An Overview of Renewable Thermal Technologies

The purpose of this note is to provide an overview of renewable thermal technologies and their most important properties.

Contents

1 Definition and Overview

Renewable thermal technologies (RTTs) harness renewable energy sources to provide heating and cooling services for space heating and cooling, domestic hot water, process heating, and cooking. RTTs can utilize a broad range of local renewable energy sources that otherwise would be lost such as waste energy from industrial processes or waste incineration.

Different RTTs deliver heating and cooling at different temperature levels. Temperature levels are important to define the suitability of different technologies for meeting specific heat requirements in the various end-use sectors. RTTs can range from small domestic applications to large scale applications used in industrial processes and district heating and cooling networks. Figure 1 gives an overview of the main renewable thermal technologies, with no claim to show the full extent of the inherent complexity of renewable heating and cooling. Complexity is caused by the variety of ways heating and cooling can be produced, transported and delivered, the many different end-use profiles and difficulties to draw boundaries.

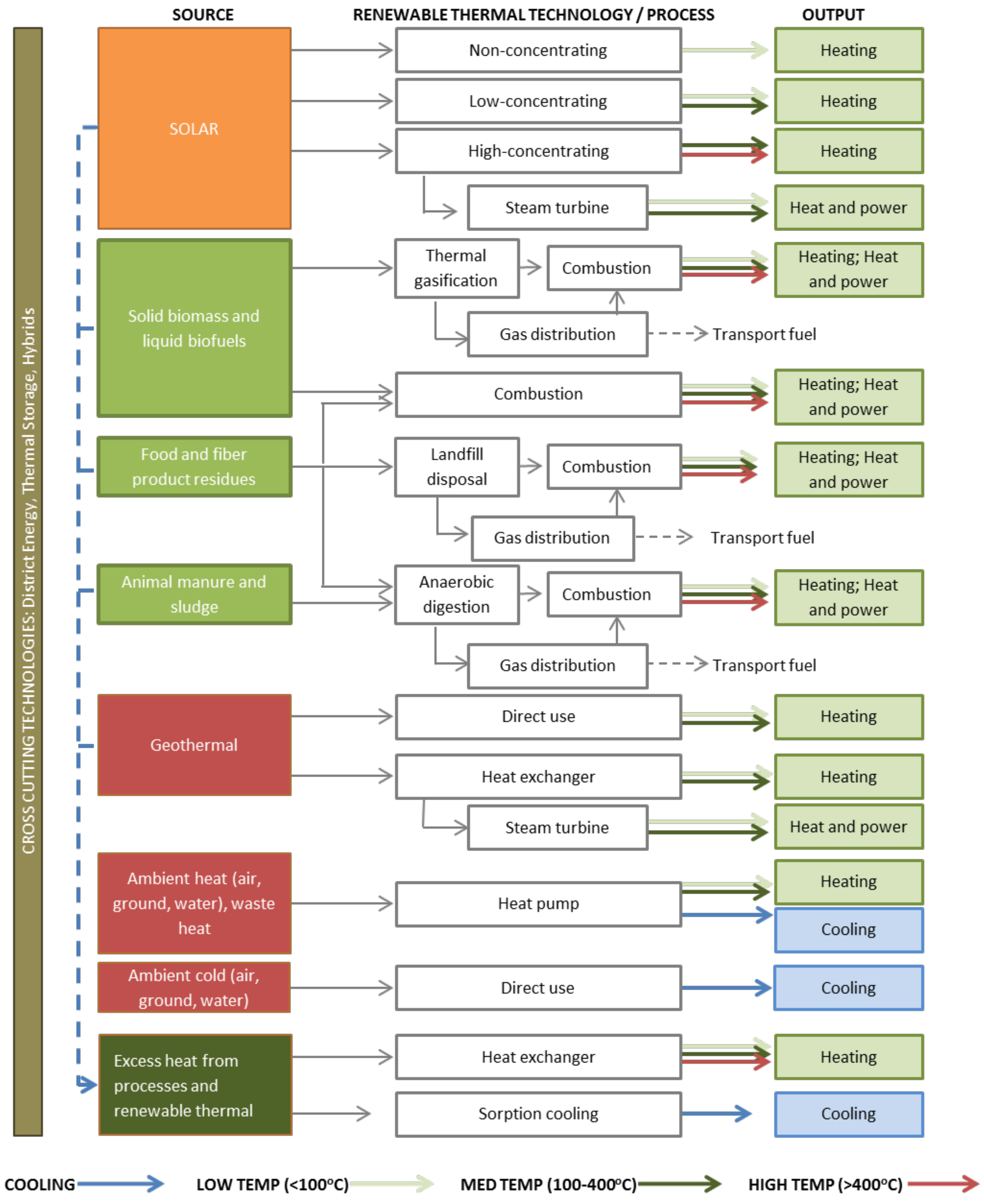

Figure 1 Overview different renewable energy sources and main technologies. (Adapted from IEA 2014)

2 The Thermal Infrastructure

The thermal infrastructure consists of several elements in addition to the renewable thermal technology itself, such as:

- Distribution system
- Radiant emitter
- Peak and reserve load
- Energy storage
- Heat exchanger

The efficiency of the whole system is influenced by the different elements and how well they are adjusted to each other. When considering different RTTs for an existing building, the thermal infrastructure already in place can impose some limitations and has to be taken into consideration in optimizing the efficiency of the installation.

The design of the system, including choice of RTT, will be influenced by several factors such as the building's thermal envelop, the building category and locally available energy sources.

Renewable heating and cooling is often delivered through an internal distribution system, which can be a ductwork or a hydronic system. (Harvey 2006) Ductworks are used in heating, ventilation, and air conditioning (HVAC) to deliver and remove air. Hydronic distribution systems utilize water or other liquid mediums (e.g. glycol) to transfer heating and cooling. Hydronic systems are of three basic types:

- Steam
- Hot water
- Chilled water

Hydronic systems utilize radiant panels or floors as emitters of heating and cooling. Conventional hydronic distribution requires a high supply temperature of 70 – 90 ^{o}C, while low temperature distribution can have a supply temperature as low as 27 - 32 ^{o}C. (Harvey 2006)

- Low temperature heating distribution allows for an efficient utilization of a broader range of energy sources for heating, such as solar heating, heat pumps and low temperature waste heat.
- Buildings with an energy efficient thermal envelop, such as passive houses and near zero energy buildings, favor low temperature distribution systems for heating.
- Low temperature heating distribution requires a different systems design to ensure that the same amount of heat is delivered as a high temperature heating system. The heat emitters are

generally larger in low temperature heating systems, which favor radiant floors and large radiant panels or walls.

- High temperature cooling distribution allows for an efficient utilization of a broader range of energy sources for cooling.

The thermal demand over a year often depends on outdoor temperatures and may vary considerably over the year. Due to this it is often cost optimal to utilize two or more thermal technologies, one to cover base load and another to cover peak load. Oversizing should be avoided to secure efficient operation of the thermal technology. Oversizing of systems is often done deliberately as a precaution to ensure that peak loads are met. This can be avoided through better estimations of thermal loads. The capacity of the base load relative to the peak load depends on local climate, the building's need for heating and cooling over the year and the technical and financial characteristics of the thermal technology in question.

Figure 2 below is an illustration of the net thermal demand curve over the period of a year for a typical building. The number of hours for the highest demand is relatively small over the year, resulting in a steep curve. The example shown by Figure 2 implies that a RTT covering 50 percent of the peak demand would cover around 90 percent of the thermal energy needs of the building. Due to low installment costs, the peak load may often be covered by gas or oil boilers to improve the economics. Biogas and bio-oil are renewable alternatives that can be used in gas or oil boilers, sometimes with adaptations required.

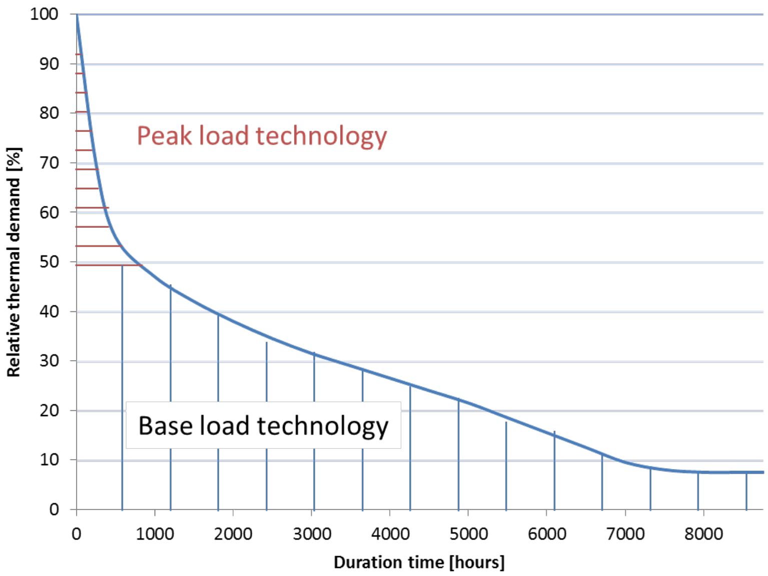

Figure 2 Thermal demand duration curve of a typical building.

The efficiency of the thermal infrastructure can be improved through thermal energy storage (TES). (IEA-ETSAP and IRENA, 2013) TES is a technology that stocks thermal energy by heating or cooling a storage medium so that the energy can be used at a later time. TES can help balance energy demand and supply on a daily, weekly and even seasonal basis. More information on TES can be found in Section 3.6 – cross-cutting technologies.

Heat exchangers transfer heat from one fluid to another. The fluids often are separated by a solid wall to prevent mixing. The efficiency of the heat exchanger depends on how well the heat transfers from one fluid to another, which is influenced by type of fluids and the material separating them.

3 Renewable Thermal Technologies

This section provides an overview of the most common renewable thermal technologies and presents research and development needs that have been identified to improve the applicability of the technologies. Furthermore, the most prevalent environmental considerations related to the operation of the technologies are presented. [1]

The four first sections discuss categories of technologies based on a specific source; solar, biomass, geothermal and ambient energy. The two last sections discuss technologies and solutions that can utilize and optimize a wide variety of renewable thermal technologies; cooling and cross-cutting technologies.

3.1 Solar Thermal Technologies

Active solar heating systems use solar energy to heat a fluid - either liquid or air - and then transfer the solar heat directly to the end-use or to a storage system for later use. Systems for liquids are more often used when storage is included and are well suited for radiant heating systems, boilers with hot water radiators, and even absorption heat pumps and coolers. Systems for both liquid and air can supplement forced air systems. (DOE 2016) Characteristics of solar thermal technologies: (IEA 2012a and IEA 2014)

- Solar thermal technologies normally cannot cover the whole thermal need of a building and need back-up systems to provide additional heating or cooling. Combining a solar thermal system with another heat source adds complexity.
- Although solar thermal technologies can deliver hot water, space heating and space cooling, normally any given system serves only one of the end-uses. Combination systems exist, but are more complex than systems delivering to one type of end-use.
- Solar thermal technologies can be readily scaled to small and large systems, ranging from residential buildings to large industrial and district heating applications.
- Different solar thermal technologies can be utilized for different temperature levels.

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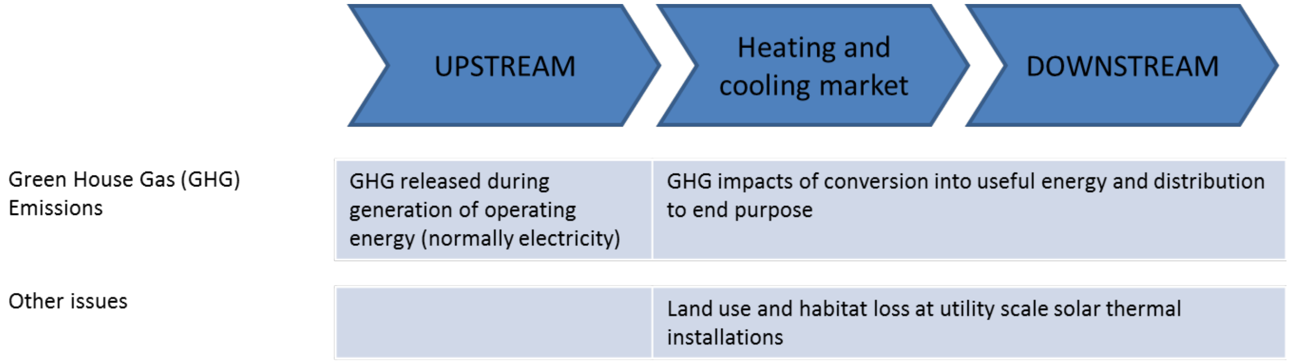
[1] Environmental considerations related to manufacturing and disposal of the technologies are not covered.

- Low and high concentrating solar thermal requires direct solar radiation, while non-concentrating solar thermal can utilize indirect solar radiation and operate when it is cloudy.
- Solar thermal technologies can be combined with other renewable energy technologies such as solar photo voltaic (PV) and heat pumps.

Solar technology		**Output temperature**	**Efficiency**
Non-concentrating heating	Flat-plate unglazed collectors	45 – 60 °C	90 - 60 percent at 0-20 °C above ambient
	Flat-plate glazed collectors	80 – 150 °C	70 - 60 percent at 0-50 °C above ambient
	Evacuated tube collectors	Up to 150 °C	75 - 50 percent at 0-140 °C above ambient
Low-concentrating heating (Compound Parabolic Concentrator)		Up to 150 °C	
High-concentrating heating (sun tracking technologies)		150 – 450 °C	

Table 1 Technical characteristics of solar thermal technologies. (IEA 2014; IEA 2012a; Harvey 2006)

Solar thermal technologies utilize a smaller amount of drive energy; normally electricity. The mix of energy sources in the generation of electricity is therefore relevant in deciding the gross environmental impacts of solar thermal technologies in operation. The net environmental impact of solar thermal technologies varies depending on the energy source that is displaced. Figure 3 sums up the most important environmental considerations related to the use of solar thermal technologies.



	UPSTREAM	Heating and cooling market / DOWNSTREAM
Green House Gas (GHG) Emissions	GHG released during generation of operating energy (normally electricity)	GHG impacts of conversion into useful energy and distribution to end purpose
Other issues		Land use and habitat loss at utility scale solar thermal installations

Figure 3 Environmental considerations related to solar thermal technologies in use along the RTT value chain.

Generally, to increase the global implementation of solar thermal technologies, steps to reduce costs, increase performance, improve reliability and increase the applicability have been identified: (IEA 2012a and RHC 2014)

- Implement alternative materials, technologies and manufacturing techniques that increase reliability and long-term performance of the collectors.
- Integrate solar collectors and energy storage in building materials.
- Develop standardized kits and plug-and-play systems for ease of use and installation.
- Develop easy to install and operate compact solar hybrid heating units combining the solar thermal and back-up heating system into one.
- Develop easy to install and operate compact hybrid energy units combining solar photo voltaic and solar thermal (PV-T).
- Expand the development of collectors for supplying higher temperature for industrial processes.
- Develop pre-engineered solutions and improve system design knowledge for larger scale systems such as district heating and cooling.
- Adapt concentrating solar technology for heat applications, which is mostly used for electricity generation today.
- Innovative control and monitoring concepts with integrated information communication technologies.

3.2 Biomass Thermal Technologies

Biomass is defined as any organic (i.e. decomposing) matter derived from plants or animals available on a renewable basis. Biomass used for energy includes wood and agricultural crops, herbaceous and woody energy crops, municipal organic wastes as well as animal manure. Biomass feedstock can be provided as a solid, gaseous or liquid fuel, which can be used for generating electricity and transport fuels, as well as heat at different temperature levels. (IEA 2014) Characteristics of bioenergy: (IEA 2012b)

- Bioenergy technologies include combustion technologies and pre-treatment technologies:
  - Combustion technologies: Fluidized bed combustion or grate furnaces for a two-phase combustion.
  - Pre-treatment technologies for feedstock and fuel production:
    1. Solid biomass feedstock through drying, pelletisation, briquetting and torrefaction.
    2. Liquid biomass feedstock through pyrolysis and hydrothermal treatment.
    3. Gaseous biomass feedstock through anaerobic digestion, pyrolysis, hydrothermal upgrading thermochemical conversion.
- Systems for using biomass have to be specifically designed to match the properties of the feedstock in question, to ensure clean and efficient combustion and to avoid fouling and corrosion problems.

- There is a wide variety of biomass feedstock, with different characteristics with regards to availability, logistics and energy content. IEA divides the potential feedstocks into four main categories based on their spatial availability and logistics, which have an impact on feedstock costs and the economically feasible scale of the conversion plant:
    - Wastes such as domestic waste and certain types of low quality bio-oil
    - Processing residues such as saw mill dust
    - Locally collected feedstock such as wood chips
    - Internationally traded feedstock such as pellets, upgraded bio-gas and bio-oil
- Biomass can be stored for shorter or longer period depending on the type of feedstock.
- Biomass can be transported for shorter or longer distances depending on type of feedstock. The less moisture content and higher bulk density, the easier and less costly the feedstock is to transport and trade on a larger market.
- Bioenergy can be utilized in small and large installations; however, there are economies of scale benefiting large scale combustion.
- Bioenergy can be utilized for high temperature end-uses such as industrial processes.

Large-scale biomass combustion plants to produce heat are commercially mature technologies. According to Basis Bioenergy (Basis Bioenergy 2015), the overall efficiency of biomass combined heat and power plants is in the 75 – 90 percent range, while overall efficiency of biomass heating plants is in the 80 - 90 percent range. The efficiency is depending on size of installation, year of installation and energy content of biomass feedstock. A wood chip installation larger than 20 MW typically is five percentage points more efficient than a 1 – 5 MW installation.

A variety of different environmental, social and economic issues need to be addressed to ensure the overall impact of bioenergy is positive compared to that of fossil fuels. The most important environmental considerations for bioenergy are illustrated by Figure 4.

	UPSTREAM	Heating and cooling market	DOWNSTREAM
Green House Gas (GHG) Emissions	CO^2 absorbed during growth	GHG impacts from combustion	
	Changes in carbon stored on land	GHG impacts due to transportation	GHG impacts from efficiency of distribution to end purpose
	GHG released during pre-treating biomass feedstock		
Particulate emissions	Particulates released during forestry	Particulates released during combustion. Reduced through filters and scrubbers in large scale installations	
Resource hierarchy	"Best use" of land – energy crops vs alternative use e.g. agriculture	"Best use" of biomass – heat energy vs other applications	"Best use" of waste resources – waste prevention, reuse, recycling vs energy
Other issues	Biodiversity, soil fertility, soil degradation, water use		

Figure 4 Environmental considerations related to bioenergy in use along the RTT value chain. (Informed by IEA 2012b)

Sustainability of bioenergy covers a variety of issues related to GHG emissions[2], particulate emissions, biodiversity, land and resource utilization. International standards, assessment methods and criteria are important to provide a basis for an efficient and sustainable production of food, feed, bioenergy and other services. The net environmental impact of biomass technologies varies depending on the energy source that is displaced.

Generally, to increase the implementation of biomass thermal technologies, steps to reduce costs, increase performance, and increase the applicability of the technologies have been identified: (IEA 2012b and RHC 2014)

- Develop standardized "off the shelf" plant design to reduce capital costs.
- Develop cost and energy efficient, environmentally friendly micro and small scale combined heat and power systems.

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[2] Unlike CO_2 emissions factors for fossil fuels, factors for biomass combustion are not directly included in energy sector accounting framework of the Intergovernmental Panel on Climate Change (IPCC). This accounting convention is based on the rationale that CO_2 of biogenic origin is part of the natural carbon cycle: carbon stored in biomass fuel has been sequestered from the atmosphere relatively recently, and it is assumed that when the fuel is burned the carbon released will be offset by carbon taken up when new biomass is grown. The assumption is made without regard for the specific forest husbandry policies and practices prevailing in the region where the biomass was harvested, even though these policies and practices strongly influence the rate of carbon uptake.

- Implement highly efficient large scale or industrial steam CHP with enhanced availability and the potential for higher heat output temperatures.
- Cost, efficiency and stability improvements for advanced biomass fuels. This includes improving pre-treatment technologies such as torrefaction, pyrolysis and thermochemical gasification.
- Combining bioenergy and biofuel production with Carbon Capture and Storage (CCS) to provide for net GHG negative devices.
- Enhanced feedstock flexibility to allow for use of a broader feedstock base and thus allow for the most economical feedstock at all times.
- Develop biomass polygeneration implying producing electricity, cooling and heating in the same installation. If possible in combination with TES technologies.
- Adopt sound sustainability certification schemes for biomass, addressing issues such as improved GHG performance through choice of feedstock and cultivation technique, address land use change and land use regulations.

3.3 Geothermal Technologies

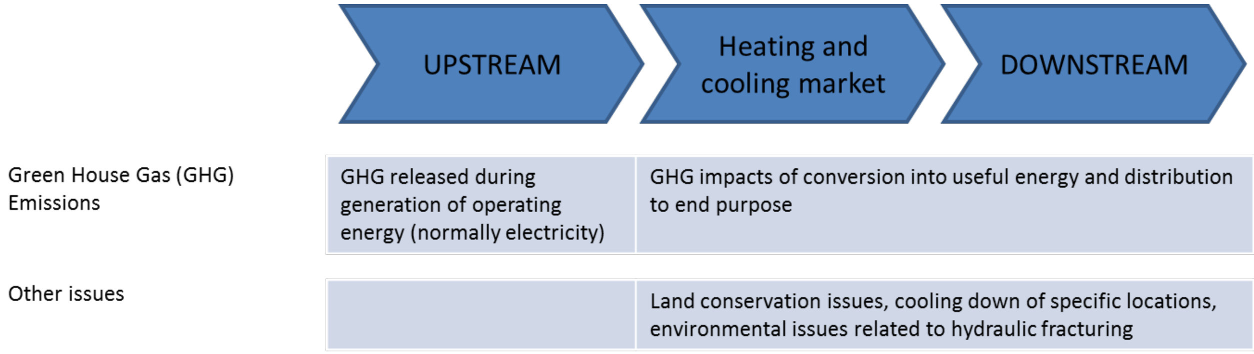
Geothermal technologies exploit thermal energy in the Earth's interior stored either in rock, liquid water or trapped streams. Geothermal heat pumps extracting ambient heat at shallow debt are covered in Section 3.4. Characteristics of geothermal technologies: (IEA 2014 and EPA 2017a)

- There are three types of geothermal resources:
    - Hydrothermal systems of naturally occurring water or vapor flows such as hot springs or geysers.
    - Deep aquifers are porous bedrock or fracture zones in which fluids are circulating.
    - Conductive systems lack a natural flow of liquid and an artificial injection of water via fracking of the bedrock is necessary.
- Hot water or steam can be used directly in a variety of applications, or it can be cycled through a heat exchanger.
- The potential for direct use geothermal energy is limited geographically.
- Enhanced or engineered systems are currently pursued for power generation rather than dedicated to heat production.

Geothermal technology		**Output temperature**
Hydrothermal systems	Direct use geothermal	60 – 180 ^{o}C (ideal locations up to 300 ^{o}C)
Deep aquifers	Direct use geothermal Enhanced geothermal	60 – 180 ^{o}C (ideal locations up to 300 ^{o}C)
Conductive systems	Enhanced geothermal	Shallow: <100 ^{o}C Hot rock: 100 – 180 ^{o}C Magma: >180 ^{o}C

Table 2 Technical characteristics of geothermal. (IEA 2014 and EPA 2017a)

Geothermal technologies utilize electricity for pumping and distribution. The amount of electricity depends on the local conditions and type of geothermal technology applied. The mix of energy sources in the generation of electricity is therefore relevant in deciding the gross environmental impacts of geothermal technologies. The net environmental impact of geothermal technologies varies depending on the energy source that is displaced. Figure 5 Environmental considerations related to geothermal in use along the RTT value chain. (Informed by EPA 2017b and the Economist 2014).sums up the most important environmental considerations related to the use of geothermal technologies.



	UPSTREAM	Heating and cooling market	DOWNSTREAM
Green House Gas (GHG) Emissions	GHG released during generation of operating energy (normally electricity)	GHG impacts of conversion into useful energy and distribution to end purpose	
Other issues		Land conservation issues, cooling down of specific locations, environmental issues related to hydraulic fracturing	

Figure 5 Environmental considerations related to geothermal in use along the RTT value chain. (Informed by EPA 2017b and the Economist 2014).

Generally, to increase the implementation of geothermal technologies, steps to reduce costs, increase performance, and increase the applicability of the technologies have been identified: (IEA 2014)

- Advancement of production pump technology.

- Optimized heat transfer from the ground to the distribution to increase the heat exchange efficiency and component longevity.
- Develop databases on geothermal resources in various regions.
- Improved efficiency of enhanced geothermal system co-generation plants to enhance the potential for geothermal heating.

3.4 Heat Pump Technologies

Heat pumps harness renewable energy from their surroundings (ambient air, water or ground) by using "high-grade" energy, e.g. electricity or gas, to raise the temperature for heating or lower it for cooling. The heat pump cycle can be used for space heating or cooling; reversible systems can alternate heating and cooling, while hybrid system can provide heating and cooling simultaneously. Heat pumps for heating and cooling are described by the medium from which they extract energy (air, water or ground), the heat transport medium they use (air and water) and the service they provide (cooling, space heating and water heating). (IEA 2011 and IEA 2010) Characteristics of heat pumps:

- There are two main types of heat pumps being used today: 1) the vapor compression heat pump requiring mechanical drive energy, and 2) the absorption heat pump requiring thermal drive energy.
- Heat pumps can be designed to meet the annual heating demand alone (monovalent), or be equipped with an integrated auxiliary heating system (bivalent). The auxiliary heating system is normally electricity and is included in order to assist on unusually cold days or when the heat pump is out of operation.
- Heat pumps use a heat transfer medium known as refrigerant required to move heat from the heat source to the heat sink. There are several refrigerants in use, some of which are less favorable with regards to Global Warming Potential and GHG emissions. Hydrofluorocarbons (HFCs) are replacing former less favorable refrigerants. Natural refrigerants such as ammonia (NH3), hydrocarbons (HCs), carbon dioxide (CO_2), air and water are being demonstrated as long-term options.
- Heat pumps can be applied in small and large systems, ranging from part loads of residential buildings to large industrial and district heating applications.
- The efficiency of the heat pump is often described by the coefficient of performance (COP).[3] COP is defined as the ratio between the useful heat and cool and the required drive energy for the heat pump. Mostly electricity is used as drive energy, but heat pumps can also be driven by natural gas and heat from different sources. Seasonal Performance Factor (SPF) takes into account the system performance over the year in addition to the efficiency of the heat pump itself.

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[3] COPs are not comparable across countries due to differing climate, technical specifications and test procedures.

- The efficiency of a heat pump system depends on several factors, but the most critical is the temperature lift or reduction that is being sought. The higher the differentials between the source and the sink, the lower the efficiency of the system.
- Although heat pumps can be designed for higher output temperatures, most heat pumps deliver output temperatures in the 40 – 50 °C range. Heat pumps which are to deliver heat to a high temperature distribution system (70 – 90 °C) will experience a lower efficiency.
- Heat pump systems can experience significant performance loss if poorly designed, installed and maintained. Common deficiencies include oversized equipment and leaky air ducts.
- Heat pumps can serve as stand-alone installations or in combination with other renewable energy sources.

Heat Pump Technology		**Output temperature**	**Efficiency (COP)**
Air source heat pumps (electricity)	To-Air, mono and multi split		2.5 – 3.0
	To-Water, cold climate	35 – 55 °C	2 – 2.5
	To-Water, warm climate	35 – 65 °C	2 – 4
Ground source heat pumps (electricity)	To-Air	35 – 75 °C	3.2 – 3.7
	To-Water	35 – 75 °C	3.5 – 4.0
Water source heat pumps (electricity)	To-Air	35 – 75 °C	3.7 – 4.2
	To-Water	35 – 75 °C	4.0 – 4.5
Gas fired heat pump	Sorption technologies	Cooling	1.2 – 1.5

Table 3 Technical characteristics of heat pumps. (IEA 2014 and HPA 2016)

In the operation of heat pump systems, there are direct contributions of greenhouse gases from refrigerant leakage and indirect contributions resulting from the energy supply required to run the system over the normal life. The efficiency of the heat pump will define how much drive energy is needed to deliver a certain amount of thermal energy. The mix of energy sources in the generation of electricity is therefore relevant in deciding the gross environmental impacts of heat pumps. The net environmental impact of heat pumps will vary depending on what energy source the technology displaces. The environmental considerations for heat pumps in use are illustrated by Figure 6.

	UPSTREAM	Heating and cooling market	DOWNSTREAM
Green House Gas (GHG) Emissions	GHG released during generation of operating energy (normally electricity)	GHG impacts from efficiency of converting ambient heat to useful energy and distribution to end purpose	
		GHG impacts of leaking refrigerants	
Other issues		Disrupting soil surface, change of ground or water temperatures (permafrost or seasonal ground freezing) water quality issues related to open loop ground source installations	

Figure 6 Environmental considerations related to heat pumps in use along the RTT value chain.

Generally, to increase the implementation of heat pump technologies, steps to reduce costs, increase performance, improve reliability and increase the applicability of heat pumps have been identified: (IEA 2011, RHC 2013 and RHC 2014a)

- Develop and introduce heat pumps with higher output temperature for application in existing buildings equipped with high temperature distribution systems.
- Improve COP through more efficient components and systems for heat pumps.
- Improve the efficiency of boreholes through improved pipe materials and better thermal transfer materials.
- Develop efficient low-temperature space heating systems and high-temperature space cooling systems integrated with heat pumps. Particularly for use in near zero energy buildings.
- Develop integrated and hybrid systems that combine multiple functions (e.g. space-conditioning and water heating) and hybrid heat pump systems that are paired with other energy technologies (e.g. storage, solar thermal and solar PV) to achieve very high levels of performance.
- Develop standardized kits and plug-and-play systems for ease of use and installation.
- Develop integrated control strategies and automation for ease of use.
- Optimization of thermally driven heat pumps and their integration in the boundary system.
- Develop enhanced industrial compression heat pumps for higher efficiency and higher output temperatures. For use in industrial processes as well as district heating.

3.5 Cooling Technologies

Due to increased outdoor temperatures, higher comfort requirements and tighter buildings, the cooling demand is expected to increase in the future. Renewable cooling can make considerable contribution to reducing emissions from growing cooling demands.

Although there are stand-alone renewable cooling technologies, cooling devices often have to be coupled with renewable heating technologies to be considered renewable. Characteristics of renewable cooling technologies: (IEA 2014)

- There are different systems and sources for renewable cooling:
    - Sorption cooling system is thermally driven using heat of at least 50 °C to 70 °C instead of electricity to drive the system. This provides the option of using renewable heat or waste heat from industry and co-generation plants to provide cooling.
    - Two different systems exist for heat driven cooling: 1) closed cycle and 2) open cycle. In a closed cycle chilled water is produced, which can be supplied to any type of air-conditioning equipment. Open cycles produce conditioned air directly.
    - Direct or free cooling systems use a cold source such as water, ice or snow that is already in the required temperature range. Some external energy is needed to operate heat exchangers and for circulating the cooling medium.
    - Indirect cooling systems require external electricity or water input, and include heat pumps as well as evaporative cooling.
- Heat driven cooling can utilize solar and waste heat at times of the year where cooling has higher market value than heating.
- The efficiency of cooling is measured through COP or Energy Efficiency Ratio (EER).

Cooling Technology		**Output temperature**	**Efficiency (COP)**
Sorption, closed cycle cooling	Adsorption	Temp of heat source: From 55°C and higher	COP 0.6 and higher
	Absorption (temperature and efficiency depends on single, double or triple effect chiller technology)	Temp of heat source: Single: 70 – 100 °C Double: 150 – 180 °C Triple: 200 – 250 °C	COP for: Single: 0.7 Double: 1.1 – 1.2 Triple: 1.6 – 1.9
Sorption, open cycle cooling	Desiccant evaporative cooling	Temp of heat source: 50 – 75 °C	
Direct cooling / Free cooling	Sources like lakes, ground, sea	Depends on temperature of source	20 – 30
Indirect cooling	Heat pumps	See Table 2	See Table 2

Table 4 Technical characteristics of cooling technologies. (IEA 2014 and IEA 2010)

As efficient heat driven cooling technologies are in a pre-commercial phase and are relatively unknown in the market in comparison with mechanical (i.e. electrical) vapor compression, the costs are relatively high. Steps to reduce costs, increase performance, improve reliability and increase the applicability have been identified: (IEA 2014 and RHC 2014b)

- Develop small scale heat driven cooling technologies for residential buildings. These can utilize e.g. solar thermal collectors for cooling purposes.
- Improve the performance of heat driven cooling technologies through improvements in basic materials, component design and system technology.
- Improve the performance of absorption and adsorption chillers through medium to high temperature collectors and multi-stage chillers.
- Develop standardized kits and plug-and-play systems.
- Develop integrated thermally driven cooling and heating technologies, including compact storage.
- Integrate cooling system components into the building at the time of construction.
- Increase the quality and reliability of solar cooling and refrigeration systems through e.g. a compact system design, stagnation-proof collector and system controller units.

3.6 Cross-Cutting Technologies

There exist synergies across renewable energy technologies, distribution and consumption that can be exploited to realize the full potential of RTTs. Cross-cutting technologies are technologies that can be used to enhance the thermal energy output of a renewable energy source, to enable a greater fraction of the output by the system to be used, or to allow for exploitation of renewable sources that would otherwise be difficult to exploit. These cross-cutting technologies include: (RHC 2013)[4]

1. **District heating and cooling (DHC)**: Increases the overall efficiency of the energy system by recycling heat losses from a variety of energy conversion processes.
2. **Thermal energy storage (TES)**: Allows for using the thermal energy at a different time than it was supplied.
3. **Hybrid renewable energy systems**: Combining two or more energy sources into a single system can overcome limitations of individual technologies. This is applicable to small and large scale applications.

While some of these systems, components and infrastructures that qualify as cross-cutting technologies are already commercially mature technologies, combining them in a system of several thermal technologies in an optimal way may require new solutions and innovation.

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[4] RHC 2013 defines four cross-cutting technologies: District heating and cooling, thermal energy storage, hybrid renewable energy systems and heat pumps. Heat pumps have been described in Section 3.4 and are therefore not included in this section.

3.6.1 District Energy

District energy systems provide heating and cooling to buildings and processes through networks of hot and cold water pipes. While the first district energy systems uses steam to carry heat, the second generation district energy uses hot water and the third generation integrates renewable source. The fourth and new generation of smart thermal energy grids will tackle the challenges of heat supply to energy efficient buildings and the integration of low-temperature heat sources such as surplus heat from industrial processes and data centers. A district energy system allows for combining and exploiting synergies between various renewable energy sources and customer profiles. RHC (RHC 2014) summarizes the research and innovation priorities for district heating and cooling as:

- Large scale demonstration of smart thermal grids.
- Booster heat pumps for DHC with temperatures up to 100 ^{o}C.
- Develop and roll-out DHC driven white goods and low temperature solution for domestic hot water preparation.
- Improved, highly efficient substations (heat exchangers) for both present and future lower temperature networks.
- Optimize integration of renewable energy sources in DHC systems and enhancement of thermal energy storage at system level. This includes connecting diverse types of buildings and industrial processes together, including prosumers[5] where appropriate.

3.6.2 Thermal Energy Storage

Thermal energy can be stored at temperatures from -40 ^{o}C to more than 400 ^{o}C. There are three kinds of TES systems:

1. Sensible thermal storage utilizing a liquid or solid storage medium (e.g. water, sand, molten salts, rocks). The maturity of the sensible TES technologies range from commercial for water tanks and boreholes to demonstration for high temperature solids.
2. Latent thermal storage utilizing phase change materials (PCM)(e.g. from a solid state into a liquid state). The maturity of the latent TES technologies range from commercial for cold storage to R&D for high temperature PCM based on waste heat.
3. Thermo-chemical storage (TCS) using chemical reactions to store and release thermal energy. The TCS technologies are in the R&D phase.

RHC (RHC 2014) summarizes the research and innovation priorities for TES as:

- Next generation of sensible TES. This includes new materials for more efficient heat transfer and better insulation.

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[5] "Prosumers" both consume and produce energy.

- Improving the efficiency of combined thermal energy transfer and storage.
- Increased storage density using phase change materials (PCM) and thermochemical materials (TCM). This enables the implementation of TES in applications with less available volume and long-term storage.
- Improvements in underground TES (UTES) to increase energy efficiency of heat storage for industrial processes and DHC systems.
- Optimized integration of renewable energy sources in DHC systems and enhancement of thermal energy storage at system level.

3.6.3 Hybrid Energy Systems

RHC 2014: "*Hybrid systems are defined as those systems which provide heating, cooling and / or domestic hot water through the combination of two or more energy sources into a single system, and therefore overcoming the limitations of individual technologies*".

In the short term, hybrids combining renewable and non-renewable sources are expected. In the long term however, hybrid systems are expected to combine two or more renewable energy sources.

RHC (RHC 2014) summarizes the research and innovation priorities for hybrid energy systems as:

- Automation, control and long term reliability assessment which includes weather and load forecasts, system optimizing maintaining a high degree of comfort and low consumption, monitoring and recording, fault detection and easy to install systems for the controller.
- Next generation of highly integrated, compact hybrid systems for residential sector. Effort should be put into developing compact and prefabricated hybrid systems with the following characteristics: easy to install, control systems that optimize the energy consumption across the renewable sources, embedded equipment for energy monitoring, immediate failure detection and systems adapted to various configurations of heating systems.
- Integration, automation and control of large scale hybrid systems for non-residential buildings.

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