A Landscape Review of the Global Renewable Heating and Cooling Market

A Report to the
Renewable Thermal Collaborative
by David Gardiner and Associates

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1. Executive Summary

This landscape review identifies the status of the existing and potential renewable thermal marketplace both globally and in the United States. David Gardiner and Associates (DGA) developed this report for the Renewable Thermal Collaborative (RTC) to provide comprehensive information on the current state and market potential for a range of renewable thermal technologies and fuel types.

This report aims to clarify for corporate and municipal decision makers, policymakers, and the public the significance of thermal energy as part of energy and carbon footprints especially in the industrial and buildings sectors, the range of renewable thermal energy applications and their potential for deployment within those sectors and the market barriers renewable thermal technologies face.

Our review focuses on four renewable thermal fuel and technology types: bioenergy (including biogas, renewable natural gas, and biomass), solar thermal, geothermal, and renewable electrification.

Key findings include:

Energy needed to produce heating and cooling is a significant part of the energy and carbon footprint.

- Energy used for heating and cooling is 50 percent of final energy use globally and contributes 39 percent of greenhouse gas emissions from energy-related sources.[1]
- The majority of this energy use is powered with fossil fuels: 40 percent natural gas, 20 percent coal, 20 percent oil, and only 10 percent of the heat production is powered with renewable energy.[2]

Thermal energy is especially important in the industrial and buildings sectors.

- Globally, industrial heat makes up two-thirds of industrial energy demand and almost one-fifth of total energy consumption.[3]
- In the U.S., industrial manufacturing accounts for one-third of the nation's total energy use (including both electricity and thermal energy).[4]
- In the E.U., heating and cooling accounts for half of the total energy consumption, and within industry over 70%.[5]
- Combustion in boilers, furnaces, and similar systems, provides 90 percent of the thermal energy needs in the U.S. manufacturing sector.[6]

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[1] IEA Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD), 2015, "Waking the Sleeping Giant" (http://iea-retd.org/wp-content/uploads/2015/02/RES-H-NEXT.pdf).
[2] International Energy Agency (IEA), 2014, "Heating without Global Warming" (https://bit.ly/2jj4mCy).
[3] IEA, Jan. 23, 2018, "Commentary: Clean and efficient heat for industry" (https://bit.ly/2DRrSm5).
[4] U.S. Department of Energy, Jan. 2006, "Best Practices: Process Heating" (https://bit.ly/2lPsk9A).
[5] European Commission, "Heating and Cooling" (https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling).
[6] U.S. Department of Energy, Energy Efficiency and Renewable Energy, (https://bit.ly/2lPsk9A).

- In the U.S., energy use for heating, ventilating and cooling (HVAC systems) is significant, comprising 39 percent of total energy consumption of commercial buildings.[7]

The thermal energy footprint is growing.

- Globally, total energy consumption for heat is projected to grow by six percent between 2014 and 2021.[8]

And the use of *renewable* thermal energy has also been growing, but more slowly than renewable electricity.

- From 2007 to 2014, renewable thermal energy use increased by 17 percent, at an annual average growth rate of 2.3 percent per year, from 13.0 EJ to 15.2 EJ.[9] The growth was less than for renewable electricity supply, which grew at around 6 percent per year.[10]
- The International Energy Agency (IEA) finds that globally, by 2021, as compared to 2014 levels:[11]
    - Total **modern renewables for heat** is projected to grow by 21 percent;
    - **Modern bioenergy** is projected to grow by 16 percent;
    - **Solar thermal** is projected to grow by 65 percent;
    - **Geothermal** is projected to grow by 75 percent;
    - **Renewable electricity for heat** is projected to grow by 43 percent.[12]

Renewable thermal technologies have significant potential in the manufacturing sector.

- By 2020, renewable thermal technologies could deliver up to 21 percent of manufacturing final energy demand and feedstock-use, a five-fold increase over 2011 levels.[13]
- By 2050, **bioenergy** and **biofeedstocks** may constitute three-quarters of the direct renewable use in the manufacturing sector, with the remainder divided between **solar heating** and **heat pumps**.[14]
- Another study finds that **solar thermal** has a technical potential to provide around 15 EJ of heat by 2030, while the share of solar thermal deployed in the industrial sector could reach 33 percent.[15]

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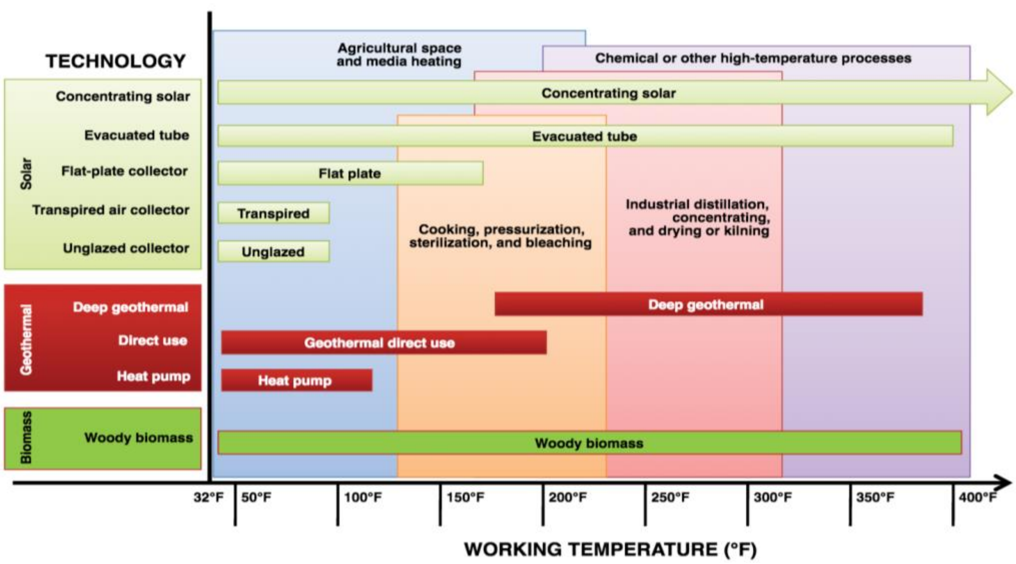
[7] World Building Design Guide, Nov. 7, 2016, "National Institute of Building Sciences" (https://bit.ly/2GyWsj3).
[8] IEA, 2017, Medium-Term Market Report 2016.
[9] *Id.*
[10] IEA 2017, *supra* note 9.
[11] IEA 2017, *supra* note 9.
[12] While large, projected percentage increases for solar thermal, geothermal, and renewable electricity for heat are made on a very small base of existing deployment.
[13] Taibi, E., D. Gielen, M. Bazilian, 2011, "The potential for renewable energy in industrial applications" (https://bit.ly/2lNNAMY).
[14] *Id.*
[15] The International Renewable Energy Agency (IRENA), Jan. 2015, "Solar Heat for Industrial Processes" (http://www.irena.org/publications/2015/Jan/Solar-Heat-for-Industrial-Processes).

- Different industrial sectors have differing potential to utilize **direct electrification** of process heating by 2050 – from zero (e.g., petrochemicals) to 100 percent (e.g., food, iron and steel, pulp and paper).[16]

Today's renewable thermal technologies can make significant progress in industry for low and medium temperatures.

- The International Energy Agency (IEA) reports, "more than half of the heat demand, on average, is in the low and medium temperature range below 400 degrees Celsius," while "two thirds of the medium temperature heat required in industry processes is at levels below 200 degrees Celsius (see Figure 5 for a summary of different temperature categories).[17] Different existing renewable thermal technologies can meet the differing temperatures needs of industrials, as shown in Figure 1.

Figure 1. Renewable Industrial Process Heat Technologies and Applications[18]



Source: EPA, 2016

However, there is also a large demand for high temperature applications.

- Around 40 percent of fossil fuel use in industry is for the generation of steam.[19] Some industries with high process steam requirements include pulp and paper (where process steam comprises 57 percent of total energy demand), petroleum refining (51 percent), and chemical manufacturing (47 percent).[20]

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[16] Lawrence Berkeley National Laboratory (LBNL), Mar. 2018, "Electrification of buildings and industry in the United States" (https://bit.ly/2Kppas6).
[17] IEA 2014, *supra* note 2.
[18] U.S. EPA, May 2016, "Renewable Industrial Process Heat" (https://www.epa.gov/rhc/renewable-industrial-process-heat).
[19] Carbon Trust, 2012, "Process heating: Introducing energy saving measures for business" (https://www.carbontrust.com/media/147550/ctv064__process_heating.pdf).
[20] U.S. DOE, 2007, "Improving Process Heating System Performance" (https://www.nrel.gov/docs/fy08osti/41589.pdf).

Renewable thermal technologies face significant market barriers that inhibit them from scaling up, especially when compared to renewable electricity. Those barriers include:

- Supply
  - The supply is often limited by geography, as some regions have limited access to biomass, sun, or geothermal resources;
  - The supply is often disaggregated and there is a disconnect between renewable thermal demand and supply;
  - For industrial uses, there is a need to match diverse supply with diverse temperature needs;
  - It is unclear if there is an adequate and consistent supply of sustainable biomass to meet projected needs;
  - Some technologies are not widely or commercially available, particularly for high-temperature technologies.
- Market
  - Renewable thermal technologies face stiff competition from fossil fuels, including low natural gas prices in the U.S.;
  - Lack of information for consumers regarding renewable thermal technologies and options;
  - Low turnover rates of heat producing technologies in industry and buildings;
  - No tracking instrument for end users to gain ownership of environmental attributes from renewable thermal projects;
  - For the building sector, owners and renters often have split incentives.
- Policy
  - Renewable thermal technologies have few supporting policies. More than 120 countries in all world regions have introduced policies designed to promote renewable electricity, whereas only around 40 have specific policies for renewable heat, most of which are within the European Union;[21]

There are also technology-specific challenges, including for bioenergy:

- Potential competition between biomass feedstocks with non-energy feedstocks (e.g., competition around certain forest products where stakeholders in the forestry industry pursue the products for their business, while stakeholders in the energy industry pursue the products for bioenergy). These potential vying interests (which would occur as demand for bioenergy increases) could create competition between industries, thus increasing prices;
- Lack of consistent and sufficient availability of sustainable biomass feedstocks in certain geographic regions.
- Lack of consensus accounting methods that give end-users a clear picture of the emissions impacts or benefits of bioenergy projects.

[21] IEA 2014, *supra* note 2.

Ultimately, expected progress in deployment of these various renewable heating and cooling technologies will fall short of expectations if these barriers are not addressed. Therefore, stakeholders should consider the following preliminary list of recommendations to overcome barriers to scaling up renewable thermal technologies:[22]

- Engage in outreach to policymakers and key opinion leaders to:
    - Raise awareness and articulate growing demand for renewable heating and cooling;
    - Develop and promote a common language for discussion of renewable heating and cooling technologies and topics among policymakers and the general public in order to reduce confusion and help those less knowledgeable understand the issues;
    - Provide guidance for policymakers to help develop long-term plans to guide market development efforts for renewable heating and cooling (e.g., establishing credible and realistic targets for deployment, performance-based incentives).
- Convene stakeholders across technology types, sectors, and geographic regions, for example, to:
    - Articulate the growing demand for renewable heating and cooling technologies among companies, cities, and states, as well as shared principles for market expectations;
    - Improve data collection and tracking of thermal energy end-use and emissions data, that agencies like EPA do not track;
    - Identify ways to overcome market disaggregation and support collaborative project approaches (e.g. industrial park or anchor-tenant solutions);
    - Map viable technology options by geography and end-use (e.g., build out
    - Figure 4, which maps technology to end-use, to be more specific about end uses and sectors);
    - Develop government partnerships to drive down soft-costs and greater research and development;
    - Work with policymakers and utilities to overcome split-incentives and provide other support for renewable thermal technologies.
- Develop action plans to address technology gaps and barriers to further deployment of renewable thermal technologies, for example, to:
    - Assess sustainable feedstock availability to determine growth potential for sustainable bioenergy;
    - Develop a vision or roadmap for thermal electrification;
    - Develop a thermal Renewable Energy Credit to track and validate thermal energy projects;
    - Develop consensus around inadequate accounting methodologies.

[22] Note that this list is not exhaustive.

2. Introduction

Energy used for heating and cooling (both process heat and building heating and cooling) is a significant contributor to global energy demand and to climate change. Globally, heating and cooling account for approximately 50 percent of total final energy demand (across the residential, commercial and industrial sectors).[23] The majority of this energy use is powered with fossil fuels: 40 percent natural gas, 20 percent coal, 20 percent oil, and only 10 percent of the heat production is powered with renewable energy.[24,25] In the United States, heating and cooling account for more than 25 percent of total energy use across residential, commercial, and industrial sectors at a cost of $270 billion annually.[26,27]

Leaders in the commercial and industrial sector have made long-term commitments to renewable energy, some up to 100 percent of total energy. Because heating and cooling comprise such a large percentage of total energy end use and of fossil fuel use, it will not be possible for corporate, government, and other institutional leaders to achieve their long-term climate and energy goals without dramatically increasing the use of renewable heating and cooling (RHC). Further, the Paris Agreement sets landmark goals for climate action, aiming to keep temperature rise to below two degrees Celsius and to pursue efforts to limit temperature increase to 1.5 degrees Celsius. Heat represents up to 25 percent of global greenhouse gas (GHG) emissions (not including transportation and heavy industry), necessitating that any strategy to achieve a 2-degree path must include RHC.

Because heating and cooling comprise such a large percentage of total energy end use, the public and private sectors must work together to dramatically increase the supply of renewable heating and cooling technologies in industry and in buildings to achieve long-term climate, security, and energy goals. Using renewable energy resources such as bioenergy, geothermal, and solar for thermal heating and cooling instead of fossil fuels represents an untapped opportunity to substantially reduce the carbon emissions that are warming the earth's atmosphere, improve national security, and create economic opportunities.

3. Methodology and Key Caveats

This report is based on a review of renewable thermal studies and analyses. While extremely helpful, relying on existing studies and analyses presents several challenges. First, DGA's review of the literature is highly likely to have missed some studies. Second, many studies examine the potential to deploy only a single renewable thermal technology, without examining the potential for other

[23] IEA-RETD 2015, *supra* note 1.
[24] IEA, 2014, *supra* note 2.
[25] IEA, 2014, *supra* note 2.
[26] U.S. Environmental Protection Agency, May 2017, "Basic Information About RHC" (https://www.epa.gov/rhc/basic-information-about-rhc).
[27] U.S. Department of Energy (DOE), 2011, "Buildings Energy Data Book" (http://buildingsdatabook.eren.doe.gov/).

technologies. Third, as the reader will discover, the studies use different units of measurement for potential deployment, making comparison among the studies extremely difficult. These challenges suggest the need for more analysis of thermal energy and renewable technologies.

4. What is Thermal Energy and Why Does It Matter?

Thermal energy results when a primary energy source is converted into kinetic energy, or heat. Unlike electricity, where mechanical energy is transformed into an electric current that is distributed to end users through a transmission system, thermal energy cannot travel over long distances, so it is produced on-site or near its use and distributed locally. In industrial manufacturing, thermal energy delivers process and non-process heating and cooling, in addition to building space heating and cooling. In commercial buildings, thermal energy is also used to provide hot water. Once produced, thermal energy is disbursed through conduction, convection, radiation, or a combination of these applications to generate material changes in the production of basic materials (e.g., steel, chemicals, aluminum, cement) and consumer goods.

Thermal energy for heating, processing, and cooling within industry and buildings commands a significant proportion of energy resources. Globally, thermal energy use in industry and buildings comprises an estimated 50 percent of total global final energy demand.[28] Primary sources to meet this demand also derive principally from fossil fuels: 40 percent from natural gas and 20 percent each from coal and oil.[29] Combustion in boilers, furnaces, and similar systems, provides 90 percent of the thermal energy needs in the U.S. manufacturing sector.[30]

The predominance of fossil fuels in the production of thermal energy presents a significant opportunity for the industrial and building sectors to reduce carbon and other GHG emissions. In the U.S., 32 percent of GHG emissions from the industrial sector derive from on-site thermal energy sources and non-utility electricity generation. These emissions comprise seven percent of total U.S. GHG emissions across all sectors.[31] Globally, industrial and building sector thermal energy production comprises up to one-third of global energy related carbon dioxide (CO_2) emissions, equating to more than 10 $GtCO_2$.[32]

In residential and commercial buildings, on-site combustion of fossil fuels comprises 28 percent of total GHG emissions associated with building operations.[33] Even in locations where renewable energy resources already supply a large component of total energy demand, such as California, thermal

[28] IEA-RETD 2015, *supra* note 1.
[29] IEA 2014, *supra* note 2.
[30] DOE 2006, *supra* note 4.
[31] Joint Institute for Strategic Energy Analysis, Dec. 2016, "Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions" (https://www.nrel.gov/docs/fy17osti/66763.pdf).
[32] IEA 2014, *supra* note 2.
[33] National Resources Defense Council (NRDC), Sep. 2016, "Slashing Emissions from Fossil Fuels Burned in Buildings" (https://on.nrdc.org/2KFPABN).

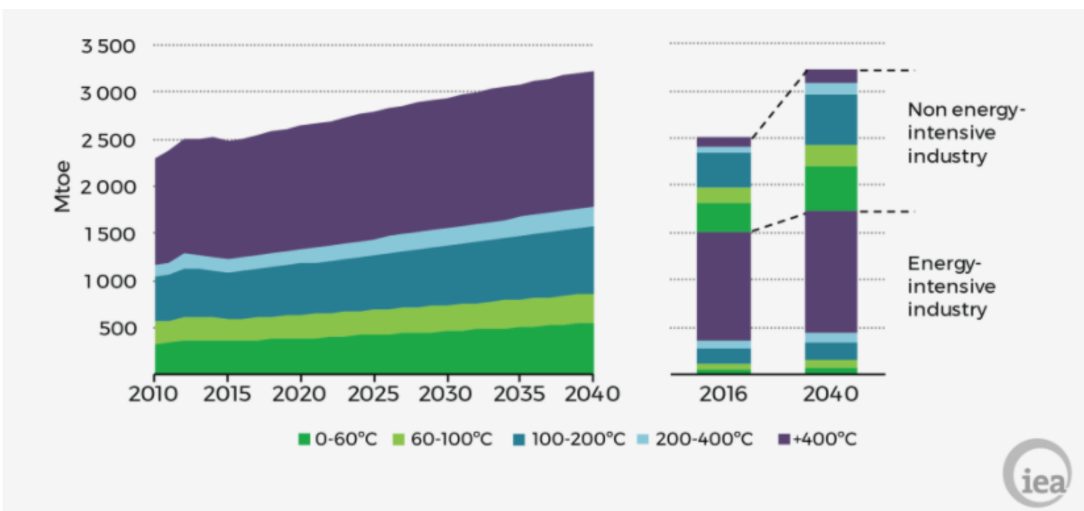
energy production in buildings is still heavily dependent on fossil fuels. Thermal energy demand in the U.S. building sector contributes 11 percent of U.S. energy-related emissions, with 75 percent of heat demand provided by fossil fuels and traditional biomass.[34]

Current demand for renewable thermal energy sources remains low. Despite a sustained average growth in demand for industrial heat of 1.7 EJ/year,[35] renewable thermal energy sources supplied only 10 percent (8 EJ)[36] of 2011 global total industrial energy use for heat. Bioenergy supplied 99 percent of renewable thermal energy demand,[37] primarily for industrial high-temperature heat production, with geothermal and solar thermal sources at 0.02 EJ and 0.001 EJ, respectively.[38] Agriculture, forestry, pulp and paper and related industries sourced from 23 to 43 percent of its heating needs through renewable thermal energy sources in 2011—typically, biomass process residues.[39]

5. Thermal Energy is Critical to Industrial and Building Sectors

Because of its use in industrial processes, thermal energy is especially important to the manufacturing sector. Globally, industrial heat makes up two-thirds of industrial energy demand and almost one-fifth of total energy consumption.[40] Further, global industrial demand is expected to grow, as Figure 2 indicates.

Figure 2. Global industrial demand by temperature and sector



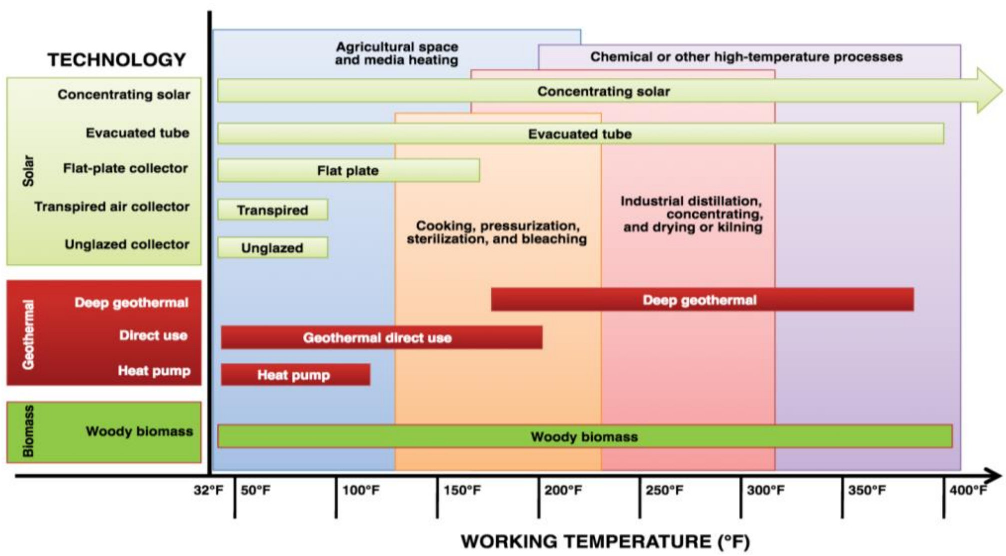
[34] IEA-RETD 2015, *supra* note 1.
[35] IEA-RETD 2015, *supra* note 1.
[36] IEA-RETD 2015, *supra* note 1.
[37] IEA-RETD 2015, *supra* note 1.
[38] IEA-RETD 2015, *supra* note 1.
[39] IEA-RETD 2015, *supra* note 1.
[40] IEA 2018, *supra* note 3.

Source: IEA World Energy Outlook, 2018

In the U.S., industrial manufacturing accounts for one-third of the nation's total energy use (including both electricity and thermal energy).[41] Process heat, vital to nearly all manufacturing industries, comprises 36 percent of total energy used in industrial manufacturing applications,[42] while production of boiler process steam comprises 36 percent to greater than 80 percent of the total energy used in manufacturing.[43] Energy use for heating, ventilating and cooling in commercial buildings is also significant, comprising 39 percent of total energy consumption in the U.S.[44]

One of the challenges of meeting heating needs in the industrial sector is the wide range of specific temperature needs in industrial processes. Different technology types are able to deliver different heating needs. Figure 3 summarizes several renewable industrial process heat technologies and their applications. Bioenergy, for example, is well-positioned to meet a variety of temperature, pressure, and quantity of heat and steam required by many industrial processes. As this diagram shows, biomass is one of the only technologies that can accommodate this wide range of temperature needs. Concentrated solar and evacuated tube solar also have a wide range of temperature applications; however, these technologies are less market ready than biomass technologies, as discussed in following sections. According to the U.S. Environmental Protection Agency (EPA), nearly 60 percent of industrial heating needs can be met with currently available low- or medium-temperature renewable heating technologies.[45]

Figure 3. Renewable Industrial Process Heat Technologies and Applications[46]

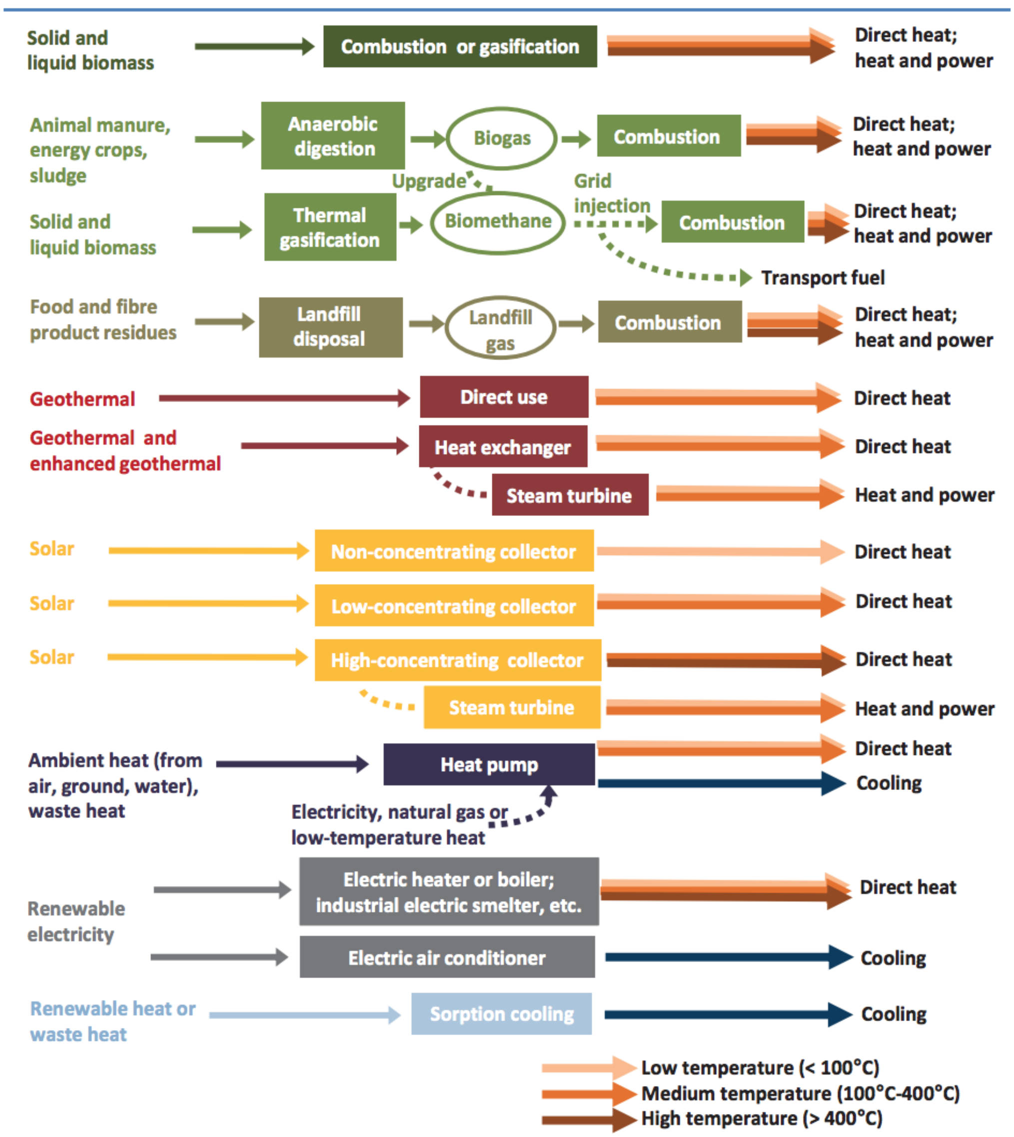


[41] DOE 2006, *supra* note 4.
[42] DOE 2006, *supra* note 4.
[43] DOE 2006, *supra* note 4.
[44] World Building Design Guide 2016, *supra* note 7.
[45] U.S. EPA, May 2016, "RHC for Industrial Processes" (https://www.epa.gov/rhc/rhc-industrial-processes).
[46] U.S. EPA, May 2016, "Renewable Industrial Process Heat" (https://www.epa.gov/rhc/renewable-industrial-process-heat).

Source: EPA, 2016

Figure 4 provides an overview of available processes to convert renewable energy to heat at low, medium, and high temperatures. The following sections describe four main uses for thermal energy in manufacturing and buildings: hot water, steam, process heat, and building heating.

Figure 4. Overview of different renewable energy sources, and main technologies to convert them into direct heat, and heat and power[47]



[47] IEA 2014, *supra* note 2.

Sources: IEA, 2014; based on IEA (2007), Renewables for Heating and Cooling: Untapped Potential, OECD/IEA, Paris; and other sources.

In most countries, building sector demand for heat is the highest of any sector. The most important uses in the buildings sectors are for cooking, hot water and space heating, most of which require low-temperature heat of less than 100°C.[48] In 2011, global final energy used for heat (FEH) in buildings reached 84 exajoules (EJ) in 2011, growing at an average rate of one percent per year, from 2000 to 2013.

3.1 Hot Water

In industrial manufacturing and commercial buildings, a primary use for thermal energy is the production of hot water used for preheating, heating, and low heat processing. In the industrial sector, hot water is used for processes such as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility. Some industries that use large amounts of water produce such basic materials as food, paper, chemicals, refined petroleum, or primary metals.[49]

3.2 Steam

When heating needs are higher than boiling temperatures (100°C), industrials can produce process steam from the combustion of fossil fuels in boilers or as an output from a combined heat and power (CHP) plant. Compared with heat transferred through a heat exchanger or fan circulation, steam is a more flexible and efficient form of thermal energy. Steam efficiently and easily transfers thermal heat at a constant temperature,[50] and is ideal for pressure control, mechanical drives, separation of components, and production of hot water for process reactions.[51] Additionally, steam is energy intensive, holding between 1,000 and 1,250 BTU per pound on a unit mass basis, representing a significant amount of latent heat.[52]

Around 40 percent of fossil fuel use in industry is for the generation of steam.[53] Some industries with high process steam requirements include pulp and paper (where process steam comprises 57 percent of total energy demand), petroleum refining (51 percent), and chemical manufacturing (47 percent).[54]

3.3 Process Heat

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[48] IEA 2014, *supra* note 2.
[49] United States Geological Survey (USGS), 2010, "Industrial Water Use" (https://water.usgs.gov/edu/wuin.html).
[50] U.S. DOE, 2007, "Improving Process Heating System Performance" (https://www.nrel.gov/docs/fy08osti/41589.pdf).
[51] DOE 2007, *supra* note 50.
[52] DOE 2007, *supra* note 50.
[53] Carbon Trust 2012, *supra* note 19.
[54] DOE 2007, *supra* note 50.

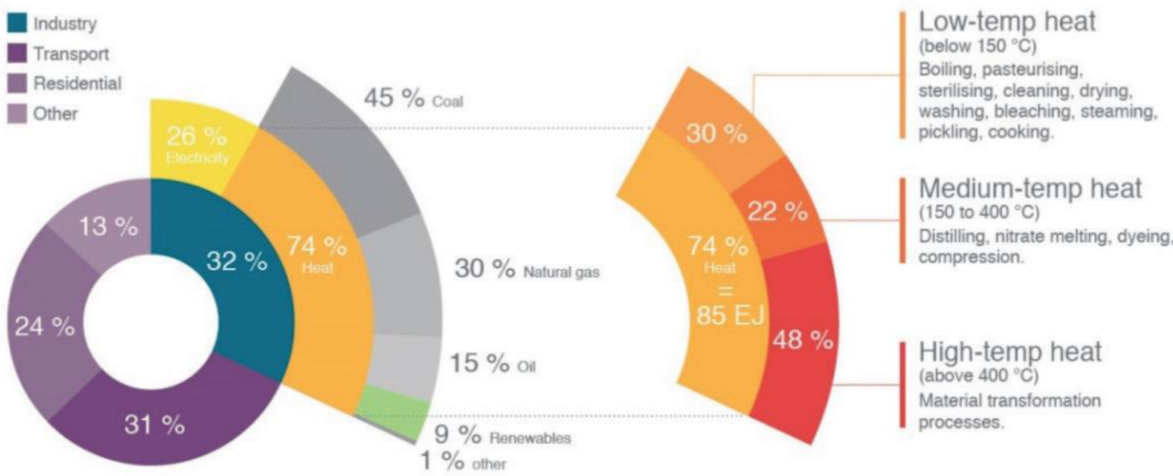
Process heat, vital to nearly all manufacturing industries, comprises 36 percent of total energy used in industrial manufacturing applications,[55] and 17 percent of total U.S. industrial energy consumption.[56] Process heat is used to produce basic materials such as iron, steel, cement, glass, and composites, as well as to manufacture value-added products such as electronics, chemicals, cosmetics, petroleum, agricultural commodities, and textiles. Conventional thermal energy technologies for process heating typically rely on the combustion of fossil fuels to create heat or pressurized steam. Industrial process systems deliver thermal energy at a specified temperature to a material or process application, often through a heat recovery and exchange system. Conventional systems produce thermal energy through combustion of a solid, liquid, or gaseous fuel in a furnace, oven, kiln, or similar mechanism.

Depending upon process complexity, process heating requirements may also include sensors, controls, material handling equipment, emissions controls for fossil fuel fired systems, and safety equipment.[57] Typically, industrial process cooling technologies such as chillers, cooling towers, and air condition heat pumps are powered by electricity to remove thermal energy from either air or water via a heat exchange mechanism.

Heat represents about three-quarters of industrial energy demand worldwide, and half of it is low- to medium-temperatures.[58] Specifically, about 30 percent of process heat is “low-temperature” (below 150°C), 22 percent is “medium-temperature” (150°C-400°C) and 48 percent is “high temperature” (above 400°C). About 10 percent of process heat is estimated to be electricity-based (Figure 5).[59]

[55] DOE 2006, *supra* note 4.
[56] U.S. DOE, Mar. 16, 2001, “Roadmap for Process Heating Technology” (https://bit.ly/2lMOysT).
[57] DOE 2006, *supra* note 4.
[58] IEA, 2017, “Renewable Energy for Industry From green energy to green materials and fuels” (https://bit.ly/2idN49N).
[59] *Id.*

Figure 5. Share and Breakdown of Heat Demand in Industry[60]



Note: EJ = exajoule.

Sources: IEA, 2017; Solar Payback (2017), based on IEA statistics and calculations by IRENA

Table 1 summarizes common industrial process heating requirements.

Table 1. Industrial Process Heating Temperature Requirements[61]

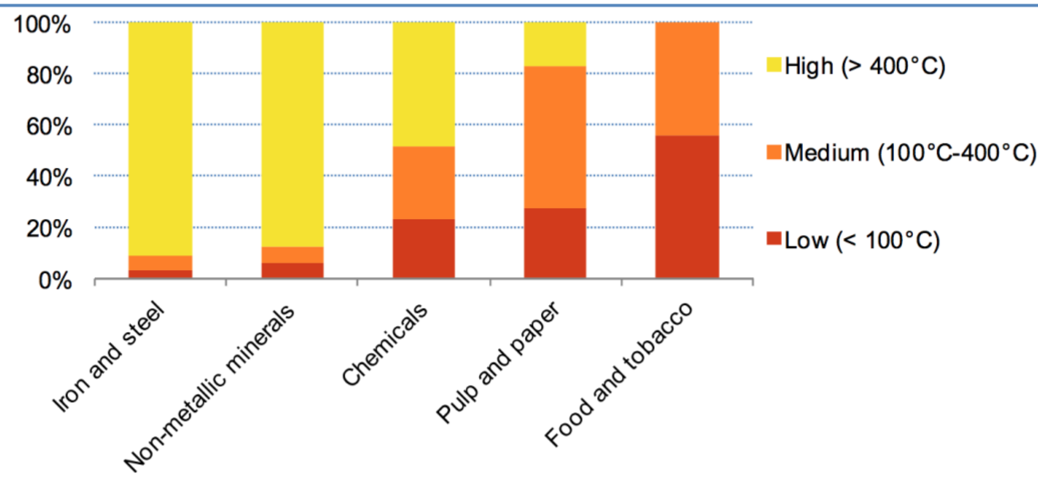
Industrial Sector	**Unit Operations**	**Temperature Range**	
		Celsius	**Fahrenheit**[62]
Food	Drying	30-90	90-210
	Washing	60-90	150-210
	Pasteurizing	60-80	150-190
	Boiling	95-105	220-140
	Sterilizing	110-120	250-270
	Heat Treatment	40-60	110-150
Beverages	Washing	60-80	150-190
	Sterilizing	60-90	150-210
	Pasteurizing	60-70	150-170
Paper Industry	Cooking and Drying	60-80	150-190
	Boiler Feed Water	60-90	150-210
	Bleaching	130-150	190-330
Metal Surface Treatment	Treatment, Electroplating, etc.	30-80	90-190
Bricks and Blocks	Curing	60-140	150-310
Textile Industry	Bleaching	60-100	150-230
	Dyeing	70-90	170-210

[60] IEA 2017, *supra* note 58.
[61] IRENA 2015, *supra* note 15.
[62] Fahrenheit values approximate.

Industrial Sector	Unit Operations	Temperature Range	
		Celsius	Fahrenheit[62]
	Drying, De-greasing	100-130	230-290
	Washing	40-80	110-190
	Fixing	160-180	350-390
	Pressing	80-100	190-230
Chemical Industry	Soaps	200-260	430-550
	Synthetic Rubber	150-200	330-430
	Processing Heat	120-180	270-390
	Preheating Water	60-80	150-190
Plastic Industry	Preparation	120-140	270-310
	Distillation	140-150	310-330
	Separation	200-220	430-470
	Extension	140-160	310-350
	Drying	180-200	390-430
	Blending	120-140	270-310
Flour By-Products	Sterilizing	60-90	150-210
All Industrial Sectors	Pre-heating of Boiler Feed Water	60-90	150-210
	Industrial Solar Cooking	55-180	140-390
	Heating of Factory Buildings	30-80	90-190

Absent from the above table, industries with the highest temperature requirements are: the iron, steel, and non-metallic minerals industries, as illustrated in Figure 6, which focuses on the European heat market. The majority of the temperature needs of these industries are above 400°C.

Figure 6. Heat requirements by temperature range in different industry sectors



Source: Euroheat & Power, 2006, The European Heat Market

3.4 Building Heating

Buildings require thermal energy to heat water, produce heat for comfort, and to serve as an energy source for refrigeration and air conditioning. Currently, space heating and cooling together with water heating are estimated to account for nearly 60 percent of global energy consumption in buildings.[63] In the U.S., energy use for heating, ventilating and cooling (HVAC systems) is significant, comprising 39 percent of total energy consumption of commercial buildings.[64]

Practically all of these building types—schools, sports stadiums, shopping malls, offices, hospitals and hotels—depend exclusively on fossil fuels to provide primary heat needs. Increasingly, air and ground-based electric heat pumps provide heating and cooling within smaller commercial buildings such as schools.

However, as in manufacturing, boilers and furnaces powered by fossil fuel combustion often supply building heat needs. Typically, hot water is circulated through a conventional piping system for delivery to kitchens, bathrooms, and other areas that use direct hot water. Or hot water or steam is circulated via a closed loop system of piping embedded in walls, ceilings, and floors to deliver radiant heat; after full circulation, water or steam returns to the boiler for reheating and recirculation. Alternatively, fossil-fired or electric furnaces produce heat delivered through a ductwork system aided by electric-powered forced air.

District heating, where steam is circulated throughout a network of interconnected buildings, also can supply heat and hot water. Air conditioning systems typically use electric powered heat pumps to heat, cool, and move air through a mechanical-compression cycle refrigeration system.

6. Potential for Renewable Thermal Energy Technologies

The following sections focus on four renewable thermal fuel and technology types: bioenergy (including biogas and biomass), solar thermal, geothermal, and renewable electrification. Globally, the combined share of renewable heat and renewable electricity for heat is projected to reach around 10 percent of total heat demand in 2021 (Figure 7).

[63] International Energy Agency, 2013, "Transition to Sustainable Buildings: Strategies and Opportunities to 2050" (https://www.iea.org/Textbase/npsum/building2013SUM.pdf).
[64] World Building Design Guide 2016, *supra* note 7.

Key findings:

Globally, by 2021, as compared to 2014 levels:

- Total **energy consumption for heat** is projected to grow by six percent;
- Total **modern renewables for heat** is projected to grow by 21 percent;
- **Modern bioenergy** is projected to grow by 16 percent;
- **Solar thermal** is projected to grow by 65 percent;
- **Geothermal** is projected to grow by 75 percent;
- **Renewable electricity for heat** is projected to grow by 43 percent.

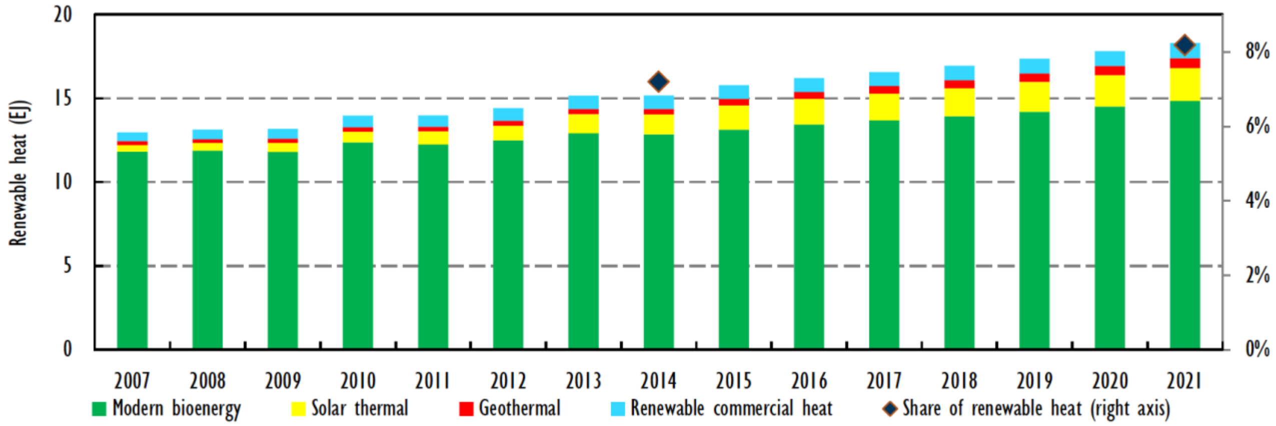
Further:

- By 2020, up to 21 percent of final energy demand and feedstock-use in the manufacturing sector could be renewable, a five-fold increase.
- By 2050, **bioenergy** and **biofeedstocks** may constitute three-quarters of the direct renewable use in the manufacturing sector, with the remainder divided between **solar heating** and **heat pumps**.
- **Solar thermal** has a technical potential to provide around 15 EJ of heat by 2030, while the share of solar thermal deployed in the industrial sector could reach 33 percent.
- The **electrification** of industrial process heating has a range of technical potential from zero to 100 percent by 2050.

The use of renewable thermal energy has been increasing, but more slowly than renewable electricity. From 2007 to 2014, renewable thermal energy use increased by 17 percent, at an annual average growth rate of 2.3 percent per year, from 13.0 EJ to 15.2 EJ (Figure 7). The growth was less than for renewable electricity supply, which grew at around 6 percent per year.[65]

[65] IEA 2017, *supra* note 9.

Figure 7. Global final renewable heat consumption (excluding traditional biomass), (2007-21)[66]



Sources: IEA (2016a), World Energy Statistics and Balances 2016, www.iea.org/statistics/; IEA (forthcoming), World Energy Outlook 2016.

In 2014, almost 95 percent of global renewable thermal energy use was from the direct use of bioenergy, solar thermal, or geothermal energy in the buildings or industrial sector (Figure 8). The remaining five percent was from the contribution of renewables to commercial heat (i.e. district heating). Bioenergy accounted for almost 90 percent of total renewable thermal energy use, while solar thermal accounted for 8 percent. Geothermal provided only two percent of the total renewable heat use.

By 2021, growth in renewable heat is expected to experience an annual average growth rate of 2.7 percent, with most of the increase from bioenergy use. As the use of electricity for heat is also expected to grow, and with a growing proportion of electricity supplied from renewables, the indirect contribution from renewables through electricity for heat increases by 43 percent. The combined share of renewable heat and renewable electricity for heat reaches around 10 percent of total heat demand in 2021.[67]

[66] IEA 2017, *supra* note 9.
[67] IEA 2017, *supra* note 9.

Figure 8. Global trends and outlook for renewable heat[68]

	2014 (EJ)	Share in total	Growth 2007-14	Growth 2014-21	CAAGR 2014-21
Total energy consumption for heat	212	n/a	n/a	6%	0.8%
Total modern renewables for heat (excluding electricity)	15.2	7.2%	17%	21%	2.7%
Of which: commercial heat	0.8	5.3%	54%	13%	1.7%
Of which: direct use	14.4	94.7%	15%	21%	2.8%
Modern bioenergy	12.8	89%	9%	16%	2.1%
Solar thermal	1.2	8%	213%	65%	7.4%
Geothermal	0.3	2%	34%	75%	8.4%
Renewable electricity for heat	3.1	1.5%	n/a	43%	5.2%

Note: All figures for heat correspond to final energy consumption in the buildings and industry sector. Figures for electricity use for heat in 2014 have been estimated. The shares of modern bioenergy, solar thermal, and geothermal refer to their share in the direct use only, excluding renewable commercial heat. CAAGR = compound annual average growth rate.

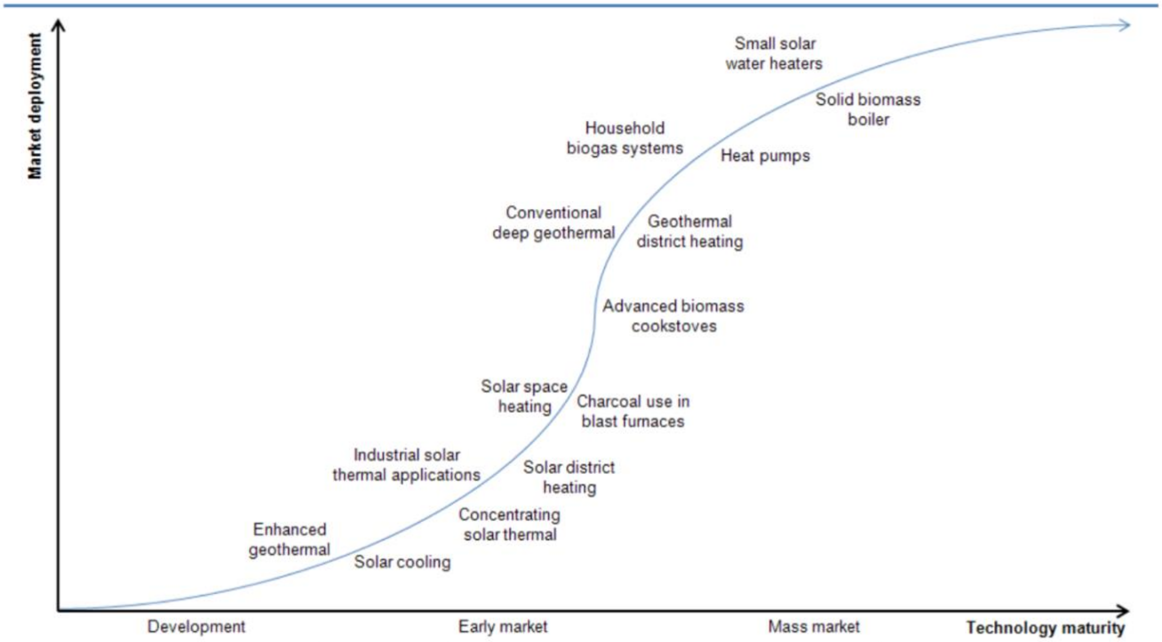
Sources: IEA (2016a), World Energy Statistics and Balances 2016, www.iea.org/statistics/; IEA (forthcoming), World Energy Outlook 2016.

Another analysis found that up to 21 percent of final energy demand and feedstock-use in the manufacturing industry sector could be of renewable origin by 2020, a five-fold increase over current levels in absolute terms.[69] The same analysis found that bioenergy and biofeedstocks can constitute three-quarters of the direct renewables use in this sector by 2050, with the remainder divided between solar heating and heat pumps.[70]

Renewable thermal technologies are currently available at various stages of market development, with small solar water heaters and solid biomass boilers at the greatest relative levels of both market deployment and technology maturity, as shown in Figure 9.

[68] IEA 2017, *supra* note 9.
[69] Taibi, E. et al. 2011, *supra* note 13.
[70] Taibi, E. et al. 2011, *supra* note 13.

Figure 9. The current state of market development of renewable energy heating and cooling technologies[71]



Source: IEA 2014; updated based on IEA (2007), Renewables for Heating and Cooling: Untapped Potential, OECD/IEA, Paris

5.1 Bioenergy

Bioenergy refers to thermal energy derived from the conversion of renewable organic matter from plants or animals for end use application. Bioenergy resources are widely diverse and include sources such as wood, agricultural crops such as sugar cane, and their associated waste streams; municipal organic waste; animal manure; aquatic organisms; and herbaceous and woody energy crops.

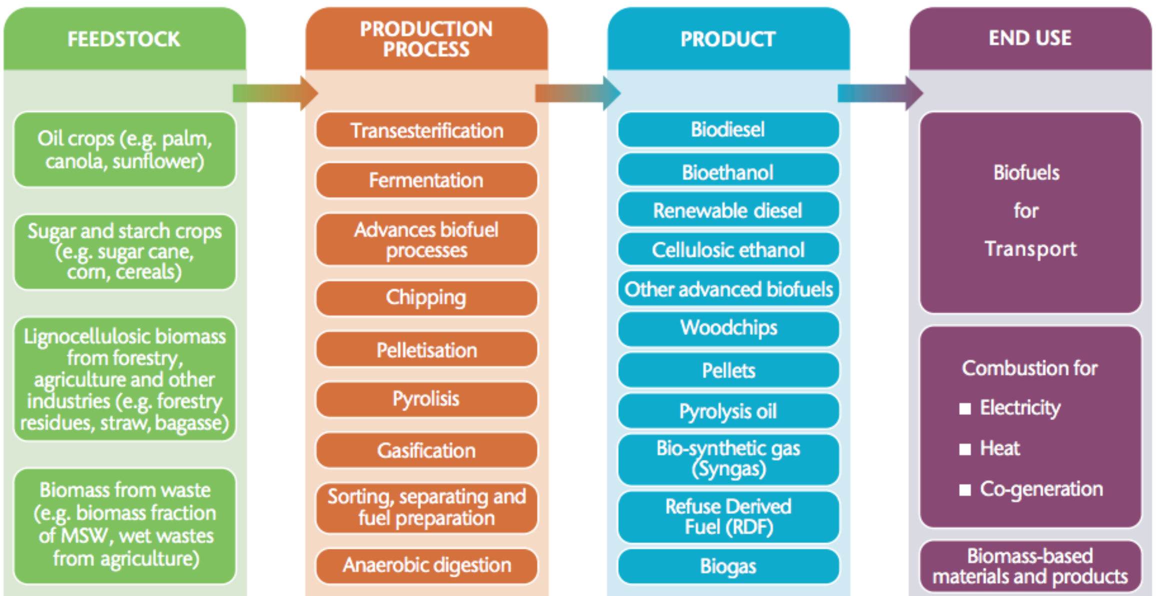
A range of bioenergy heating technologies are currently available and include biogas systems and large-scale heating and cogeneration plants. For the purpose of this report, bioenergy is divided into two categories: solid biomass (e.g., wood, harvesting residues) and biogas (including renewable natural gas). Biomass can be used in its original form as fuel, or be refined to different kinds of solid, gaseous or liquid biofuels. “Biogas” is the gas form produced by anaerobic fermentation of different forms of organic matter and is composed mainly of methane (CH_4) and carbon dioxide (CO_2). Typical feedstock for biogas production are manure and sewage, residues of crop production (e.g., straw), the organic fraction of the waste from households and industry, as well as energy crops including maize and grass

[71] IEA 2014, *supra* note 2.

silage.[72] "Renewable natural gas" is biogas that has been upgraded to a quality similar to fossil natural gas and capable of being transported through natural gas pipelines.

Heat derived from bioenergy can be cost-competitive with fossil fuels in buildings and industry in many cases, already today. Figure 10 summarizes the various bioenergy pathways that exist.

Figure 10. Potential bioenergy pathways: From biomass to final energy use[73]

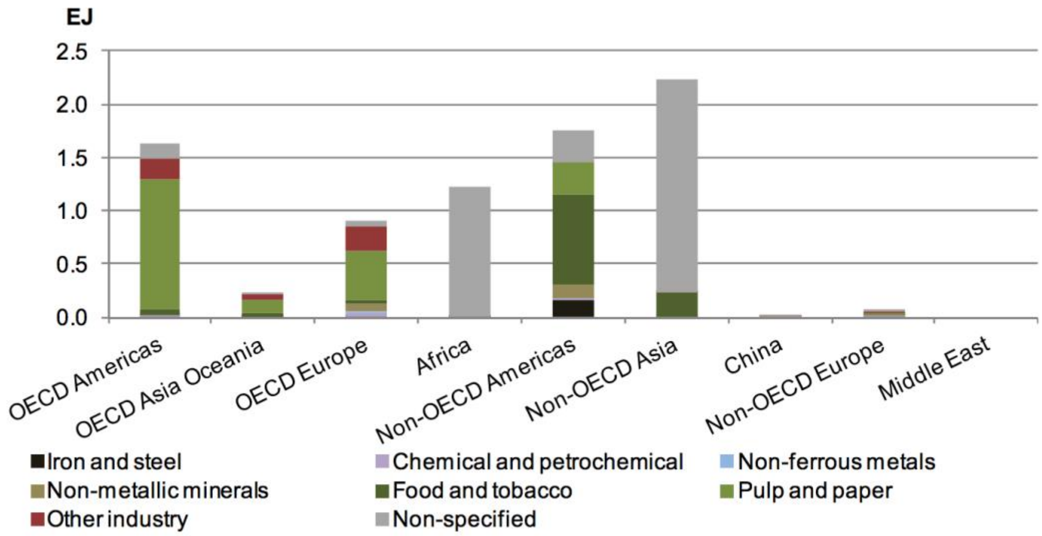


Source: IEA and FAO, 2017

Bioenergy is well-positioned to meet the temperature, pressure, and quantity of heat and steam required by many industrial processes. Bioenergy deployment is highest within industries that produce biomass wastes and residues as part of their operations, such as the pulp and paper and food industries, where it generally provides low- and medium-temperature process heat. As Figure 11 shows, globally, the pulp, paper, and food sectors account for the largest amount of current bioenergy use in most parts of the world.

[72] World Energy Council, 2016, "World Energy Resources 2016" (https://bit.ly/2tMoaUx).
[73] International Energy Agency, 2017, "Technology Roadmap: Delivering Sustainable Bioenergy" (https://bit.ly/2KoMVjU).

Figure 11. Global final bioenergy use for heat in industry by subsector in different regions, 2011[74]



Source: IEA, 2014

The largest application of modern bioenergy[75] is for heat. In 2015, bioenergy accounted for 70 percent of all renewable energy use for heat.[76] The delivery of heat for industrial processes was the largest end user (63 percent), followed by buildings (34 percent) and agriculture (3 percent).[77] However, growth has been slow—between 2010 and 2015, consumption of bioenergy in the heating sector increased at an annual average growth rate of approximately one percent.[78]

Heat requirements, technology specifications, and application are the main determinants of the best choice bioenergy resource. These factors are considered in conjunction with the energy intensity, quality and consistency of bioenergy sourced heat and its fuel source. Together, the extensive variety and flexibility of bioenergy resources, technologies and applications present a wide range of opportunities for heat production in industrial manufacturing and in buildings.

5.1.1 Biomass

a. What is biomass energy?

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[74] IEA 2014, *supra* note 2.
[75] "Modern bioenergy" excludes the traditional use of biomass in low-income households.
[76] IEA 2017, *supra* note 73.
[77] IEA 2017, *supra* note 73.
[78] IEA 2017, *supra* note 73.

Biomass energy is derived from combustion of organic material. Sources of biomass include forest wood and crop residues; organic, animal and municipal waste; crops cultivated to serve as biomass fuel, and byproducts such as black liquor, from the pulp and paper industry.

Biomass combustion technology is rapidly becoming available in the U.S. marketplace. Efficient fuel distribution systems are in place to expand the adoption of central heating systems in home and business heating, industrial process heat, district heating of whole communities, and combined heat and power (CHP).[79] Direct combustion is the most established and commonly-used technology for converting biomass to heat.[80]

b. How is biomass energy used today and how widespread is that use?

In the pulp and paper, food and tobacco industries, the share of renewable thermal energy production from biomass comprises greater than 40 percent for tobacco and greater than 20 percent for pulp and paper.[81] In Brazil, biomass in the form of high quality charcoal provides 37 percent of the heat required to produce iron and steel, effectively displacing coal in blast furnaces that produce very high temperature heat. Other bioenergy thermal energy opportunities for high temperature applications include torrefaction which produces a fuel similar in characteristics to coke and biomass gasification.

In selected commercial buildings and industries in Europe and the U.S., boilers with capacities of 100 kilowatts (kW) to 500 kW use solid biomass sources such as wood chips to produce thermal energy through a two-phase, grate furnace combustion system.[82] In these and larger applications such as district heating plants with capacities from one to 50 megawatts (MW), biomass systems incorporate fluidized bed combustion systems and boiler systems to achieve high efficiency rates.[83]

c. What is the potential for biomass energy use to meet thermal needs?

Biomass energy use is expected to grow from current levels. IEA's Medium-Term Market Report projects that by 2021, global modern bioenergy will grow by 16 percent as compared to 2014 levels across all sectors.[84]

In another study, IEA estimates that by 2060, the use of bioenergy rises by a factor of nearly three, to 24 EJ, providing nearly 14 percent of industrial energy needs.[85] In their model, the industrial sector is the greatest user of bioenergy after the transport sector. Bioenergy can help reduce emissions in the

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[79] Biomass Thermal Energy Council, "Biomass Thermal Energy FAQs" (https://www.biomassthermal.org/resource/faq.asp).
[80] BioEnergy Consult, "Summary of Biomass Combustion Technologies" (https://bit.ly/2KpjRZv).
[81] IEA 2014, *supra* note 2.
[82] IEA 2014, *supra* note 2.
[83] IEA 2014, *supra* note 2.
[84] IEA 2017, *supra* note 9.
[85] IEA 2017, *supra* note 73.

industrial sector by replacing fossil sources in both low- and medium-temperature applications (e.g. for hot water production or for drying), as well as for higher-temperature applications, such as high temperature steam supply and for direct use in kilns and furnaces.[86]

In the IEA model, growth is concentrated in the delivery of process heat and steam in non-energy-intensive industries, including food and beverage (accounting for almost 80 percent of total industrial bioenergy use in 2060 in the IEA scenario). Bioenergy also makes a growing contribution to energy demand in the pulp and paper sector.[87]

For high-temperature applications, growth is concentrated in the cement industry where some 10 percent of energy comes from biomass sources (plus a further 15 percent from other fossil-based waste materials). IEA asserts that to achieve these higher levels of biomass utilization in the cement industry, the mobilization of fuel supply chains will be necessary. Biomass-based routes for the production of chemicals, such as bioethanol dehydration to produce ethylene, account for 3 percent of total energy use in the sector by 2060. This represents ten-fold growth of bioenergy use in absolute terms compared with current levels.[88]

d. Biomass energy challenges

One challenge for scaling up biomass is the potential competition between biomass feedstocks with non-energy feedstocks. For example, there may be competition around certain forest products where stakeholders in the forestry industry pursue the products for their business, while stakeholders in the energy industry pursue the products for bioenergy. These vying interests would create competition between industries, thus increasing prices. Such competition may be present for other agricultural feedstocks as well. One recommendation is to continue analysis for deeper understanding of this issue and how it could impact markets for agriculture and forestry.

Another challenge for biomass are its environmental aspects, including the need to properly account for GHG emissions reductions and sustainable sourcing of inputs. The debate over the greenhouse gas emissions reductions from biomass is focused on the capacity to offset emissions associated with burning biomass as that carbon is sequestered in other biomass over time. The lack of a workable and clear set of GHG accounting rules for this combustion also provides a challenge. For sustainable sourcing, some advocates are seeking alternatives to burning whole trees for biomass energy generation, and, instead, to utilize short-rotation crops, wood waste and reclaimed wood, or timber harvest residue. Some environmental organizations seek a sustainably-sourced feedstock to address other environmental issues in addition to climate change, such as biological diversity.

[86] IEA 2017, *supra* note 73.
[87] IEA 2017, *supra* note 73.
[88] IEA 2017, *supra* note 73.

5.1.2 Biogas and Renewable Natural Gas (RNG)

a. What are biogas and renewable natural gas?

Biogas systems use the natural, biological process of anaerobic digestion to recycle organic waste, turning it into biogas, which is used for energy. Biogas is comprised primarily of methane (50–70 percent) and carbon dioxide (30–50 percent), with trace amounts of other particulates and contaminants.[89] Biogas can be produced from a variety of sources, including agricultural digesters, wastewater treatment facilities, and landfills.

Renewable natural gas (RNG), or biomethane, is a pipeline-quality gas that is fully interchangeable with natural gas and compatible with U.S. pipeline infrastructure.[90] There are two principal technology platforms for producing renewable gas: (1) thermal gasification and (2) anaerobic digestion. Each platform involves the production of raw gas (i.e., biogas) that is then upgraded to pipeline quality gas (i.e., RNG).[91]

b. How are biogas and RNG used today and how widespread is that use?

The U.S. produces biogas in every state with over 2,100 existing sites: 247 anaerobic digesters on farms, 1,241 anaerobic digesters in wastewater treatment plants (WWTP) (approximately 860 WWTPs currently use the biogas they produce), 54 stand-alone systems that digest food waste, and 645 landfill gas projects.[92]

To date, direct injection of renewable gas has been limited to a small number of projects in the United States, but is growing. RNG production grew from 1.4 million ethanol-equivalent gallons in 2011 to nearly 190 million in 2016.[93] However, some of this increase in RNG is aimed at delivering the gas for transportation needs.

Although less popular in the U.S., grid injection of RNG is increasing in Europe, driven mainly by feed-in-tariffs for power generation. Germany leads the market with approximately 20 plants injecting into the gas grid and approximately 40 additional plants under development or construction. Germany also has

[89] National Renewable Energy Laboratory (NREL), Oct. 2013, "Energy Analysis: Biogas Potential in the United States" (https://www.nrel.gov/docs/fy14osti/60178.pdf).
[90] American Gas Foundation, Sep. 2011, "The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality" (http://www.eesi.org/files/agf-renewable-gas-assessment-report-110901.pdf).
[91] National Grid, 2010, "Renewable Gas: Vision for a Sustainable Gas Network" (https://www9.nationalgridus.com/non_html/NG_renewable_WP.pdf)
[92] American Biogas Council, "Biogas 101" (https://www.americanbiogascouncil.org/pdf/ABC%20Biogas%20101%20Handout%20NEW.pdf).
[93] World Resources Institute, Apr. 2018, "The Production and Use of Renewable Natural Gas as a Climate Strategy in the United States" (https://bit.ly/2FVuD2J).

a national target of six percent of gas demand to be provided by RNG by 2020. The Netherlands, Austria and Switzerland also utilize RNG grid injection.[94]

c. What is the potential for biogas and RNG to meet thermal needs?

There is significant potential for growth in the U.S. biogas industry. For comparison, Europe has over 10,000 operating biogas projects, or approximately five times the number in the U.S..[95] A recent industry assessment conducted with the USDA, EPA and DOE as part of the Federal Biogas Opportunities Roadmap estimates nearly 11,000 sites have potential for development: 8,241 dairy and swine farms and 2,440 wastewater treatment plants which could support a digester (including ~381 who are making biogas but not using it) and 440 untapped landfill gas projects.[96]

The methane potential from landfill material, animal manure, wastewater, and industrial, institutional, and commercial organic waste in the United States is estimated at about 7.9 million tonnes per year, equal to about 420 billion cubic feet or 431 trillion British thermal units.[97] This amount could displace about 5 percent of current natural gas consumption in the electric power sector and 56 percent of natural gas consumption in the transportation sector.[98]

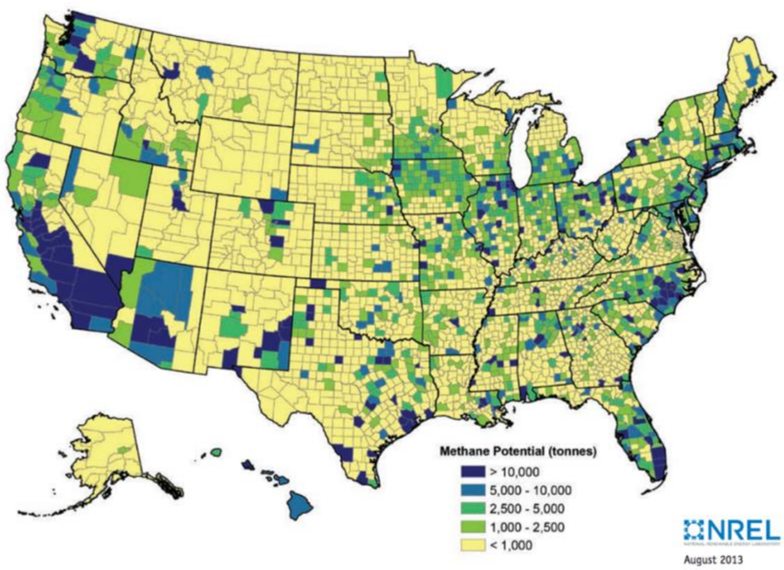
Table 2. Estimated methane generation potential for select biogas sources in the U.S.

Source	**Methane Potential (tonnes/yr)**
Wastewater	2,339,339
Landfills	2,454,974
Animal manure	1,905,253
Industrial, institutional, and commercial (IIC) organic waste	1,157,883
Total	**7,857,449**

This potential is present throughout the U.S., but is greatest along the east and west coasts, as shown in Figure 12.

[94] National Grid 2010, *supra* note 91.
[95] National Grid 2010, *supra* note 91.
[96] American Biogas Council, *supra* note 92.
[97] NREL 2013, *supra* note 89.
[98] NREL 2013, *supra* note 89.

Figure 12. Estimated methane generation potential for select biogas sources by county[99]



Source: NREL, 2013

RNG has an estimated 4.8 trillion cubic feet in the U.S. alone.[100] A study by National Grid found that RNG has the technical potential to meet up to 25 percent of the natural gas demand in the four states they serve (Massachusetts, New Hampshire, New York and Rhode Island), not including natural gas demand for power generation.[101]

In the U.S. industrial sector, RNG has the potential to displace approximately 32 percent of 2015 natural gas deliveries (or about 2.4 billion Mscf), as shown in Table 3.[102]

Table 3. RNG potential estimates as a percentage of 2015 U.S. natural gas deliveries, by customer type[103]

Customer Type	**Natural Gas Delivered (Mscf)**	**RNG Potential as % of 2015 Deliveries**
Residential	4,609,669,883	52%
Commercial	3,198,797,217	75%
Industrial	7,534,589,246	32%
Electricity Generation	9,689,827,433	25%

[99] NREL 2013, *supra* note 89.
[100] Westport Fuel Systems, "Renewable Natural Gas (Biomethane)" (http://www.westport.com/is/natural-gas/biomethane).
[101] National Grid 2010, *supra* note 91.
[102] American Gas Foundation 2011, *supra* note 90.
[103] American Gas Foundation 2011, *supra* note 90.

Customer Type	Natural Gas Delivered (Mscf)	RNG Potential as % of 2015 Deliveries
Vehicle Fuel	39,348,210	6119%
Total	**25,072,231,989**	**10%**

Source: American Gas Foundation, 2011.

d. Biogas energy challenges

Growth of the biogas sector continues to be limited due to many barriers that remain unresolved. These barriers include:

- Lack of awareness of biogas benefits or the need for renewable alternatives to natural gas among state regulators responsible for natural gas markets
- Unpredictable biogas market conditions
- Lack of market maturity
- Lack of full valuation
- Inconsistencies across federal, state, and local governments
- Lack of technical and applied research and development.[104]

5.2 Solar thermal

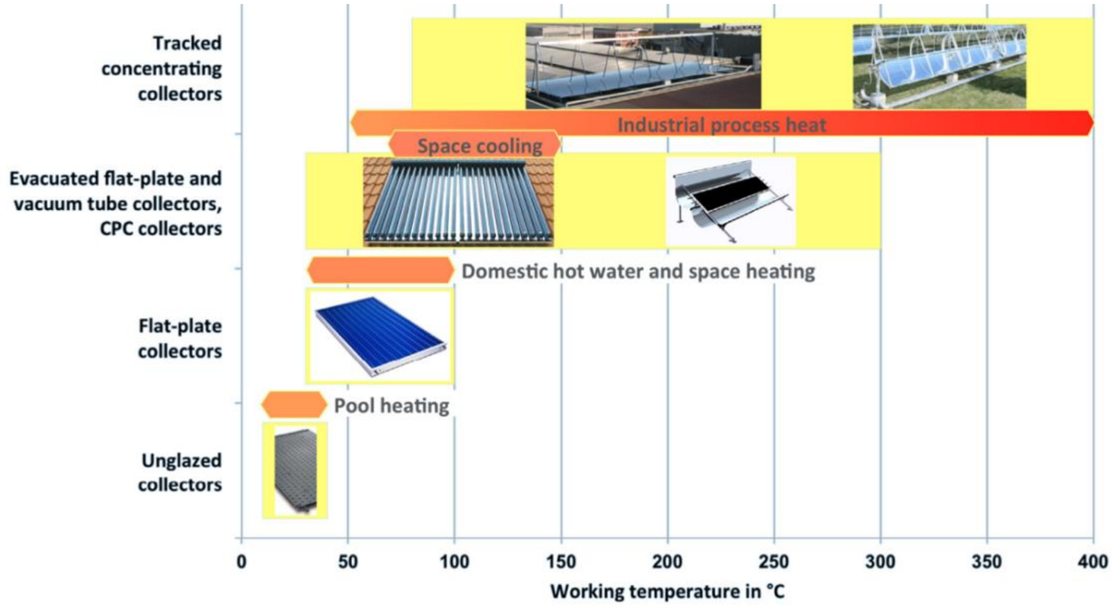
a. What is solar thermal?

Industrial process heating may utilize several different types of solar thermal systems: glazed/unglazed solar collector, flat plate solar collector, evacuated tube solar collector, and a concentrating solar power system (CSP) are some examples. Flat plate and evacuate tube solar collectors are usually used for lower temperature heat demands (up to 100°C); whereas, CSP collectors and parabolic troughs are used for higher temperature heat demands (up to 400°C).

Figure 13 summarizes the working temperature for which different applications are used.

[104] USDA, EPA, DOE, Dec. 2015, "Biogas Opportunities Roadmap Progress Report" (https://bit.ly/2MFQe2H).

Figure 13. Solar collectors and working temperatures for different applications[105]



Sources: IEA, 2014; European Renewable Heating and Cooling-Platform. Photos courtesy of Industrial Solar; Roth Werke; Solitem; Solvis; SRB Energy; Wagner & Co.

Solar thermal collectors have a high solar conversion efficiency, which is the ratio of energy produced from the panel or the collector to the energy content of the sunlight itself. Solar thermal conversion efficiency is approximately 70 percent compared to PV panels, which converts light to electricity at roughly 17 percent efficiency. Despite a high conversion rate and wide-ranging application, solar thermal energy has not been deployed widely across the industrial sector.[106]

b. How is solar thermal used today and how widespread is that use?

Solar thermal technologies can provide low, medium and high heat in industry and in buildings. Concentrating solar systems, which focus sunlight onto a small area through mirrors, can provide heat within a medium range of 150 to 450 degrees Celsius. While experimental industrial solar ovens have the potential to generate temperatures of up to several thousands of degrees Celsius to process aluminum and bronze, and fire kilns for pottery and glass.[107]

High concentrating, solar tracking technologies can produce steam for industrial electricity generation or co-generation. While experimental industrial solar ovens have the potential to generate temperatures

[105] IEA 2014, *supra* note 2.
[106] Environmental and Energy Study Institute (EESI), Dec. 2011, "Solar Thermal Energy for Industrial Uses" (http://www.eesi.org/files/solar_thermal_120111.pdf).
[107] IEA 2014, *supra* note 2.

of up to several thousands of degrees Celsius to process aluminum and bronze, and fire kilns for pottery and glass.[108]

c. *What is the potential for solar thermal to meet thermal needs?*

Across sectors, solar thermal capacity in 2030 in the U.S. could reach more than 310 GWth – as much as all the solar thermal capacity installed worldwide today.[109] With advanced solar process heat technologies, temperatures of up to 400°C can be provided, potentially fulfilling almost 50 percent of heat demand in the industrial sector.[110] Heat in the lower temperature range (<80°C) can easily be provided with systems commercially available, such as flat plate collectors and evacuated tube Collectors.

IRENA estimates that there is a technical potential to provide around 15 EJ of solar thermal heat by 2030 (around 10 percent of industrial energy demand) while the share of solar thermal deployed in the industrial sector could reach 33 percent.[111] Prime application areas for solar thermal systems are in the food, beverage, transport equipment, textile, machinery, and pulp and paper industries, where approximately 60 percent of the heating needs can be met by temperatures below 250°C.[112]

Another study found that the best opportunities for solar industrial process heating reside in the state of California due to its excellent solar resource, strong industrial base, and solar-friendly policies. Their initial analysis identified 48 TWh_{th}/year of process heat demand in certain California industries versus a technical solar-thermal energy potential of 23,000 TWh_{th}/year.[113]

d. *Solar thermal energy challenges*

High upfront costs are a barrier to solar thermal adoption, particularly for small or mid-sized companies. Large, energy-intensive industries are constrained by integration challenges, along with risk aversion and expectations of shorter payback times.[114]

Another barrier for the deployment of solar process heat is the structure of the industrial sector. Energy-intensive industries account for 75 percent of heat demand, but consist of only 30,000 to 60,000 plants.[115] For larger industrial plants, integration into existing process heating streams, as well as the lack of familiarity with the technology, constitute critical bottlenecks. The other 95 percent of the

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108 IEA 2014, *supra* note 2.
109 IRENA 2015, *supra* note 15.
110 IRENA 2015, *supra* note 15.
111 IRENA 2015, *supra* note 15.
112 IRENA 2015, *supra* note 15.
113 Kurup, P. and Turchi, C., 2016, "Potential for solar industrial process heat in the United States: A look at California" (https://aip.scitation.org/doi/10.1063/1.4949198).
114 IRENA 2015, *supra* note 15.
115 IRENA 2015, *supra* note 15.

industrial plants are small- and medium-size businesses. This means that solar process heat technologies need to be customized to provide the specific energy demand needs at individual locations.[116]

Finally, solar thermal technologies must be paired with a heat storage device, if there is a need for the thermal energy when the sun is not shining. Thermal energy storage is an area which has received little attention.

5.3 Geothermal

a. What is geothermal energy?

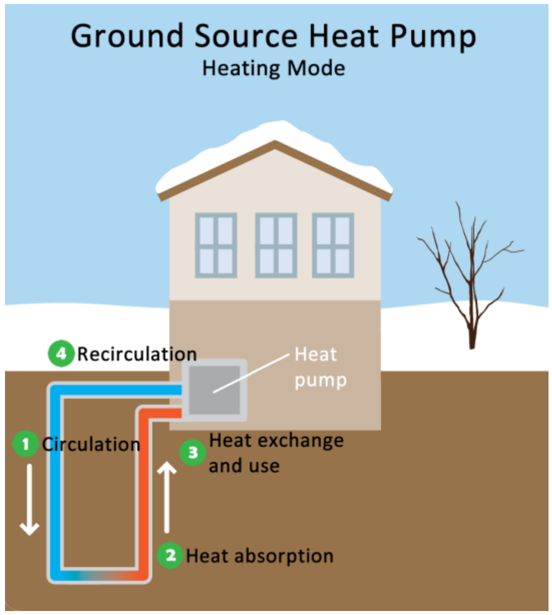
Geothermal energy is heat from the Earth. It includes reservoirs of hot water that exist at various temperatures and depths below the Earth's surface, as well as energy in the ground at shallow depths. Wells can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for use in a variety of applications, including heating and cooling. In the U.S., most geothermal reservoirs are located in western states.[117] At shallow depths, the ground maintains a nearly constant temperature between 50° and 60°F (10° and 16°C) and can be captured using ground source heat pumps. It is widely available across the U.S.

Geothermal resources can be naturally-occurring or man-made. Three main technologies utilize geothermal sources: (1) ground source heat pumps, (2) direct use geothermal, and (3) deep and enhanced geothermal systems.

A ground source heat pump takes advantage of the naturally occurring difference between the above-ground air temperature and the subsurface soil temperature to move heat in support of end uses such as space heating, space cooling (air conditioning), and water heating (Figure 14). A ground source, or geoexchange, system consists of a heat pump connected to a series of buried pipes. One can install the pipes either in horizontal trenches just below the ground surface or in vertical boreholes that go several hundred feet below ground. The heat pump circulates a heat-conveying fluid, sometimes water, through the pipes to move heat from point to point. Heat pumps are best used for low-temperature heat applications in industrial manufacturing and for heating, cooling and providing hot water in buildings.

[116] IRENA 2015, *supra* note 15.
[117] U.S. DOE, "Geothermal Basics" (http://energy.gov/eere/geothermal/geothermal-basics).

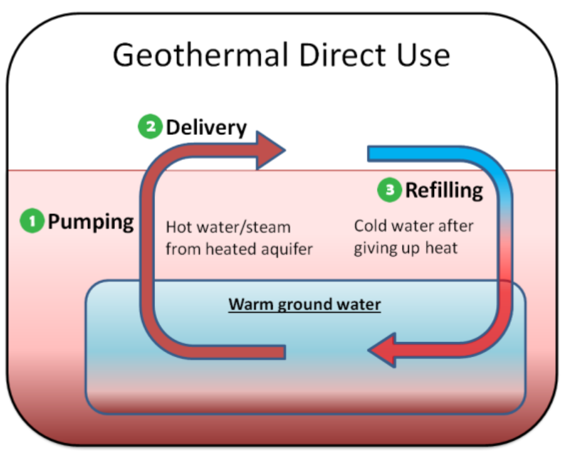
Figure 14. Geothermal Ground Source Heat Pump[118]



Source: EPA

Direct use geothermal systems use groundwater that is heated by natural geological processes below the Earth's surface. Bodies of hot groundwater can be found in many areas with volcanic or tectonic activity. Hot water can be pumped from the surface or from underground for a wide range of useful applications.

Figure 15. Geothermal Direct Use[119]

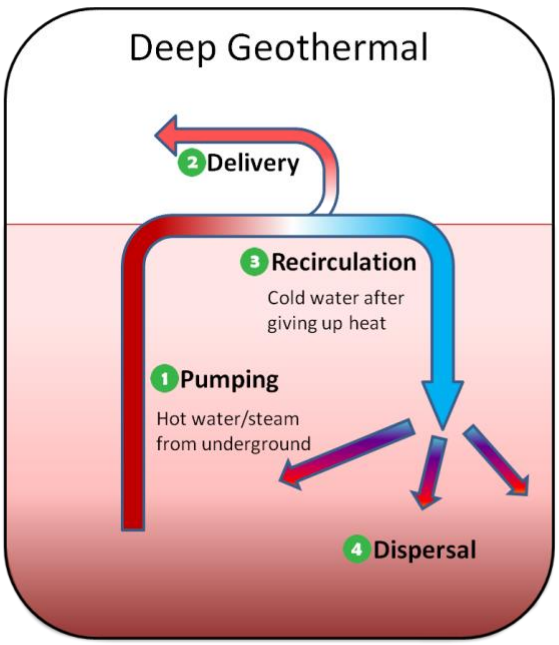


Source: EPA

[118] EPA, "Geothermal Heating and Cooling Technologies" (https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies#Direct-Use-Geothermal).
[119] *Id.*

Deep geothermal systems use steam from far below the Earth's surface for applications that require temperatures of several hundred degrees Fahrenheit (Figure 16). These systems typically inject water into the ground through one well and bring water or steam to the surface through another. Other variations can capture steam directly from underground ("dry steam"). Unlike ground source heat pumps or direct use geothermal systems, deep geothermal projects can involve drilling a mile or more below the Earth's surface. At these depths, high pressure keeps the water in a liquid state even at temperatures of several hundred degrees Fahrenheit. An Enhanced Geothermal System (EGS) is a man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. EGS technology has the potential to help meet U.S. energy needs by accessing the Earth's large heat resource, an estimated 100 gigawatt electrical (GWe), located at depth.

Figure 16. Deep Geothermal[120]



Source: EPA

b. *How is geothermal energy used today and how widespread is that use?*

Geothermal energy could provide thermal energy to food processing plants and to plants that use lower temperature heat to concentrate and/or dry process feedstocks and products, such as wet corn milling. Current geothermal energy production techniques for thermal applications usually provide lower temperature energy (typically ranging from 50–150ºC) than is required by many manufacturing

[120] EPA, *supra* note 118.

industries. Enhanced geothermal systems that could achieve higher temperature output are currently being developed.[121]

Currently, geothermal energy constitutes less than one percent of the total U.S. electricity generation, and it is mainly located in the Western states in the mountainous regions associated with active tectonic plate movement and near volcanic hot spots.[122] Since 2005, the U.S. has built over 38 geothermal power projects, adding nearly 700 MWe to the U.S. electricity capacity.[123] Globally, installed geothermal capacity for direct heat was 20.6 GW (equivalent electric power) in 2016, while installed geothermal capacity for electricity generation was 13.5 GW.[124] To date, the contribution of geothermal energy systems to the total energy mix has been limited: 0.15 percent or 0.565 EJ yr−1 of the world final energy consumption in 2015 (363.5 EJ yr−1).[125] Approximately 50 percent is used for direct heat applications.

c. What is the potential for geothermal to meet thermal needs?

By 2050, the International Energy Agency (IEA) estimate geothermal production to be 5.8 EJ yr^{-1} for heat (3.9 percent of projected world final energy for heat) and 1400 TW h yr^{-1} for electricity (3.5 percent of projected world electricity production).[126,127] In total, this production could avoid emission of almost 900 Mt yr^{-1} of CO_2.

According to IEA, In the period to 2030, rapid expansion of geothermal electricity and heat production will be dominated by accelerated deployment of conventional high-temperature hydrothermal resources, driven by relatively attractive economics but limited to areas where such resources are available. Deployment of low- and medium-temperature hydrothermal resources in deep aquifers will also grow quickly, reflecting wider availability and increasing interest in their use for both heat and power.[128]

d. Geothermal energy challenges

One of the inherent challenges with geothermal energy is that it is region-specific; it cannot be moved or transported to generation sites or near an industry compared as other renewable sources can. It

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[121] Joint Institute for Strategic Energy Analysis 2016, *supra* note 31.
[122] Joint Institute for Strategic Energy Analysis 2016, *supra* note 31.
[123] Joint Institute for Strategic Energy Analysis 2016, *supra* note 31.
[124] Limberger, L. et al, Feb. 2018, "Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization" (https://www.sciencedirect.com/science/article/pii/S1364032117313345).
[125] *Id.*
[126] International Energy Agency (IEA), 2011, "Geothermal Heat and Power Roadmap" (https://www.iea.org/publications/freepublications/publication/Geothermal_Foldout.pdf).
[127] Limberger, L. et al., *supra* note 124.
[128] IEA 2011, *supra* note 126.

must be located in regions with advantageous subsurface conditions, which do not always coincide with the locations of the industries.[129]

Further, even under ideal conditions however, the cost of geothermal production may be a limiting factor. IEA estimates that delivery of on-site geothermal heat production may cost from USD 35/MWh_{th} to USD 55/MW_{th}.[130]

5.4 Renewable electrification

a. What is renewable electrification?

Renewable electrification of industrial processes is another approach to achieve CO_2 emissions reductions. This approach entails continued electrification of energy for motion and force and electrification of heat and steam production via a series of technologies. Some technologies, such as heat pumps, are particularly effective.[131]

Total electrification requires replacing technologies that still run on combustion, like natural gas heating and cooling, with alternatives that run on electricity, like heat pumps, and powering that electricity with renewable sources. From there, there are several options to provide renewables, such as wind and solar. This concept of electrifying energy end uses that have been powered by fossil fuels (natural gas, propane, gasoline, diesel, or fuel oil) in order to reduce greenhouse gas emissions, is called "environmentally beneficial electrification."[132]

Many of the fundamental technological elements for industrial electrification exist, but much greater diversity of processes and high levels of process integration make solutions in the industrial sector more complex. Electrification of process heating can be relatively cost-effective where product quality and manufacturing productivity is improved (e.g., induction heating for metal processing), or when electricity costs are low relative to combustion fuel energy costs. Cost-effective electrification of process heating is generally more challenging at very high temperatures (e.g., cement manufacturing), where processes are highly integrated, where combined heat and power is extensively utilized, and where natural gas prices are very low.[133]

b. How is renewable electrification used today and how widespread is that use?

In 2017, electricity sales comprised about 14 percent of site energy in the industrial sector. High energy-consuming sectors (oil and gas refining, chemicals, and iron and steel) are dominated by non-

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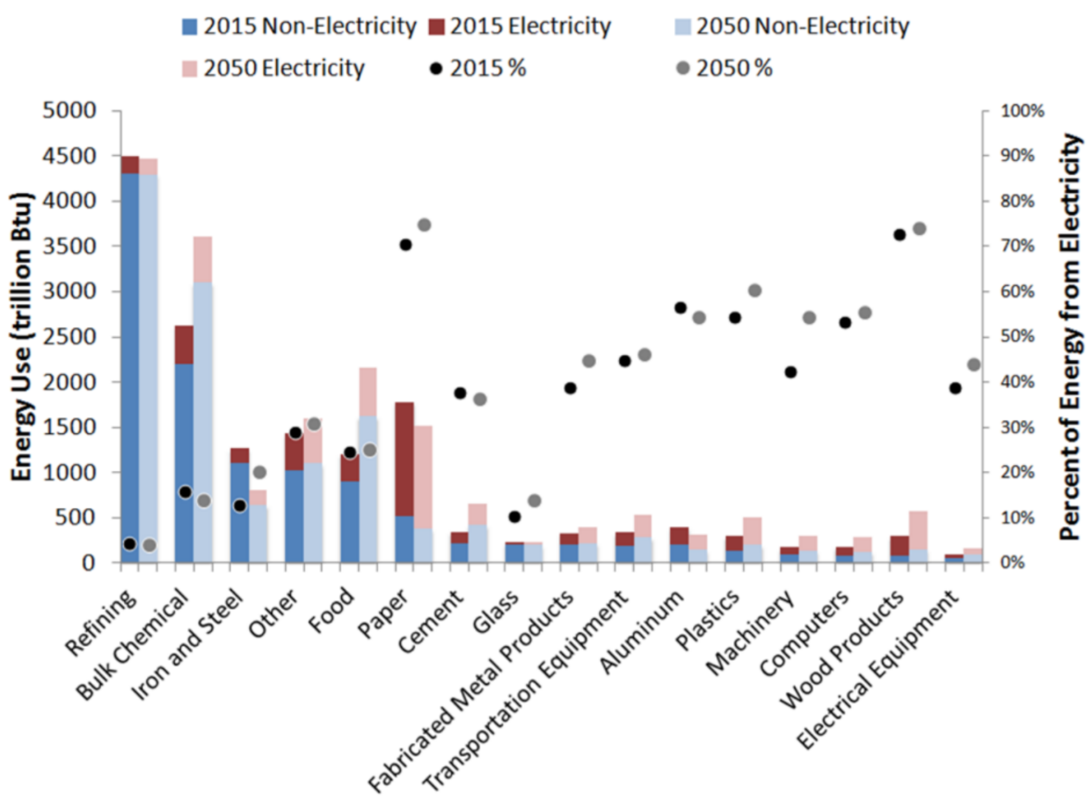
[129] Joint Institute for Strategic Energy Analysis 2016, *supra* note 31.
[130] IEA 2014, *supra* note 2.
[131] IEA 2017, *supra* note 59.
[132] Dennis, K., 2015, "Environmentally Beneficial Electrification: Electricity as the End-Use Option." (https://bit.ly/2lNZOVN).
[133] LBNL 2018, *supra* note 16.

electricity fuel use. The fraction of end-use electricity consumption is projected to be fairly stable from 2015 to 2050. In 2017, about 17 percent of U.S. electricity production came from renewable sources.[134] For electrification to work, renewable electricity must scale up rapidly. Figure 17 summarizes electricity and non-electricity fuel use by industrial sector in 2015 and projected demands in 2050 according to the 2017 Annual Energy Outlook 2017.[135]

Figure 17 Electricity and non-electricity fuel use by industry sector in 2015 and projection to 2050[136]



Source: EIA, 2017

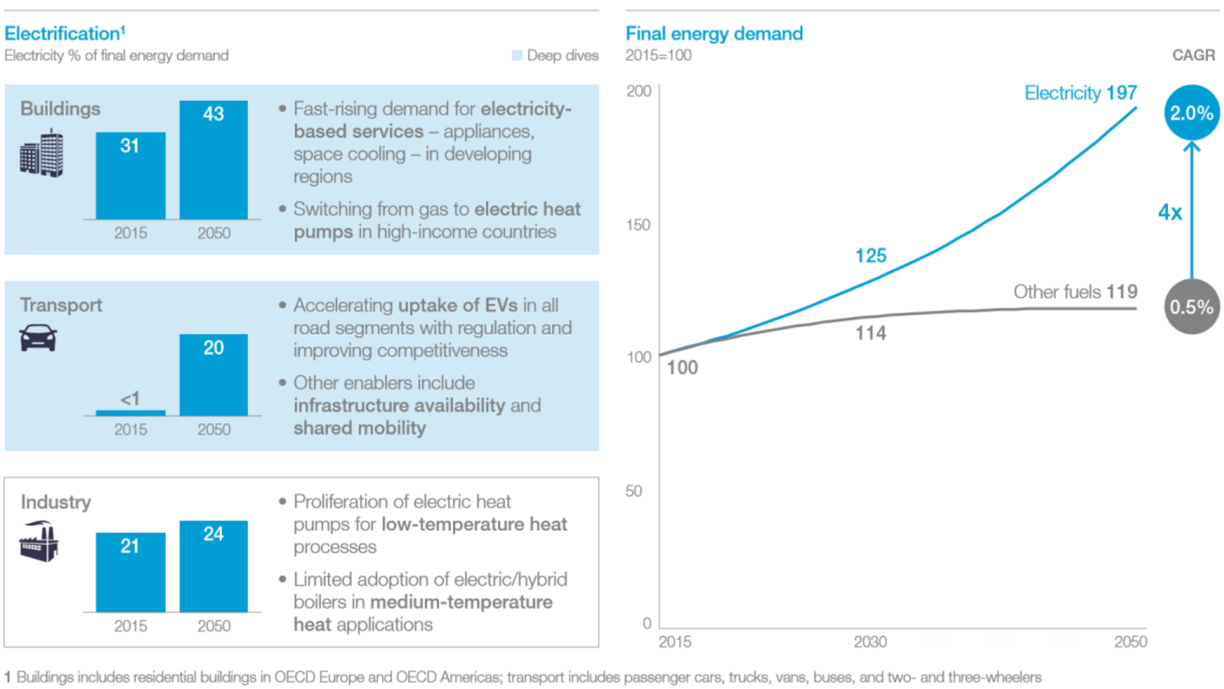
c. *What is the potential for renewable electrification to meet thermal needs?*

Electrification across key end uses, as shown in Figure 18, results from acceleration of electricity demand relative to demand for other fuels. In the industrial sector, McKinsey estimates that the percentage of electricity comprising final energy demand will grow from 21 percent in 2015 to 24 percent in 2050.[137] This growth would be due to proliferation of electric heat pumps for low-temperature

[134] EIA, "Electricity Explained; Electricity in the United States", (https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states).
[135] LBNL 2018, *supra* note 16.
[136] LBNL 2018, *supra* note 16.
[137] McKinsey, Dec. 2017, "Global Energy Perspective: Reference Case 2018" (https://gep.mckinseyenergyinsights.com/).

heat processes and adoption of electric/hybrid boilers in medium-temperature heat applications. McKinsey estimates that in buildings, the percentage of electricity comprising final energy demand will grow from 31 percent in 2015 to 43 percent in 2050. This potential growth would be due to electricity-based services in developing countries and switching from gas to electric heat pumps in high income countries.

Figure 18. Electrification across key end uses[138]



Source: McKinsey Energy Insights' Global Energy Perspective, 2017

Overall the potential is very high for high-temperature process heating sectors (i.e., cement, glass, iron and steel), and thus the technical potential in lower temperature process heating sectors not shown here is also essentially 100 percent.[139]
Table 4 summarizes technical electrification potential of the industrial sector analyzed in three recent studies.

Industries such as fabricated metal products, iron and steel, wood products, and plastics have a high potential for electrification, while industries such as paper mills and petroleum have a low potential for electrification, according to LBNL.[140] Another study by Northeast Energy Efficiency Partnerships (NEEP) states that much of the fuel usage used for process heating can be electrified by focusing on commercially available technologies in two key applications: glassmaking and production of iron, steel,

[138] *Id.*
[139] LBNL 2018, *supra* note 16.
[140] LBNL 2018, *supra* note 16.

and other metal products.[141] For both glassmaking and steel production, the primary electrification technology is electric furnaces. In the production of chemicals and food, however, most process heat is delivered along with moisture, in the form of steam. High-quality steam (i.e., steam at a high temperature and with a sufficient ratio of water vapor to air) is generally produced in fossil-fired boilers or as an output of on-site combined heat and power generation. Some uses of steam can be electrified by conversion to direct electric heating, however the favorable properties of steam mean that most electrification of steam generation must be through replacement of fossil heat as applied to water with heat produced using electricity. Full electrification of steam generation depends on completely replacing fossil-fired boilers with electric technologies. The simplest and most common of these technologies is electric boilers based on resistive heating.[142]

Another study by the National Renewable Energy Laboratory (NREL) found in one modeled scenario that aggressive electrification could also lead to adoption of industrial electrotechnologies: 63 percent of curing needs, 32 percent of drying services, 56 percent of other process heating and a range of other industrial end-uses by 2050 would be electrified.[143]

Table 5 summaries onsite fuel consumption, representative process temperatures, and general outlook for electrification in industrial sectors.

[141] NEEP, Jul. 2017, “Northeastern Regional Assessment of Strategic Electrification” (https://bit.ly/2wxpBJU).
[142] *Id.*
[143] National Renewable Energy Laboratory (NREL), 2008, “Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States” (https://www.nrel.gov/docs/fy18osti/71500.pdf).

Table 4. Electrification potential summary of three recent industry electrification studies[144]

Sector	Direct Electrification of Process Heating -- Potential by 2050	Reference	Technologies
All sectors – conventional boilers	100%	Steinberg et al. (d)	All conventional boilers electrified
Cement	100% (a)	Lechtenböhmer et al. 2016; Purr et al. 2014	Electrification of end uses (e.g., plasma-based heating), electrolysis production of hydrogen, and renewable natural gas production for fuel
Chemicals	100%	Steinberg et al. 2017(d)	Industrial process heat pumps
Chemicals (chlorine and ammonia)	100% (b)	Lechtenböhmer et al. 2016	Electrification of end uses, electrolysis production of hydrogen
Chemicals (petrochemicals)	0% (c)	Lechtenböhmer et al. 2016	No direct electrification; fossil fuels replaced by electrolysis production of hydrogen and renewable natural gas production for both process fuel and petro chemical feedstocks
Food	100%	Steinberg et al. 2017(d)	Industrial process heat pumps
Food	100%	Purr et al. 2014	Various electro technologies
Glass	100%	Steinberg et al. 2017(d); Lechtenböhmer et al. 2016; Purr et al. 2014	Electrification of end uses, resistance heating and melting
Iron and steel	21%	Steinberg et al. 2017(d)	Electric arc furnaces
Iron and steel	100%	Lechtenböhmer et al. 2016; Purr et al. 2014	Electric arc furnaces, electrowinning; plasma or induction ovens for smelting
Lime	100%	Lechtenböhmer et al. 2016	Electrification of direct end uses
Metal fabrication	100%	Steinberg et al. 2017(d)	Induction heating
Metal fabrication (foundries)	> 50%	Purr et al. 2014	Electric furnaces
Nonferrous metals, excluding aluminum	100%	Steinberg et al. 2017(d)	Electrolytic reduction
Pulp and paper	100%	Steinberg et al. 2017(d)	Industrial process heat pumps

(a) Purr et al. 2014 describes the transition away from fossil fuel-based heating in the production of cement to a combination of electrification of direct end uses, electrolysis production of hydrogen, and renewable natural gas production for fuel. Electrification potential is quoted as 100% here, because this report also states that high temperature furnace processes for cement can be fully electrified.

(b) Electrolysis-produced H2 is used as a feedstock for ammonia.

(c) Zero direct electrification of end uses is assumed, but electricity is used extensively for hydrogen and syngas/Fischer-Tropsch naphtha production.

(d) Steinberg et al. 2017 recently modeled the impact of high electrification of end uses by 2050 on the US electricity grid. The Steinberg et al. study is largely based on market potential analysis conducted by the Electric Power Research Institute (EPRI 2010). The "high electrification scenario" in Steinberg et al. assumes the following: (i) all conventional boilers converted to electric boilers by 2050; and (ii) all process heating is 100% electrified by 2050 in the following sectors: electrolytic reduction of nonferrous metals (excluding aluminum), induction heating for metal fabrication, resistance heating and melting for glass, and industrial heat pumps in the food, pulp and paper, and chemicals sectors. Iron and steel is assumed to be 21% electrified by 2050. This cap is due to "the nascence of the arc furnace production route and the limits to available scrap that would be required for expanded arc furnace production." Key electro-technologies include induction melting, resistance heating and melting, and heat pumps.

Table 5. Industrial sector breakdown of onsite fuel consumption, representative process temperatures, and general outlook for electrification[145]

Industrial Sector	Boiler System	CHP	Process Heating	Facility HVAC	High temperature process steps [Brown, 1996]	Temp L/M/H	Approximated Potential for Electrification	Disposition for electrification
	Percentage On-site Fuel Consumption							
Primary Metals excluding steel	3.9%	7.4%	74.8%	5.8%	Primary Al Furnace 2200F (1200C); Copper furnace 1200C; Zinc Furnace (1260C)	HIGH	HIGH	Induction melting candidate
Fabricated metal products	7.2%	6.6%	61.2%	19.7%	Al sheet, foil furnace melting 1250F (680C); preheating 1000F (540C); annealing 800F (430C)	HIGH	HIGH	Induction heating/melting candidate, but low overall energy consumption
Machinery	4.2%	4.2%	38.9%	45.8%	Farm and construction equipment Heat Treatment 1350F (732C)	HIGH	HIGH	Induction heating candidate, but low overall energy consumption
Iron and Steel Mills	0.0%	0.0%	87.0%	4.1%	Blast furnace 2600F(1430C) Basic oxygen furnace 2800F (1540C)	HIGH	HIGH	Electric arc furnace; electrowinning
Wood Products	4.8%	14.3%	50.0%	9.5%	Fiberboard Stabilization/Drying 350F (180C)	MED	HIGH	Good candidate for electrification, but low overall energy consumption
Transportation equipment	13.6%	12.1%	32.6%	31.1%	Motor vehicle car body Drier 300F (150C); Vehicle parts Furnace 2900F (1600C)	MED/ HIGH	HIGH	Driers ok for electrification but furnace challenging; but low overall energy consumption
Plastics and rubber products	19.4%	24.3%	33.0%	20.4%	Polystyrene Heater 500F (260C); Synthetic Rubber Dryer 180F (82C)	LOW/ MED	HIGH	Good candidate for electrification, but low overall energy consumption
Food and beverages	25.0%	40.3%	24.9%	4.2%	250-350°F boiler (121-149°C); 450°F (232°C) baking oven; 930°F charcoal regen. (cane sugar) (499°C); 600°F lime kiln (beet sugar) (316°C)	MED/ HIGH	MED	Good candidate except high degree of CHP systems
Chemical manufacturing	16.8%	43.0%	32.0%	1.3%	H2, Ammonia – 1550°F furnace (840°C), Ammonia 600°F boiler (315°C); Pharma. 250°F (121°C) boiler, drying; Ethanol cooker/dryer 212°F (100°C) Boiler 250°F (121°C)	HIGH	MED	See text for basic chemicals e.g., Ammonia, chlorine; and for petro chemicals; high degree of CHP systems
Paper Mills	10.0%	63.3%	21.2%	2.2%	Pulp/Paperboard mill lime kiln 1200F (650C)	HIGH	LOW	High degree of integrated process design (high CHP)
Non-metallic mineral proc	0.6%	1.4%	90.1%	3.2%	Flat glass (2900°F, 1593°C furnace, 1600°F (870°C) final heat treatment; Cement 2700°F (1482°C) dry kiln; Brick 2100°F (1149°C) kiln	HIGH	LOW	Very high temperatures make this challenging but technically possible
Petroleum and coal products manufacturing	11.4%	22.0%	57.9%	0.4%	e.g.: Catalytic cracking 900°F (482°C), Catalyst reforming 1000°F (538°C), Boiler 422°F (217°C)	HIGH	LOW	Hard b/c high degree of process design and own-use fuel consumption

Note: MECS 2010 does not specify end-use fuel uses for all industrial subsectors. In particular, the "Other" unspecified component of fuel use is a large component for many sectors. We use the reported fuel use for specified end uses for the percentages above and do not attempt to allocate any of the Other unspecified fuel uses.

[144] LBNL 2018, *supra* note 16.
[145] LBNL 2018, *supra* note 16.

d. Renewable electrification challenges

One major challenge associated with electrifying the industrial sector for heating is the temperature required for the end use. Most industrial processes are not currently designed to use electricity and electrified alternatives are not currently available for many applications. The maximum temperature provided by heat pumps in limited and may not be sufficient for some applications. Higher temperature heat pumps are beginning to emerge on the market but are not yet widely available. New buildings are typically the easiest end users to electrify.

Another barrier is the operating economics of electrified end uses relative to direct use of combustion fuels. The price of natural gas has dropped recently, while the cost of electricity has been flat or rising, making the relative cost of energy more unfavorable for electricity.[146]

Further, the industrial sector has a diversity of sub-sectors and products and a variety of process heating modules and applications. This diversity of processes may present a barrier since each industry sub-sector and product can have its own process heating requirements and product specifications that require application-specific designs and performance requirements for electrified processing.[147]

And, finally, electricity production from renewable sources must accelerate rapidly to ensure renewable electrification.

7. Challenges and Barriers to Scaling Up the RHC Market

As described in previous sections, there are technology-specific barriers to scaling up renewable thermal technologies. Several other general barriers exist in the commercial and industrial sectors to scale up RHC, beyond the obvious challenge of low natural gas prices. Barriers include information barriers, market barriers, and financing and policy barriers:

5.1 Supply

- **Limited by Geography.** The supply of renewable thermal technologies is often limited by geography, as some regions have limited access to biomass, sun, or geothermal resources.

- **Disaggregated supply and general disconnect between RHC demand and supply**. RHC buyers have limited tools available to map out feedstock and technology opportunities relative to their demand in specific geographic locations. This makes it challenging to develop a systematic and comprehensive strategy to evaluate RHC opportunities. The supply of RHC is typically very disaggregated, in part because costs for transporting the feedstocks, such as biomass, are

[146] LBNL 2018, *supra* note 16.
[147] LBNL 2018, *supra* note 16.

prohibitively expensive (biomass feedstock considerations are typically limited to a 50-mile radius). Moreover, thermal energy cannot travel long distances (cost-effective delivery of LFG is typically limited to a 10-mile radius). As a result, it often makes economic sense to create RHC on site or very near to the user, or to convert feedstock to biogas which can be transported economically through existing pipelines.[148]

- **Matching Supply and Demand.** For industrial uses, there is a need to match diverse supply with diverse temperature needs, which adds significant complexity to decision-making.

- **Biomass Supply.** It is unclear if there is an adequate supply of sustainable biomass to meet projected needs.

- **Limited scale of certain RHC technologies.** RHC projects may be inadequate to meet the thermal load requirements for large manufacturers. In some applications, renewable heating projects might only address a portion of a facility's total heating energy use.[149] It also appears as if very few technologies are widely available to meet high-temperature industrial needs.

5.2 Market Barriers

- **Low natural gas prices.** Renewable thermal technologies face stiff competition from fossil fuels, including low natural gas prices in the U.S.

- **Lack of information regarding RHC technology.** Many policymakers, consumers, and industrial facility managers are unfamiliar with RHC technologies and their benefits. A lack of information about RHC technologies may be due to a low level of exposure to the technologies, lack of effective marketing by suppliers, and absence of technical assistance programs. A further factor may be the lack of data on the carbon footprint of heating and cooling demand, which requires further analysis.[150] RHC buyers need a standard set of definitions for the technology options available to them. At a minimum, this would be helpful in order to identify whether a particular RHC technology qualifies as renewable. In addition, this would enable RHC policies and incentives to be applied in the most effective manner.

- **Low turnover rates for heating capital stock equipment.** Typically, commercial HVAC and water heating systems have long replacement cycles and low annual refurbishment rates. Given the significant capital expense, property owners may be more inclined to make incremental repairs to older, less efficient systems than to invest in new RHC technologies. Low refurbishment and replacement rates reduce the opportunity to scale deployment of RHC

[148] IEA, 2018, "Renewable heat policies: Delivering clean heat solutions for the energy transition" (http://www.iea.org/publications/insights/insightpublications/Renewable_Heat_Policies.pdf).
[149] EPA 2016, *supra* note 45.
[150] IEA-RETD 2015, *supra* note 1.

markets quickly. For example, most commercial buildings replace heating systems only once every 15 to 30 years, and so the decisions that building owners make today will influence the RHC market for the next several decades.[151]

- **Difficulty tracking or gaining ownership of environmental attributes from RHC projects.** Specific attribution for individual RHC projects relative to broader natural gas use is challenging, unlike renewable electricity projects. State Renewable Portfolio Standards have been historically designed to measure electricity, not thermal, which can pose a barrier to accounting for the value of RHC projects.[152] A weak accounting instrument means that, among other things, the signal to the market from buyers of RHC is not "loud enough", which conceals the increasing demand from interested RHC suppliers.

  One physical challenge that relates to this accounting issue is that many renewable heat sources are not equivalent to their fossil fuel analog. For example, the electrons produced by a wind turbine are identical to those produced by a coal-fired facility. However, the biogas produced by a landfill or anaerobic digester is not identical to pipeline quality natural gas – which either limits the use of the biogas or imposes extra costs to scrub it to pipeline equivalency.

- **Split incentives.** In the case of commercial rental properties, depending on lease structure, the building tenant may be responsible for paying energy costs; however, the landlord makes investment decisions related to building heating system upgrades. In such cases, the landlord is typically not incentivized to invest in technologies that potentially reduce energy cost unless system costs can be passed on to the tenants, who benefit from reduced utility bills.

5.3 Policy Barriers

- **Few supporting policies.** Historically, RHC has not been recognized as a policy priority and has only been supported by extremely limited specific incentives. Further, renewable energy policies typically focus on electricity generation, rather than heating and cooling. More than 120 countries in all world regions have introduced policies designed to promote renewable electricity, whereas only around 40 have specific policies for renewable heat, most of which are within the European Union.[153]

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[151] IEA-RETD 2015, *supra* note 1.
[152] However, several states have begun incorporating renewable thermal power for heat generation into their RPS as a way to support the development and market growth of renewable thermal technologies, although there is significant variation in terms of which renewable thermal technologies are eligible. *See, e.g,* Clean Energy States Alliance, Apr. 2015, "Renewable Thermal in State Renewable Portfolio Standards" (https://www.cesa.org/assets/Uploads/Renewable-Thermal-in-State-RPS-April-2015.pdf).
[153] IEA-RETD 2015, *supra* note 1.

8. Recommendations

Stakeholders should consider the following preliminary list of recommendations to overcome barriers to scaling up renewable thermal technologies:

- Engage in outreach to policymakers and key opinion leaders to:
    - Raise awareness and articulate growing demand for renewable heating and cooling;
    - Develop and promote a common language for discussion of renewable heating and cooling technologies and topics among policymakers and the general public in order to reduce confusion and help those less knowledgeable understand the issues;
    - Provide guidance for policymakers to help develop long-term plans to guide market development efforts for renewable heating and cooling (e.g., establishing credible and realistic targets for deployment, performance-based incentives).
- Convene stakeholders across technology types, sectors, and geographic regions, for example, to:
    - Articulate the growing demand for renewable heating and cooling technologies among companies, cities, and states, as well as shared principles for market expectations;
    - Improve data collection and tracking of thermal energy end-use and emissions data, that agencies like EPA do not track;
    - Identify ways to overcome market disaggregation and support collaborative project approaches (e.g. industrial park or anchor-tenant solutions);
    - Map viable technology options by geography and end-use (e.g., build out
    - Figure *4*, which maps technology to end-use, to be more specific about end uses and sectors);
    - Develop government partnerships to drive down soft-costs and greater research and development;
    - Work with policymakers and utilities to overcome split-incentives and provide other support for renewable thermal technologies.
- Develop action plans to address technology gaps and barriers to further deployment of renewable thermal technologies, for example, to:
    - Assess sustainable feedstock availability to determine growth potential for sustainable bioenergy;
    - Develop a vision or roadmap for thermal electrification;
    - Develop a thermal Renewable Energy Credit to track and validate thermal energy projects;
    - Develop consensus around inadequate accounting methodologies.

9. Conclusion

Renewable thermal technologies, including biomass, biogas, geothermal, landfill gas, and solar thermal, have significant potential to reduce carbon emissions in industry and buildings. However, there are a range of information, market, and financial barriers that prevent these technologies from scaling up. A range of educational, policy, and market approaches are needed to realize the full potential and benefits of renewable heating and cooling.

Appendix A: The Renewable Thermal Collaborative

The Renewable Thermal Collaborative (RTC) serves as the leading coalition for large thermal energy users that are committed to scaling up renewable heating and cooling within their facilities to dramatically cut carbon emissions. RTC members recognize the growing demand and necessity for renewable heating and cooling and the urgent need to meet this demand in a manner that delivers sustainable, cost-competitive options at scale. As a coalition, the RTC offers value to its members by collectively identifying opportunities to integrate renewable thermal technologies into industry operations. By collectively understanding opportunities and constraints within markets for energy resources, RTC members have the opportunity to learn from each other in overcoming barriers and taking advantage of opportunities to deploy renewable heating and cooling. RTC members leverage its collective efforts to research and share experiences in application of these technologies as well as to drive market transformation within the industrial sector to reduce carbon emissions.

RTC founding members are Cargill, General Motors, Mars, Kimberly Clark, Proctor & Gamble, and the City of Philadelphia. RTC's collaborative efforts are facilitated jointly by the Center for Energy and Climate Solutions, David Gardiner and Associates, and the World Wildlife Fund, and is an initiative of the Renewable Energy Buyers Alliance (REBA). As the central platform coordinating efforts to expand large buyer's access to renewable energy options, REBA works with energy buyers, suppliers and policy makers to identify barriers to procuring clean and renewable energy and develop solutions that meet rapidly growing demand. REBA is led by four non-profit organizations, the World Wildlife Fund, the World Resources Institute, the Rocky Mountain Institute and BSR, who bring together their deep expertise in transforming energy markets and complementary programs. Together, REBA's partners, The Climate Group's RE100 campaign, delivered in partnership with CDP, are committed to helping corporations purchase 60GW of additional renewable energy in the U.S. by 2025.

Appendix B: Summary Tables

Table 6. Summary of Renewable Heating and Cooling Technology Types, Buyers, and Suppliers

Technology Type	Project Examples
Biogas/ Anaerobic digesters	**Campbell Soup Company Biogas Facility (Napoleon, OH)** • The biogas power plant directs waste generated from soup, sauce and beverage production, diverting 35-50 percent of its current waste away from Henry County landfills • The power generated for the beverage facility will replace about 25 percent of the facility's annual electricity use • A 15-year power purchase agreement will allow Campbell to use all the electricity generated at a flat cost • Campbell Soup partnered with CH4 Biogas to complete the project in 2013 • Additional background here and here **Cargill Meat Processing Plants**[154] • Cargill meat plants in North America reclaim methane from wastewater lagoons and use the biogas to fuel their facilities. Biogas has displaced 20-25 percent of natural gas demand at Cargill's North American beef processing plants.
Wastewater treatment facilities	**False Creek Community (Vancouver, Canada)**[155] • The Neighbourhood Energy Utility (NEU) provides heat and hot water to the Southeast False Creek community, including the Olympic Village, the first utility in North America to use waste heat recovery from untreated urban waste water. Integrated with a sewage pumping station, the Center recovers heat from untreated urban wastewater, a renewable energy source. Similar to a geothermal application, heat pumps transfer the energy to hot water distribution system. **Metropolitan Wastewater Department (San Diego, CA)** • This project utilizes cogeneration using LFG. Methane is a by-product produced in the digesters at the Metro Biosolids Center (MBC), and in the adjacent Miramar Landfill. Methane produced by the MBC on-site digesters and from the adjacent landfill is converted to electricity which is used to run the facility. Thermal energy produced by the generators is used to heat the MBC, as well as air condition the facility through a process called absorption chilling.[156] **Water Pollution Control Plant (San Jose, CA and Santa Clara, CA)**

[154] National Biosolids Partnership, "The Potential Power of Renewable Energy Generation From Wastewater and Biosolids Fact Sheet" (http://www.cargill.com/corporate-responsibility/responsible-supply-chains/environmental-performance/index.jsp).
[155] Vancouver Green Capital, "Neighbourhood Energy Utility" (http://vancouver.ca/docs/planning/renewable-energy-neighbourhood-utility-factsheet.pdf).
[156] U.S. EPA, Feb. 2016, "Water & Energy Efficiency in Water and Wastewater Facilities" (https://www3.epa.gov/region9/waterinfrastructure/technology.html).

Technology Type	Project Examples
	• This plant is the largest advanced facility on the West Coast, serving 1.4 million people and 16,000 businesses across eight cities. • Currently, plant operations require about 10.8 MW daily. Of this amount, the plant generates about 5.6 MW of electricity and 3 MW equivalent of compressed process-air by running six internal combustion engines and three engine-driven compressors on a blend of two-thirds biogas (produced from on-site digesters and the adjacent Newby Island landfill) and one-third purchased natural gas. • This total of 8.6 MW produced offsets approximately 75 percent of the Plant's electricity needs. All of the plant's digester-produced biogas is used by the engines, and the waste heat from the engines is used to heat the digesters and several support buildings. The plant's estimated annual cost savings from this project is approximately $4 million. Plant officials anticipate that the facility will become energy self-sufficient by 2022.[157]
Landfill gas capture	**Cargill Landfill Gas Energy Project (Fayetteville, NC)** • This project converts LFG collected from the Cumberland County Landfill, which has approximately 1.65 million tons waste-in-place. • The converted gas is used to fuel a steam boiler, which suppliers approximately 20 percent of the facility's fossil fuel needs, and a process heater at the nearby Cargill oilseed processing plant (steam boiler and process heater consume a combined 30 million Btu per hour). • The fuel is transported through a two-mile pipeline that runs under the Cape Fear River. **BMW Manufacturing Landfill Gas Energy Projects (Greer, SC)[158]** • Nearly 70 percent of BMW's energy consumption comes from LFG. • This project is the first automotive paint shop to integrate use of LFG in process equipment in the world. • A 9.5-mile pipeline crosses a river, two creeks, an interstate, and BMW's test track, delivering about 4,800 scfm of filtered and dehydrated landfill gas. • According to BMW, a reduction of CO_2 emissions equivalent to driving 105 million miles per year, or more than 4,000 times around the earth. **General Motors Ft. Wayne Truck Assembly Plant (Fort Wayne, IN)[159]** • An 8-mile pipeline delivers LFG from Macbeth Road Landfill.

[157] *Id.*
[158] U.S. EPA, Mar. 2016, "Project Profile: BMW Manufacturing Landfill Gas Energy Projects" (https://www3.epa.gov/lmop/projects-candidates/profiles/bmwmanufacturinglandfillg.html).
[159] U.S. EPA, Mar. 2016, "Project Profile: General Motors Ft. Wayne Truck Assembly Plant" (https://www3.epa.gov/lmop/projects-candidates/profiles/generalmotorsftwaynetruck.html).

Technology Type	Project Examples
	• LFG supplies about 16 percent of the plant's energy needs, saving $500,000 annually. • EPA's LMOP Energy Partner of Year awarded to GM in 2003. **Granger Energy and Rolls-Royce (Indianapolis, IN)**[160] • Granger approached Rolls-Royce about using surplus LFG from the South Side Landfill to fuel the manufacturing plant. • In 1999, Rolls-Royce signed a partnership agreement with Granger, who is the project developer, gas lessor, and project co-owner. • Granger supplies LFG to the boilers, which produce steam to support the company's aircraft engine manufacturing operation. **Kimberly-Clark LFG Energy Project (Beech Island, SC)**[161] • LFG fuels part of Kimberly-Clark's largest manufacturing facility in North America. • Landfill Size is 2.89 million tons waste-in-place as of 2009 • The use of LFG is expected to save $800,000 per year.
Renewable Natural Gas	**Newtown Creek Wastewater Treatment Plant (New York, NY)**[162] • National Grid and New York City Department of Environmental Protection are working together to deliver RNG from the largest wastewater treatment plant in New York City. • This will be one of the first projects in the United States that directly injects RNG into the distribution system by utilizing digester gas from a wastewater treatment plant. • The project will inject enough gas to provide heat to approximately 2,500 homes and reduce CO_2 emissions by about 16,000 tons annually (equal to CO_2 emissions of approximately 3,000 cars).
Biomass	**Procter & Gamble 50 MW Biomass Facility (Albany, GA)**[163] • 50-megawatt (MW) biomass plant to run one of P&G's largest U.S. manufacturing facilities • Constellation will build, own and operate the $200M cogeneration plant, which will supply steam to P&G paper manufacturing facility and generate power for the local utility, Georgia Power • Plant will provide 100 percent of the steam and up to 60-70 percent of the total energy used by the facility • P&G worked with WWF to create sustainable fuel supply "procurement standards" • Scheduled to begin commercial operation in June 2017

[160] U.S. EPA, Mar. 2016, "Project Profile: Granger Energy and Rolls-Royce" (https://www3.epa.gov/lmop/projects-candidates/profiles/grangerenergyandrollsroyc.html).
[161] U.S. EPA, Mar. 2016, "Project Profile: Kimberly-Clark LFG Energy Project" (https://www3.epa.gov/lmop/projects-candidates/profiles/kimberly-clark.html).
[162] National Grid 2010, *supra* note 91.
[163] P&G, Mar. 18, 2015, "Procter & Gamble, Constellation and Community Celebrate One of Nation's Largest Biomass Renewable Energy Plants" (https://bit.ly/2NilFS0).

Technology Type	Project Examples
	Lindt USA Biomass Project (Stratham, NH)[164] • Lindt will deliver shells to PSNH's Schiller Station power plant in Portsmouth, N.H., to be used as a supplementary fuel source. • Every ton of cocoa bean shells used to generate electricity will replace the need to burn one half-ton of coal, which also helps the utility reduce a portion of its coal-producing power with biomass
Solar thermal systems	**Gatorade Manufacturing Facility (Tolleson, AZ)[165]** • In June 2008, Gatorade, under its parent company PepsiCo, announced plans to install solar thermal water heaters on the roof of their manufacturing facility in Tolleson, Arizona. Gatorade hired Austrian solar manufacturer S.O.L.I.D. GmbH, and their U.S. subsidiary, S.O.L.I.D USA, to install a total of 85 flat plate collectors covering a combined surface area of 893 m^2 (9,605 ft^2). The collectors were installed in just three months, and went into operation on December 31, 2008. Gatorade now uses the system to preheat water to a temperature of 35°C (95°F). While the collectors have the capacity to produce temperatures above 35°C, Gatorade does not need hotter temperatures. In fact, the system actually includes a safety mechanism to ensure this never happens because it would damage the reverse osmosis equipment used to purify the water. **Prestage Foods (St. Pauls, NC)[166]** • In 2012, Prestage Foods completed the nation's largest solar thermal farm at its processing facility in St. Pauls, North Carolina. At the time of its installation, the solar energy system was six-times larger than any existing solar thermal system currently in operation. • The system will produce an average of 100,000 gallons of hot water per day for use in the turkey processor operations. • The project did not require capital investment from Prestage Foods: FLS Energy financed the project and will sell Prestage the energy it needs to heat water used in daily plant operations. • The system will cut Prestage's utility costs for heating hot water by more than 35%.
Geothermal	**Albany Molecular Research (Albany, NY)[167]** • Albany Molecular Research, Inc., a large pharmaceutical manufacturer, decided to improve and expand an existing building by adding a geothermal groundwater cooling-system. • The company worked with NYSERDA for assistance through the New York Energy $martSM New Construction Program and the New York Energy $martSM FlexTech Program.

[164] Environmental Leader, Feb. 25, 2010, "Lindt Recycles Cocoa Bean Shells into Biomass Energy" (https://bit.ly/2ILDYv7).
[165] EESI 2011, *supra* note 106.
[166] Prestage Farms, Apr. 3, 2012, "Nation's Largest Solar Thermal Farm at Prestage Foods Dedicated" (http://www.prestagefarms.com/prestage-foods/nations-largest-solar-thermal-farm-at-prestage-foods-dedicated/).
[167] NYSERDA, Jul. 2007, "Understanding and Evaluating Understanding and Evaluating Geothermal Heat Pump Systems Geothermal Heat Pump Systems" (http://www.nyserda.ny.gov/-/media/Files/EERP/Residential/Geothermal/geothermal-manual.pdf).

Technology Type	Project Examples
	• NYSERDA cost shared $33,220 of the study cost and offered $400,000 to help offset the cost of installing these high-efficiency measures. • These measures will result in cost savings of $139,745 annually, 397,453 kWh reduction in energy use per year, payback period of three years.
Waste heat from electricity powered by other renewable sources	**Amazon Westin Data Center (Seattle, WA)[168]** • Heat coming from Amazon's 34-story Westin Building Exchange is used to warm over 4 million square feet of development on Amazon's four-block campus. • The project is estimated to save 80 million kilowatt-hours over 20 years, or about 4 million kilowatt-hours a year. • The waste heat recovered by Amazon would heat about 365 homes a year.

[168] The Seattle Time, Nov. 12, 2015, "Amazon, data center turn hot idea into cool technology" (http://www.seattletimes.com/business/real-estate/amazon-towers-will-be-heated-by-neighbors-excess-energy/).

Appendix C: Resource Library

C.1 Government Resources

- EPA Renewable Heating and Cooling: https://www.epa.gov/rhc
- EPA Municipal Wastewater Treatment Facilities: http://www.epa.gov/chp/markets/wastewater.html
- EPA AgSTAR Program: http://www.epa.gov/agstar/
- EPA Landfill Methane Outreach Program: http://www.epa.gov/lmop/
- EPA Combined Heat and Power Partnership: http://www.epa.gov/chp/
- USDA, EPA, DOE Biogas Opportunities Roadmap: http://www.usda.gov/oce/reports/energy/Biogas_Opportunities_Roadmap_8-1-14.pdf

C.2 Industry Resources

- American Biogas Council: https://www.americanbiogascouncil.org/
- Biomass Power Association: http://www.biomasspowerassociation.com/
- Geothermal Energy Association: http://www.geo-energy.org/
- Innovation Center for U.S. Dairy: http://www.usdairy.com/sustainability/industry-commitment
- Solar Energy Industries Association: http://www.seia.org/research-resources/solar-heating-cooling-energy-secure-future

C.3 Global Trends in Renewable Thermal Energy

Heating Without Global Warming: Market Developments and Policy Considerations for Renewable Heat, International Energy Agency, 2014
Overview of renewable thermal energy technologies, policies and market conditions necessary for deployment in industry and buildings. Comprehensive, extensive data presentation and analysis.
https://www.iea.org/publications/freepublications/publication/FeaturedInsight_HeatingWithoutGlobalWarming_FINAL.pdf

Heat and Cooling Demand and Market Perspective, European Commission Joint Research Centre, Institute for Energy and Transport, 2012
Focus on European Union energy demand by country and industry with implications for district heating.
http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/26989/1/ldna25381enn.pdf

Renewables for Heating and Cooling: Untapped Potential, International Energy Agency, Organization for Economic Cooperation and Development, 2007
Identifies solar, biomass and geothermal thermal energy resource applications with a focus on their application in OECD countries. Focus is on policy analysis and recommendations for decision makers.
http://www.iea.org/publications/freepublications/publication/Renewable_Heating_Cooling_Final_WEB.pdf

Renewables Global Future Report, Renewable Energy Policy Network for the 21st Century, 2017

International collaborative assessment of potential for a 100 percent renewable energy future and corresponding economic impacts. Focus on electrification of thermal energy applications.
http://www.ren21.net/wp-content/uploads/2017/10/GFR-Full-Report-2017_webversion_3.pdf

America's Clean Energy Frontier: The Pathway to a Safer Climate Future, Natural Resources Defense Council, 2017
Comprehensive review of decarbonization pathway of the U.S. energy sector. Notable for its promotion of maximum electrification of the industrial sector, improved energy efficiency within buildings, and terse discussion of renewable thermal energy options.
https://www.nrdc.org/sites/default/files/americas-clean-energy-frontier-report.pdf

Mitigation of Climate Change, Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2014
Definitive global resource on scientific analysis of climate change trends, economic options and policy recommendations to mitigate for greenhouse gas emissions.
http://ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf

Pathways to Deep Decarbonization in the United States, Energy and Environmental Economics; Lawrence Berkeley Laboratory; Pacific Northwest National Laboratory, 2014
Feasibility study of decarbonization of U.S. economy to achieve 80 percent reduction of greenhouse gases by 2050. Assesses various scenario models/strategies that focus on energy efficiency, decarbonization of electricity and fuel switching.
http://unsdsn.org/wp-content/uploads/2014/09/US-Deep-Decarbonization-Report.pdf

Electrification of Heating and Cooling, Eurolectric, 2011
Discusses electrification of thermal energy resources in building and industrial sectors to meet carbon emissions reduction goals. Presents industrial processing application of electricity for various industrial heat values.
http://www.eurelectric.org/media/26110/final_policy_paper-electrification_of_heating_and_cooling-2011-421-0001-01-e.pdf

Worldwide Trends in Energy Use and Efficiency, International Energy Agency, 2008
Within the context of global energy efficiency trends, provides overview of energy use in key industries in countries with the greatest production, with references to heat production and thermal energy requirements. Excludes information on energy use in commercial buildings.
https://www.iea.org/publications/freepublications/publication/Indicators_2008.pdf

C.4 Industrial and Building Thermal Energy

Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions, National Renewable Energy Laboratory, Idaho National Laboratory, 2016
Considers deployment of small modular nuclear reactors, solar thermal and geothermal energy thermal energy sources within the U.S. industrial sector in place of fossil fuels. Deployment of electrical heating

and hydrogen thermal energy is also presented. Extensive information on key industries regarding thermal processing needs, greenhouse gas emissions, and other related data.
https://www.nrel.gov/docs/fy17osti/66763.pdf

Waking the Sleeping Giant: Next Generation Policy Instruments for Renewable Heating and Cooling in Commercial Buildings, 2015
Assesses approach to develop policies to promote cost-effective renewable thermal energy technologies in the commercial building sector. Highlights market barriers, energy planning and market development.
http://iea-retd.org/wp-content/uploads/2015/02/RES-H-NEXT.pdf

Energy Efficient Buildings: Heating and Cooling Equipment, International Energy Agency, 2011
Overview of thermal energy consumption in buildings and potential for renewable thermal energy technology such as solar thermal, heat pumps, thermal storage, combined heat and power. Good visual presentation of building renewable thermal energy technologies, related emissions reductions and investment requirements.
https://www.iea.org/publications/freepublications/publication/buildings_roadmap.pdf

Improving Process Heating System Performance, U.S. Department of Energy, Renewable Energy and Energy Efficiency; Industrial Heating Equipment Association, 2007
General and detailed overview of industry specific process heating applications, systems and technologies. Focus on fossil fuel technologies.
https://www.nrel.gov/docs/fy08osti/41589.pdf

Roadmap for Process Heating Technology, U.S. Department of Energy, Office of Industrial Technologies; Industrial Heating Equipment Association, 2001
Information on industrial process technologies and energy needs in various manufacturing sectors. No mention of renewable thermal sources in plan to reduce emissions.
https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/process_heating_0401.pdf

C.5 Bio-Thermal Energy

Technology Roadmap: Delivering Sustainable Energy, International Energy Agency, Organization for Economic Cooperation and Development, 2017
Comprehensive planning guidance for public and private sector stakeholders to develop bioenergy industry and promote technology deployment at the national or regional level. Mention of biogas and bio-based hydrogen application in industry, in biogas in district heating and greenhouse gas scenarios.
https://www.iea.org/publications/freepublications/publication/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf

Is Biopower Carbon Neutral?, Congressional Research Service, 2016
General overview of biopower carbon neutrality debate for policy makers. Reviews 2011 and 2014 US EPA studies outlying an assessment framework. Useful resource for better understanding legislative/regulatory perspective and analysis. https://fas.org/sgp/crs/misc/R41603.pdf

Biomass for Heat and Power – International Energy Agency, International Renewable Energy Agency, 2015
Technology Brief by IEA's Energy Technology Systems Analysis Program. Good overview of current state of biomass technology applications for electricity and combined heat and power. Includes insights for policy makers and potential market, cost, environmental and resource availability barriers to technology deployment.
http://irena.org/DocumentDownloads/Publications/IRENA-ETSAP_Tech_Brief_E05_Biomass%20for%20Heat%20and%20Power.pdf

Biomass for Electricity and Heating: Opportunities and Challenges, European Parliament Briefing, 2015
Useful background information on European biomass-related legislation and policy framework, supply, consumption and greenhouse gas emissions.
http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568329/EPRS_BRI(2015)568329_EN.pdf

Biomass Combined Heat and Power Catalogue of Technologies, U.S. Environmental Protection Agency, 2007
Focus is primarily on biomass combined heat and power with fossil fuels. However, also includes well organized, detailed description of biomass and biogas resource opportunities and constraints as well as references to potential future of hydrogen fuel cell biogas thermal energy.
https://www.epa.gov/sites/production/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_v.1.1.pdf

C.6 Thermal Solar

Solar Heat Worldwide: Global Market and Trends in 2016, International Energy Agency Heating and Cooling Programme, 2017
Survey of potential for deployment of solar thermal technologies in 66 countries, with note of application for industry processing and building heating and cooling.
http://www.iea-shc.org/data/sites/1/publications/Solar-Heat-Worldwide-2017.pdf

Solar Heating and Cooling, International Energy Agency, 2012
Reviews potential for deployment of solar thermal technologies for heating and cooling in the building and industrial sectors. Addresses market, information and research and development barriers for policy makers. Includes hybrid applications and advanced technologies.
http://www.iea-shc.org/data/sites/1/publications/2012_SolarHeatingCooling_Roadmap.pdf

Solar Thermal Energy for Industrial Uses, Environment and Energy Study Group, 2011
Issue brief on the potential for solar thermal technologies in industrial processing. Includes barriers such as cost, variability, process integration, energy storage, as well as market trends. current policies and case studies.
http://www.eesi.org/files/solar_thermal_120111.pdf