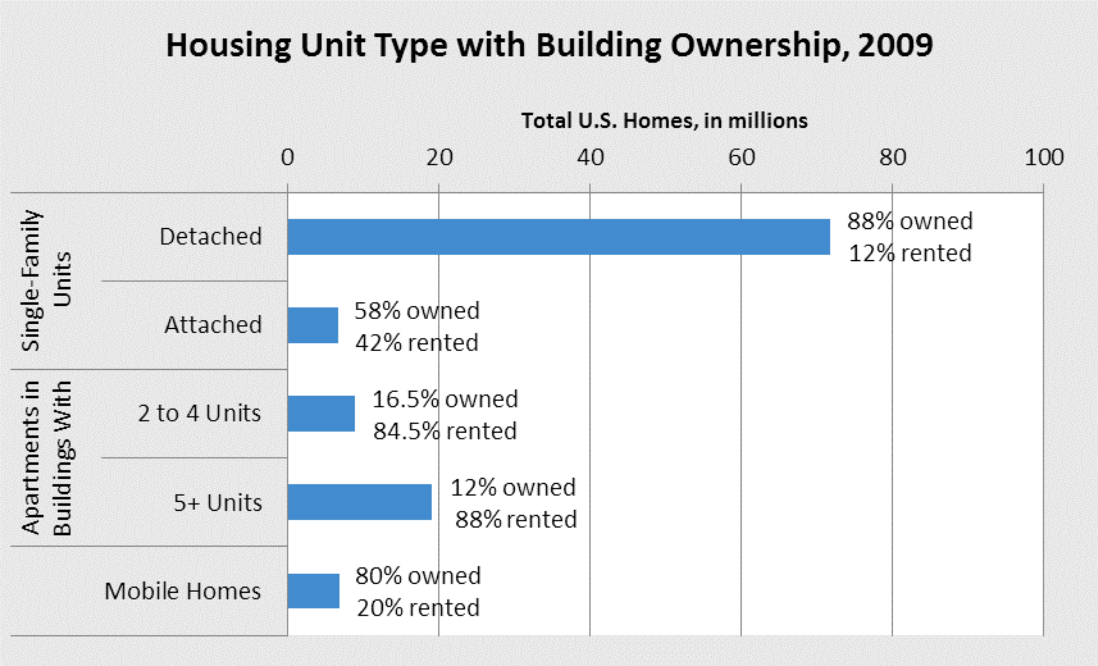
Type of Dwelling and Building Ownership

As of 2009, the majority (63%) of residential living spaces in the United States were detached single-family units, of which 88% are owned by the occupant (see Figure 15). Energy bills are almost always paid separately by the household; occupants in rental housing units sometimes have the energy bills included in monthly rent payments. Very rarely did occupants of these homes received housing assistance. In sixty percent of cases, at least one occupant stays home all day.

Multi-family buildings comprise the next largest segment of the U. S. housing market, most commonly in buildings with five or more units. About 80 to 90% of this market is comprised of rental units, and it is most common for each apartment to be occupied by only one person. Like detached single-family units, energy bills are generally paid separately by the occupant. In apartments, 13 to 22% of occupants received housing assistance of some kind. In 48 to 51% of the cases, at least one occupant stays home all day.

Finally, mobile homes account for 6 percent of U.S. residential dwellings, of which 80% are owned by the occupant. In two-thirds of cases, at least one occupant stays home all day.

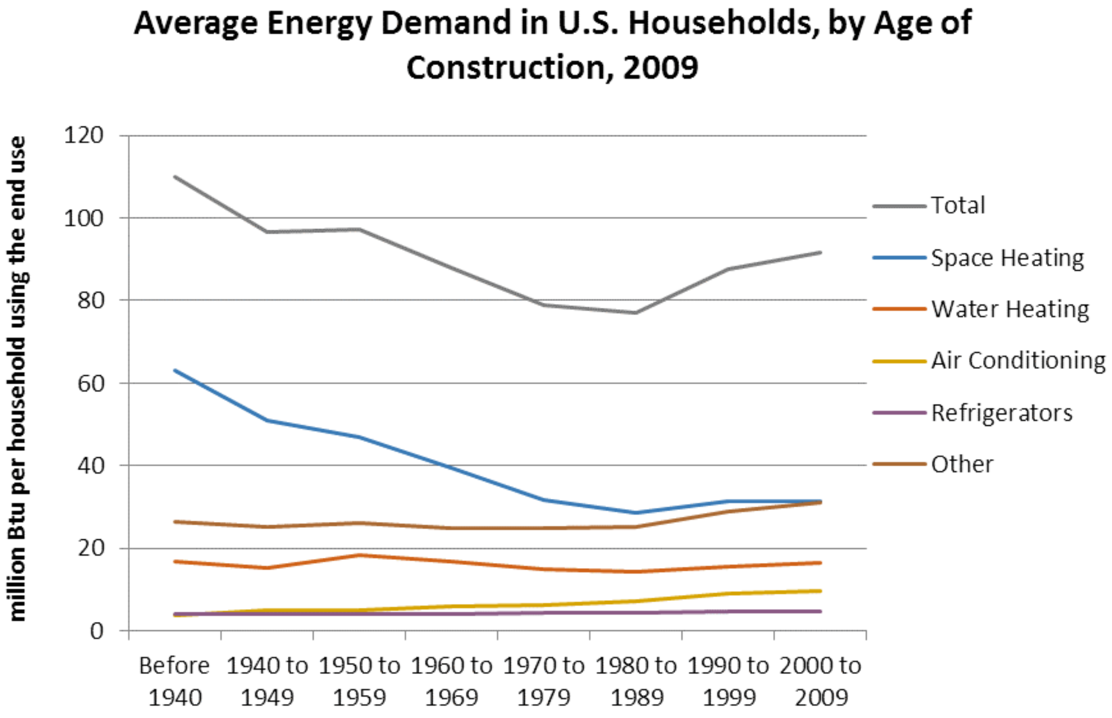
Figure 15 – Housing stock, by unit type and ownership.



Heat or Energy Demand

Space heating and water heating are responsible for 42% and 17% of average U.S. residential site energy consumption, respectively (Figure 7). Figure 16 shows the trends in average energy demand of U.S. households since 1940. Water heating demand has remained steady, but space heating demand dropped by ~50% between 1940 and about 1985 and has remained relatively constant since. Among the reasons for this decline in space heating demand are improved insulation, adoption of more efficient heating systems and windows, and population shifts to warmer climates. Total energy demand has been increasing since the mid-1980's. The principal causes of this higher demand are increased use of 1) space cooling or air-conditioning systems and 2) non-weather related electronic devices ("Other" category).

Figure 16 – US residential site average energy demand over time.



Heating System Type and Fuel Type

District energy systems in the United States use steam, hot water, or chilled water produced at a central power plant and pipe it underground to individual buildings for heating and cooling applications. In many cases, the excess heat is used for "combined heat and power," or cogeneration, applications where it spins turbines to generate electricity. The International District Energy Association has been collecting data on district heating systems since 1990. In 2011, about 542.2 million ft^2 (50.3 million m^2) of floor space had been reported for North America (the United States only value is not reported) [29].

Table 2 shows growth of district energy space by sector in North America over the past decade. On average, the commercial sector experienced the largest growth in heated space followed by schools, hospitals, and institutions. Combined, the district energy space has grown on average by 28.9 million ft^2/y (2.68 m^2/y).

Table 2 – Growth of district energy space by sector, 2000 – 2011.

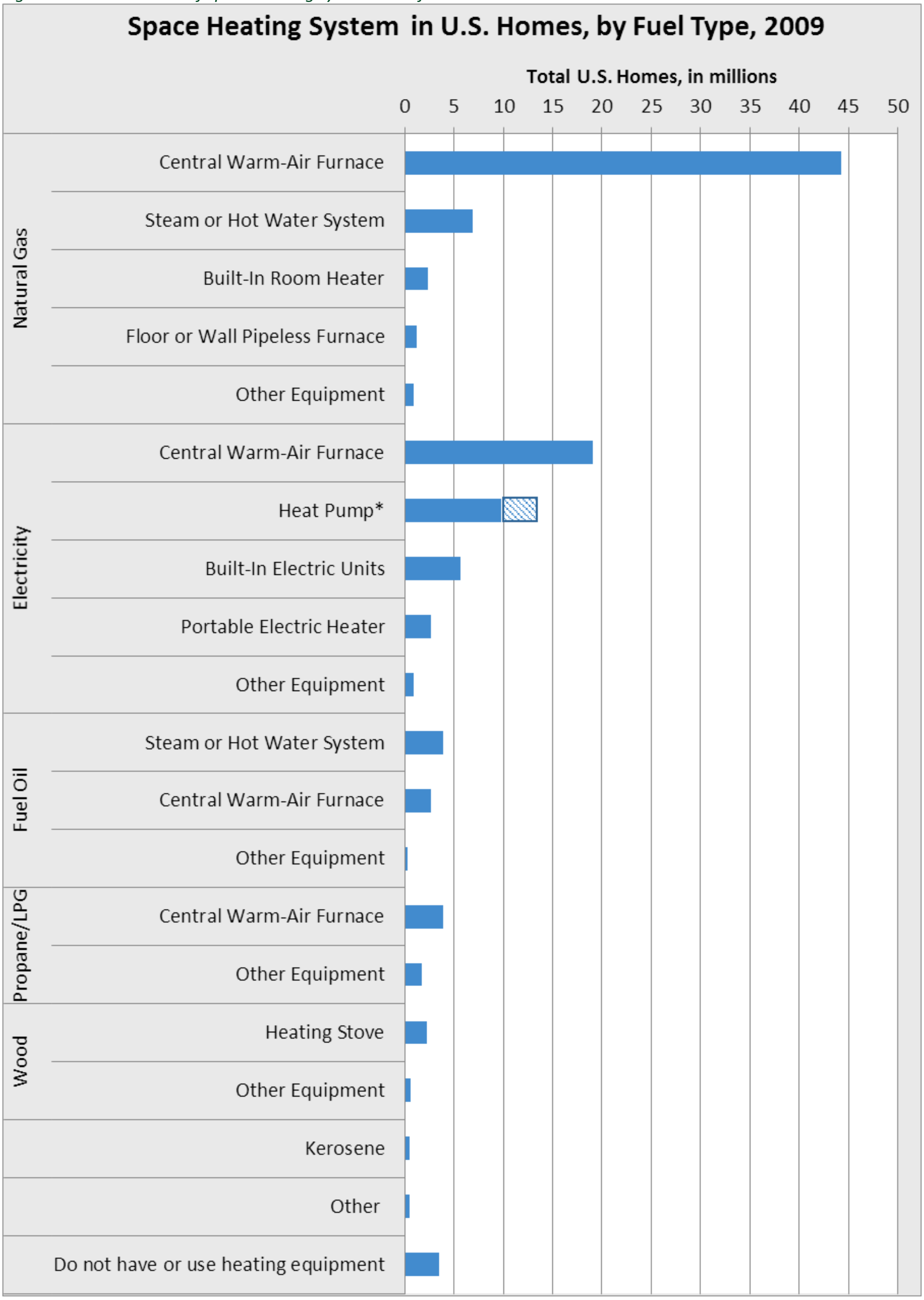
District Energy Space Growth by Sector - North America:
Annual Customer Space Committed (million sq ft)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	11-Year Average
Commercial	12.6	7.3	9.2	9.3	12.0	12.6	18.6	14.3	20.2	11.5	6.6	10.9	12.1
Entertainment , Cultural or Sporting Center	2.6	10.3	1.6	5.9	1.6	0.4	0.6	3.8	1.1	0.7	0.1	0.6	2.4
Government	3.2	4.6	2.0	7.9	6.6	6.5	2.2	0.8	1.0	4.8	4.0	4.2	3.9
Hotels	1.5	1.5	1.5	2.7	1.8	3.5	1.4	1.7	4.8	4.3	2.0	1.5	2.3
Residential & Other	3.3	4.2	3.5	3.4	3.1	4.0	8.2	6.6	7.8	1.1	2.6	1.7	4.1
School, Hospital or Institution	1.4	0.8	4.8	12.3	3.5	3.7	9.6	6.6	10.1	5.0	7.9	4.7	5.9
Total	24.5	28.6	22.6	41.5	27.4	30.7	40.6	33.8	45.0	27.4	23.2	23.6	28.9

Figure 17 provides a matrix of space heating systems in the U.S. residential sector, broken down by fuel type, as of 2009. Approximately one half of homes with space heating equipment use natural gas for heating fuel, followed by 35% of homes using electricity. Fuel oil, propane/LPG, and wood are also used to a much lesser extent. For both natural gas and electricity, the most popular space heating system is a central warm-air furnace. Of the homes with electricity, one-quarter use heat pumps [30]. Note that there is some uncertainty about the real number of U.S. residences using heat pumps. According to the latest RECS data, almost 10 million homes were estimated to be using heat pumps as their main heating equipment in 2011. However, this number is believed to be underestimated since RECS respondents often have trouble identifying heat pumps.

But the RECS data also indicate that 13.5 million residences use heat pumps for space cooling. The general impression is that the number of electric central furnaces is overstated and the number of heat pumps is understated.

Figure 17 – Distribution of space heating systems and fuels used in U.S. homes.



** Extended row represents the uncertainty in RECS data regarding the actual number of heat pumps in US homes.*

Use of storage tank

Given that only a small percentage of U.S. residents use boilers as their heating system, the use of thermal storage tanks in residential space heating systems is not common. Water heating heat pump systems (aka heat pump water heaters or HPWHs) conversely, almost exclusively use tanks for domestic hot water storage; ranging in size from about 50 to 80 gallons (190 to 300 liters).

Heat distribution system

The large majority of residential heating systems in the United States use a central forced air system to distribute heat throughout the home using air ducts and wall vents. Between 2005 and 2009, 68% of U.S. homes were equipped with forced warm-air furnaces with ducts and vents to individual rooms, compared to 59% of homes built in the 1960s or earlier.

Other heat distribution systems used include steam radiant, electric radiant, hot water baseboard units, and electric baseboard units. Steam and hot water systems have dropped in popularity over the past few decades with only 3% of units built between 2005 and 2009 using this system (compared to 18% in the 1960s or earlier). As a result, the use of steam radiant and hot water baseboard systems in U.S. homes is also rare.

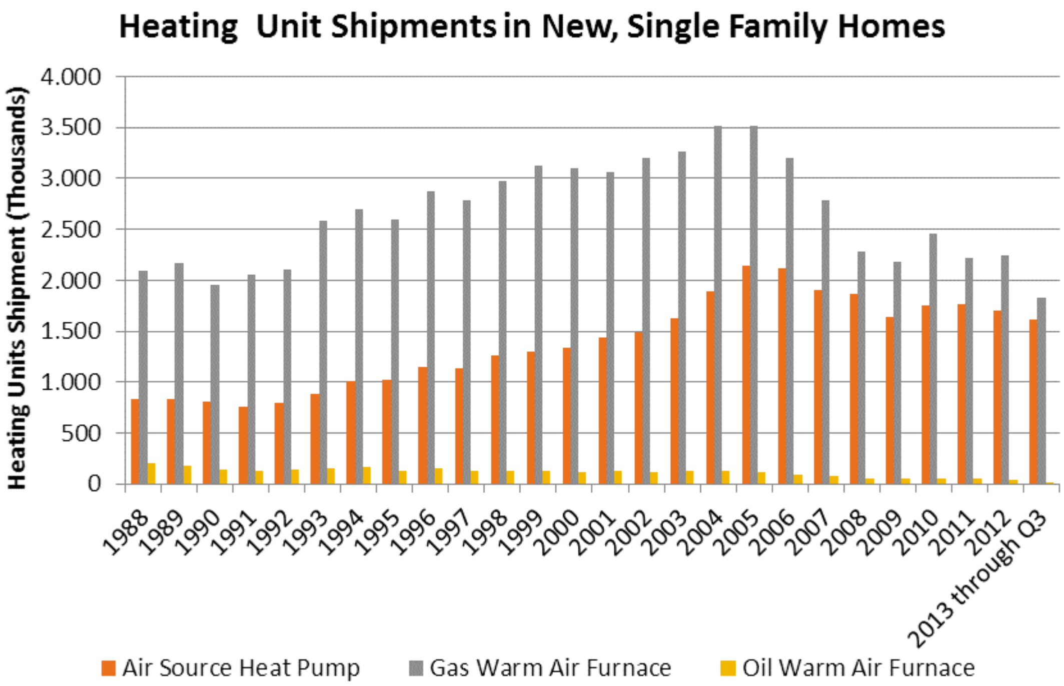
Air conditioning systems have also seen a major transition over the past fifty years. The presence of central air conditioning systems using central forced air distribution networks have nearly doubled from 45.3% in homes built in the 1960s and earlier to 88.7% built between 2005 and 2009. Consequently, the presence of room air conditioners declined from 35.5% of homes in 1960s and earlier to only 4.5% of homes built between 2005 and 2009 [31]. The increasing demand for central air conditioning systems is responsible in large part for the dominance of central forced air heat distribution systems.

2.3 Trends in the Heating Market

Heating systems types and fuel types

Figure 18 shows heating unit shipment trends from 1988 through the 3rd quarter of 2013 for three most popular heating equipment types in the United States – air-source heat pumps (ASHP), gas furnaces, and oil furnaces. All three types show a significant drop in shipments due to the economic crisis beginning in 2006, but heat pumps have been the least impacted. Figure 18 shows 1.7 million heat pump shipments in 2012; ~80% of the shipments seen in 2005. In comparison gas furnace shipments in 2012 were only ~64% of their 2005 level [32].

Figure 18 – Heating system trends in new singlefamily US homes.



2.4 Customer Preferences

Most U.S. residential heating and cooling systems use relatively simple on/off thermostat controls and, consequently customers tend to keep them set at a constant temperature. More sophisticated controls are available (e.g., programmable and "self-learning" or smart thermostats, etc.) and increasing numbers of energy-wise customers use them to reduce heating/cooling consumption (and utility costs) when away from home or during sleeping hours. For instance, 37% of housing units were equipped with programmable thermostats in 2009. Of this 37%, 53% and 61% of occupants reported using them to reduce the temperature of the home during unoccupied and sleeping hours, respectively [30].

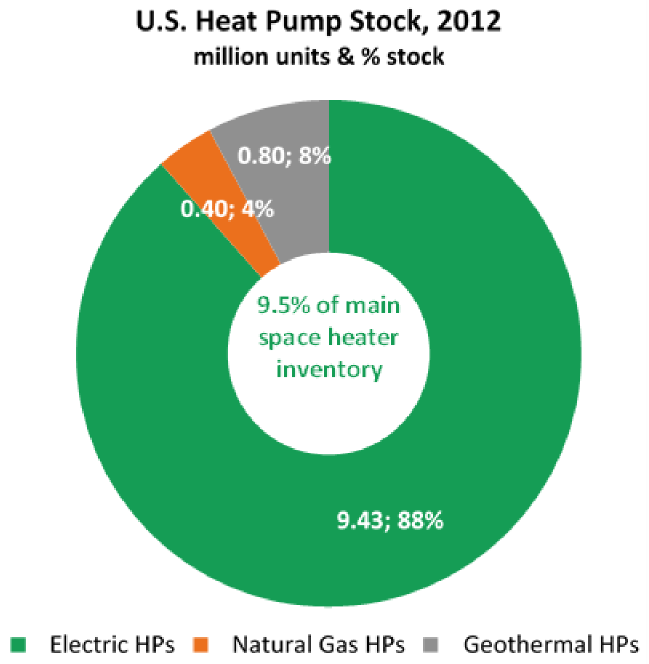
As TOU pricing becomes more common practice for residential customers, they will likely become more cognizant of its impact on utility bills. This will lead to greater adoption of smart thermostats (e.g., Honeywell's Prestige® programmable thermostat [33]) capable of sensing and reacting to increasing utility rates may rise in upcoming years.

3 Analysis of the U.S. Domestic Heat Pump Market

3.1 Installed Heat Pump Capacity

The use of heat pump technology in the residential sector has increased significantly in the past two decades as shown in Figure 18 above. According to AEO 2014ER, 9.5% of the main space heater market consists of heat pumps (Figure 19), of which 88% are air-source heat pumps (ASHP). ASHP installations in the United States are concentrated in the southern and coastal regions which have climates ideally suited to them. Furthermore, the South accounts for the largest population of all census regions with 37% of all U.S. households as of 2009 and has consistently had a net gain in population since the 1980s [34]. This historical population trend contributes to heat pumps' rising market share.

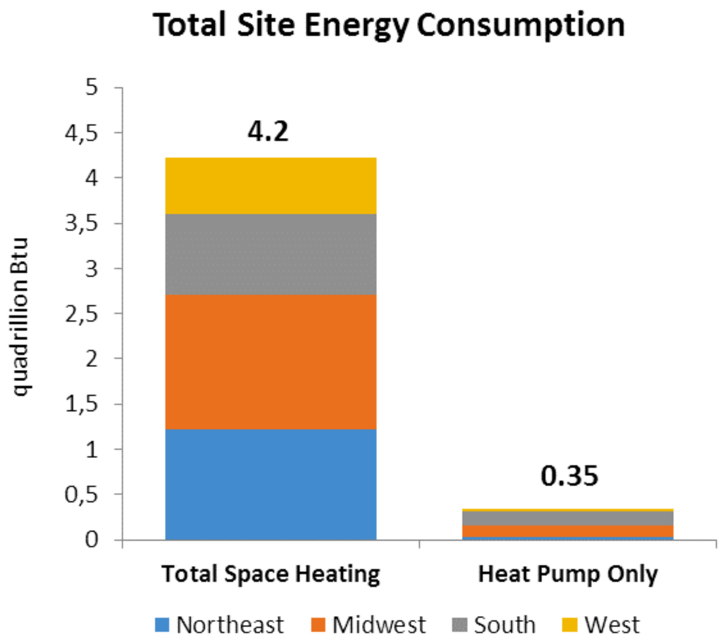
Figure 19 – Heat pump stock, 2012.



Most U.S. heat pumps are designed for central forced-air distribution systems, but so-called ductless or mini-split ASHPs are seeing increasing use especially for retrofit of older homes which do not have duct systems. Natural gas-powered heat pumps are a very small part of the market. Ground-source or geothermal heat pumps (GHPs) are also experiencing increased use, in part due to their ability to operate efficiently in more extreme colder climate regions.

Figure 20 displays the total heating load of all occupied housing units in the United States in 2009 - 4.23 quads (4.46 EJ). Since most heat pumps in the United States are primarily installed in moderate to warm climates with lower heating loads, U.S. heat pump equipped homes only account for 0.35 quads (0.37 EJ) or 8.2% of the U.S. total residential heating load [35].

Figure 20 – Heating load of total space heating.



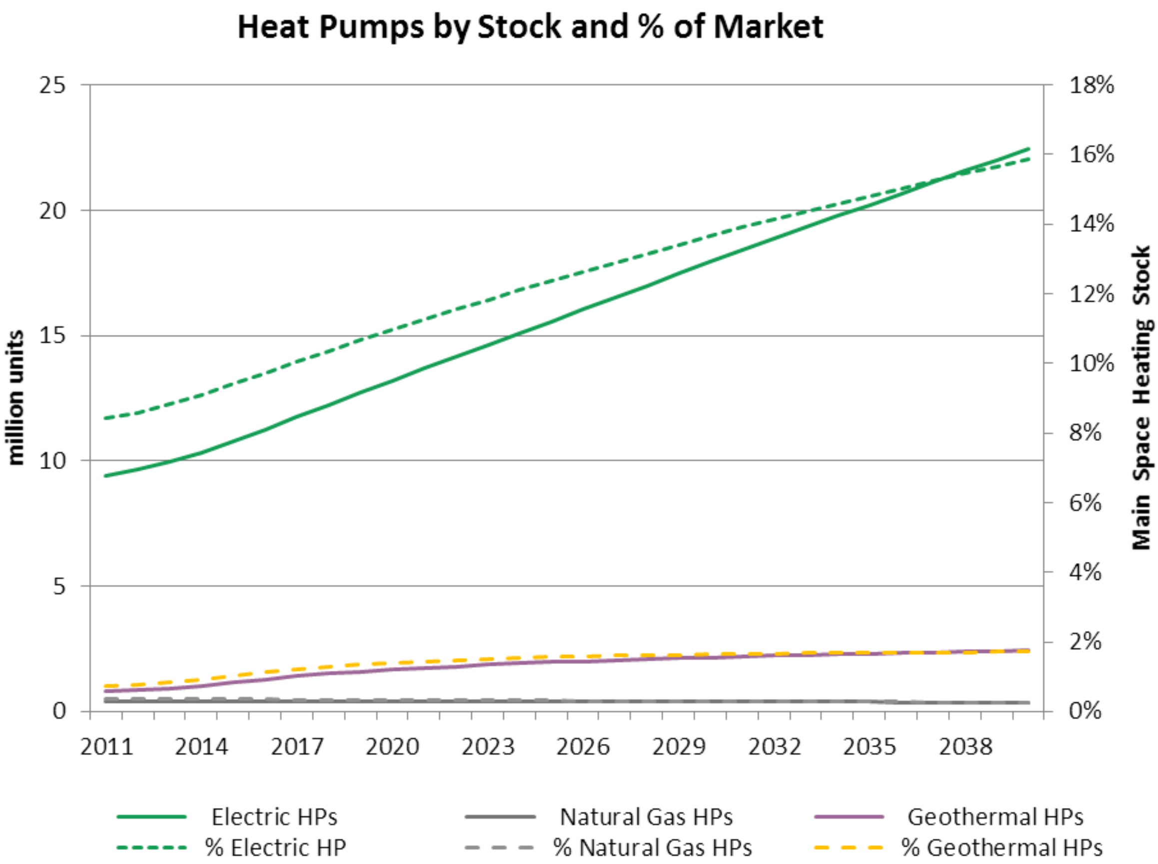
3.2 Trends in the Heat Pump Market

By Technology Type

As previously mentioned, heat pumps (particularly ASHPs) have gained significant market share over the past two decades, and projected shipments in the AEO 2014ER support this continued positive trend. Figure 21 shows that between 2011 and 2040, electric heat pumps (mostly air-source) are forecasted to rise in market share from 12% to 16%. Natural gas heat pumps are expected to maintain a lower percentage with less than 0.5% of the total market.

In the early 2000s, GHPs had relatively small sales - <1% of total heat pump sales. Tax incentives and supportive policies, in addition to improved consumer awareness, are leading to increased market acceptance of GHPs and, according to AEO 2014ER, they are anticipated to nearly double their market share to just below 2% of the market by 2040. A more near-term projection by Pike Research forecasts U.S. GHP shipments to reach 326,000 units/year by 2017 [36].

Figure 21 – Projected growth of heat pump technology through 2040.

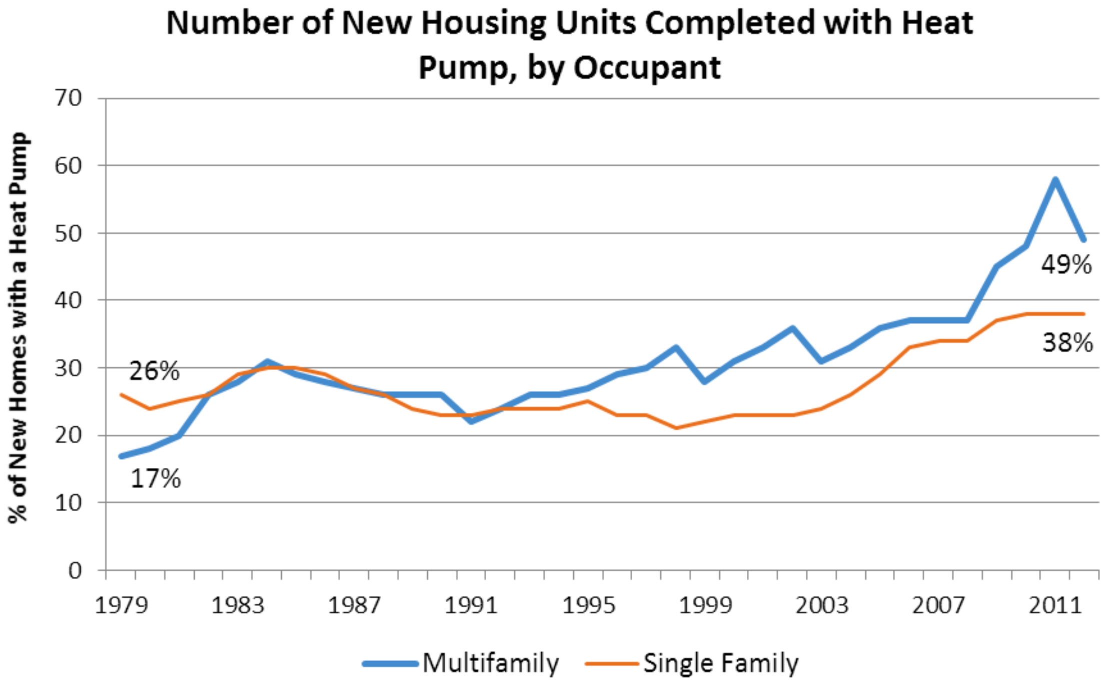


HPWHs have also gained traction in recent years due to their ability to deliver significantly more heat for the same amount of electricity, when compared to conventional electric storage water heaters. Numerous reputable water heating manufacturers have released their own models, and in 2012, HPWH shipments totalled 34,000 with an estimated market penetration of 1% [37].

By Building Stock Segment

Only historical data (not projected) was accessed for this report concerning heat pump sales broken down by occupant type. The 2011 American Housing Survey states that approximately 13% of existing single family homes and 10% of multifamily units use heat pumps as their primary heating system [38]. For new homes, these percentages are much higher, according to the U.S. Census Bureau, who estimates 38% of new single family homes and nearly half of new multifamily units to use heat pumps, as shown in Figure 22 [39].

Figure 22 – Percentage of new homew equipped with heat pump, by occupant.



By Ownership

U.S. Census Bureau data show that, of the single-family homes that where built since 1980:

- Approximately 30-40% homes that were contractor-built (meaning built for owner-occupancy on the owner's land under the supervision of a general contractor) were equipped with heat pumps;
- Approximately 20-30% of homes that were owner-built or built-to sale between 1980 and 2005 were equipped with heat pumps; after 2005, approximately 30-50% of homes that were owner-built or built-to-sale were equipped with heat pumps.

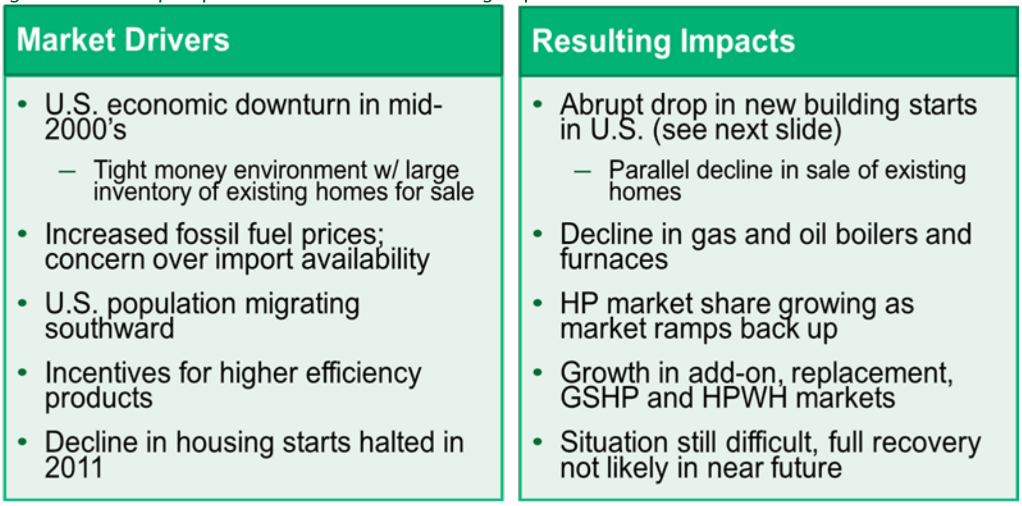
The U.S. Census Bureau only began collecting this data for multifamily units in 1999, but the limited data shows that:

- Approximately 30-40% homes that were built-for-rent between 1999 and 2008 were equipped with heat pumps; between 2009 and 2012, this percentage rose to between 45-65% of homes.
- Approximately 25-40% homes that were built-for-sale between 1999 and 2012 were equipped with heat pumps [39].

3.3 Market Drivers

The U.S. heat pump market (in addition to the entire heating system market) was significantly impacted in recent years due to the economic crisis and resulting sharp decline in new building starts beginning in 2005-2006. In parallel, increased oil and natural gas prices in the mid-2000s resulted in more favourable competitiveness for electric heat pumps for new homes and as add-on and replacement solutions. {NOTE – with the advent of new gas extraction technologies, e.g. fracking, etc., natural gas prices have fallen relative to electricity since the late 2000's so this temporary market advantage has largely disappeared.} Finally, incentives for higher efficiency products further increased the appeal of electric heat pumps during this time; hence, their rise in market share during this time period was considerable [39]. Figure 23 summarizes major heat pump market drivers and the resulting impact on sales.

Figure 23 – Heat pump market drivers and resulting impacts.



Federal performance standards have also been a major driver for development in the heat pump market. Most notable are the Minimum Energy Performance Standards (MEPS) set by the EPAct of 1975, which have become increasingly stringent for residential furnaces, air conditioners, and heat pumps each time the standard is amended.

In 2010, the U.S. Congress and DOE were petitioned to establish regional standards that recognize climate differences and different operational requirements. DOE responded in 2011 by publishing a ruling that defined distinct regions with different MEPS for residential gas furnaces and air conditioners; however, heat pumps and oil furnaces will have a national MEPS. The standards apply to residential single-phase air conditioners and heat pumps with less than 65,000 Btu/hr (19 kW) of cooling capacity and single-phase indoor and outdoor furnaces with less than 225,000 Btu/hr (66 kW) heat input. Table 3 provides details on the heat pump-specific standards, which are scheduled to go into effect in 2015 [40].

Table 3 – Pending heat pump minimum efficiency performance standard [41].

Product class	National standards	Southeastern Region standards	Southwestern Region standards	Off-mode electric power consumption
Split-system heat pumps	SEER = 14 HSPF = 8.2	SEER = 14 HSPF = 8.2	SEER = 14 HSPF = 8.2	33 W
Single-package heat pumps	SEER = 14 HSPF = 8.0	SEER = 14 HSPF = 8.0	SEER = 14 HSPF = 8.0	33 W
Small-duct, high-velocity systems	SEER = 13 HSPF = 7.7	SEER = 13 HSPF = 7.7	SEER = 13 HSPF = 7.7	30 W
Space-constrained products — HPs	SEER = 12 HSPF = 7.4	SEER = 12 HSPF = 7.4	SEER = 12 HSPF = 7.4	30 W

3.4 Market Barriers

Today, heat pump sales/shipments are highly concentrated in the warmer United States, which are more conducive to efficient performance. ASHPs are less popular in colder U.S. climates because most available models suffer significant reduction in heating capacity at low temperatures and resultant increased usage of back-up electric resistance heating. In addition natural gas tends to be relatively less expensive compared to electricity in these regions.

Research and development (R&D) and market transformation efforts are underway to address the barriers to increased acceptance of heat pumps (mainly ASHPs) in colder climates. For example, the Northeast Energy Efficiency Partnership has identified strategies to help transform the heating equipment market in the Northeast and Mid-Atlantic region by creating a consumer and contractor awareness campaign that will use modelling software to estimate energy and cost savings in cold climate regions. DOE and its national labs are also coordinating efforts to address the key technical challenge – loss of heating capacity during extreme low temperature operation.

4 List of Smart Heat Pump Projects in the United States

4.1 Analysis of Capabilities of Variable Capacity Heat Pumps for Demand Side Management [42]

Participating Entities	*Electric Power Research Institute (Lead), Southern Company, Tennessee Valley Authority, Duke Energy, CenterPoint Energy*
Time frame:	Ongoing, through ~2015
Objective:	The team will conduct laboratory and field analysis of variable capacity heat pumps for the provision of energy efficiency and demand management resources.
Description:	Variable capacity heat pumps offer new flexibility to heat pump systems, enabling them to be applied in non-traditional climates and to be used for advanced load management. This project evaluates the capabilities of various manufacturers' variable capacity heat pumps in the lab and in the field for these new capabilities. Analysis will consist of several systems evaluated in laboratory conditions and between 10-20 systems evaluated in the field at various locations and climates across the United States. This new technology is expected to help expand the heat pump market into northern climates, eliminate second stage heat, optimize demand management, and enable auto fault detection and correction.

4.2 Smart Grid Equipment Testing at PNNL Lab Homes [43]

Participating Entities	*Pacific Northwest National Laboratory*
Time frame:	Has not yet begun
Objective:	Use new software framework to coordinate EV charging, grid-smart appliances, and HPWHs with pricing and load signals from the grid.
Description:	PNNL has developed VOLTTRON, a software framework that adds intelligence to networked sensors in the electric power system. This creates the information channels to enable two-way power flows to speed up the integration of distributed generation in the power system, and to allow for decentralized control to support micro-grids. PNNL's Lab Homes will be used to test VOLLTRON's ability to coordinate EV charging, grid-smart appliances, and HPWHs. VOLLTRON supports decentralized cooperative decision making, and will be used to control the electricity consumption of connected equipment by enabling the equipment to respond to pricing and load signals from the grid, including the transactive incentive signal from the Pacific Northwest Smart Grid Demonstration Project, or a utility-set maximum power consumption limit. Proposed experiments include: ● Electric Vehicle Charging ● EV Charging with load balancing ● HVAC + Electric Water Heater with load balancing ● Coordinated Energy Management for HVAC + Electric Water Heater + EV Charging.

4.3 Testing and Demonstrating of Residential Smart Grid Technologies at Berkeley Demand to Grid Lab [44]

Participating Entities	*Lawrence Berkeley National Laboratory*

Participating Entities	*Lawrence Berkeley National Laboratory*
Time frame:	2011 to present
Objective:	Use LBNL's Demand to Grid (D2G) Lab to demonstrate smart grid controls on residential appliances.
Description:	Work at the D2G Lab focuses on the testing and improving strategies and standards for demand-side interoperability, wired and wireless communications, communication architectures, devices, and monitoring and controls technologies. The Guest House at LBNL was selected as one of the demonstration sites and the test bed for the D2G Lab because the necessary infrastructure was already in place. At the Guest House, wireless and wired Internet (Wi-Fi), and in-home protocols and standards such as ZigBee Smart Energy Profile 1.0 and other proprietary protocols are used to interoperate with OpenADR and respond with a change in energy use. Among other appliances, the Guest House features a HPWH loaned by General Electric. It, like the other appliances is controlled by the HAN using DR signals and with Web-based energy visualization tools to provide information on energy choices being made during demand response events. The HPWH has two modes of heating—resistive heating (where a heating coil heats the water) for everyday operation, and a heat exchanger that is used during a demand response event. As part of the demonstration, the heater is programmed to use 4,500 Watts of electricity during standard electric mode, then powers down to 550 Watts using the heat exchanger during demand response events.

4.4 HD Supply Utilities and General Electric Partner to Provide Hybrid Water Heater to Electric Utilities for Residential Customers [45]

Participating Entities	*HD Supply Utilities and GE Appliances & Lighting*
Time frame:	10/01/2009 – Present
Objective:	Distribute demand response-capable HPWHs to residential customers to
Description:	HD Supply Utilities and GE Appliances & Lighting have partnered to provide GE's new GeoSpring HPWH to residential customers with the help of federal funding. This Energy Star®-qualified water heater is ideally suited for utilities' smart grid initiatives and will help them achieve their energy conservation program goals. The GE hybrid water heater is demand response capable, with four pre–programmed settings, and adaptable to multiple communication protocols. HD Supply Utilities will use the GE HWPHs as part of their fully integrated technology solutions for the smart grid — from smart meters and home area network (HAN) devices to the AMI network and demand response, demand side management and meter data management software platforms at the utility data and operations center.

5 Analysis of Smart-Ready Products

5.1 Criteria for 'Smart-Ready': Analysis of Full Range of "Smart" Capabilities

Criteria	*Description*	*Importance for peak shifting*	*Maturity*	*Future evolution*
Heat pump functionality	Inverter-driven compressor which can ramp down rather than switch off	High	Growth stage	Likely to become mainstream technology
	On/off	High	Mature	Mainstream
Control	Pre-heat algorithms	Medium	Low	Some potential

Criteria	*Description*	*Importance for peak shifting*	*Maturity*	*Future evolution*
strategies: building thermal mass & storage	'Learning' building thermal response	Medium	Growth stage	High potential
	Optimising integration with storage	High	Medium	Niche
Control strategies: outside environment	Weather compensation & variable capacity	Medium	Low	Some potential
	Responding to weather forecast data	Medium	Low	Some potential
Control strategies: energy price	Responding to dynamic price signals	High	Low	Likely to become more prevalent
	Responding to pre-set price (& CO_2 signals?)	Medium	Low	Likely to become more prevalent
Communication capability	2-way communication	High	Low	Promising
	1-way communication	High	Mature	Mature, but some new technologies will emerge
Speed of response to communication signal	Dynamic response (minutes)	High	Medium	Likely to become more prevalent
	Needs advanced notice (hours/days)	Medium	High	Subset of above
Communication protocol	Open ADR	High	Low	Promising
	SEP 2	High	Low	Limited adoption
	CEA-2045	High	Low	Transitional platform
Thermal storage	Sensible heat storage (water tanks)	Medium	Growth stage	Continued growth
	Advanced heat storage technologies e.g. phase-change materials	High	Mature	Niche
Integration with 2nd energy source	Bivalent system with set-point control to switch from heat pump to other source			
	Hybrid which switches between heat sources according to price, CO_2			
	Sophisticated control hybrid which can switch between sources in response to dynamic tariffs			

5.2 Defining the Minimum Capabilities for Smart-Ready Heat Pump Systems

- Capability to receive, interpret and act on a signal received from a utility or a third party, preferably via open communication protocols.;
- Automatically adjust heat pump operation according to pre-set minimum performance standards depending on both the signal's contents and settings managed by the user or consumer;
- Communicate the heat pump's relevant status back to the utility;
- Provide consumers the ability to override a demand response signal. Upon such override, the system should communicate to the utility that the override has been implemented.

5.3 Review of U.S. Products That Meet These Smart-Ready Criteria

At the moment, there are no heat pump products (ASHPs or GHPs) on the U.S. market that meet the smart-ready criteria above. At best, there are a few that can be relay controlled to stage power draw—e.g. Daikin & Mitsubishi variable refrigerant flow (VRF) systems.

GHPs however, do have some inherent grid demand leveling benefits owing to their reliance on relatively stable temperature geothermal energy sources/sinks. A characteristic of GHP systems is that on any given day, the instantaneous load is quite constant, with the source temperature for heating (or sink for cooling) being more "temperate" during peak load conditions than is the air temperature that acts as the source (or sink) for ASHPs or central air conditioners. Run times will vary to a degree with the system thermal load, but the instantaneous electrical demand for a GHP system will not vary much from the peak thermal load to the thermal trough on any given day – a very favorable load pattern for electric utilities.

- During peak demand periods, ASHPs or central ACs tend to run longer with increased instantaneous demand, while
- GHPs during peak demand periods tend to run longer but at a nominal demand.

GHPs could, thus, reduce the demand while fully (and transparently) serving the homeowners' needs. But, in order to realize this peak demand benefit on a large enough scale will require more effort to improve the market acceptance (i. e., reduce the installation cost to homeowners) of GHPs.

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