ESG Economist

Heating technologies to reduce emissions

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- **Data from Eurostat show that heat in the EU is mainly produced from natural gas (48%) solid biofuels, renewable wastes (33%) and coal (20%). The composition differs per country. For the Netherlands there is almost no coal used and natural gas takes a 55% share followed by solid biofuels and renewable waste (25%). The share of the other renewables are very low in EU and in the Netherlands.**
- **To move away from fossil fuels and reaching net zero for heating is a complex task**
- **One option is to burn fuels or mass that emit less or no emissions such as synthetic fuels including bio-fuels and bio-mass.**
- **But these fuels are not all zero carbon, they are expensive, production is limited, and some technologies are not commercially available yet. Replacing fossil fuels by synthetic fuels is in terms of infrastructure often the easiest option.**
- **Another option is to absorb heat from other sources such as the sun, ground, air, water or rest heat. These technologies are expensive, some need a substantial upfront investment for the infrastructure and they are not suitable for every application. However, these technologies are efficient and very promising**
- **The last option is to create heat from electricity. These are less efficient than the previous option while the renewable electricity needs to be used to result in zero emissions**
- **So there are several options but these options are currently more expensive than burning fossil fuels**
- **These alternative heating technologies need to become more affordable, supply/availability needs to increase and the use of fossil fuels needs to become more expensive.**

In this ESG economist we start with an overview of what the current sources of heat in the EU and the Netherlands. Then we highlight the alternative sources of heat and their technologies. This is followed by an overview of all the pros and cons of every technology followed by a conclusion.

Introduction

Life on earth depends on heat for survival. In this ESG Economist publication, we focus on how to reduce emissions from heating but we first start with what heating is and how it is generated. Heat is the thermal energy that is transferred from one body to another as the result of a difference in temperature. So if two bodies at different temperatures are brought together, energy is transferred, i.e. heat flows from the hotter to the colder body. It is transferred through conduction, convection and radiation. All substances above absolute zero have thermal energy, which means that the particles contained in them have some form of motion. In contrast, when sitting outside on a cold day you will feel "cold" because the heat transferred from the sun to you is less than the radiant heat you are giving off (along with convective heat transfer cooling you off). The most significant radiant heat sources in your home include heat from the walls, roof, windows, and your body. Convection is the energy transferred by molecular motion. Radiation is the energy transferred by electromagnetic waves and conduction is the energy transferred by direct contact.

We now have an idea what heat is. How is heat generated? According to a survey conducted in 2022 by the UK department for Business Energy & Industrial Strategy (BEIS), most UK residents keep warm using gas central heating during the winter months. The next most common heating source was electric. Data from Eurostat show that heat in the EU is mainly produced from natural gas (48%) solid biofuels and renewable wastes (33%) and coal (20%). The composition differs per country. For the Netherlands there is almost no coal used and natural gas takes a 55% share followed by solid biofuels and renewable waste (25%). The share of the other renewables are very low in EU and in the Netherlands. According to the IEA in 2018 50% of the total heat produced was used for industrial processes another 46% was consumed in buildings for space and water heating and to a less er extent for cooking.

Heat produced by source EU

2021 Heat Produced	EU				NL			
	in PJ	%	in PJ	in %	In PJ	in %	in PJ	in %
Solid fossil fuels, peat and products, oil shale and oil sands	472	20			2	2		
of which hard coal			348	15			2	2
of which brown coal			96	4			0	0
Oil and petroleum products	75	3	75	3	8	8	8	8
Natural gas and manufactured gas	883	38			55	56		
of which natural gas			850	37			55	56
Nuclear	4	0	4		0	0	0	
Renewables and biofuels	768	33			25	26		
Solid biofuels and renewable wastes			681	30			25	25
Biogases			36	2			0	0
Liquid biofuels			7	0			0	0
Solar thermal			2	0			0	0
Geothermal			14	1			0	0
Ambient heat			28	1			0	0
Wastes non-renewable resources	139	6	139	6	9	9	9	9
Other	2	0	2	0	0	0	0	0
Total	2343	100	2282	100	99	100	98	100

Source: Eurostat

So a large percentage of heating is currently generated from fossil fuels. To move away from burning fossil fuels and reduce greenhouse gas emissions the process becomes far more complicated. We zoom into alternative heating technologies to reduce greenhouse gas emissions.

Sources of heat - burning something

Burning fuels and mass with lower or no emissions

Burning fuel would be the easiest solution to create heating. Boilers and thermal heat pumps burn fuel to create heat. A boiler heats a fuel to transfer the heat to water. The hot water is then pumped around the home. In power plants, boilers are used in order to produce high pressured steam by heating water so the plant can generate electricity. To reduce emissions and create heat, fossil fuels in boilers/burners could be replaced by fuels that emit less or no emissions.

Synthetic fuels (see also **here**)

To replace fossil fuels in boilers, synthetic fuels could be used. Synthetic fuels are liquid fuels that have the same properties as fossil fuels but are produced artificially. Synthetic fuels can be blended with fossil fuels or replace the fossil fuel in internal combustion engines. There are three types of synthetic fuels and the way they are produced makes the difference (see **here**).

- Biomass-to-liquid produces biofuels (any fuel that is derived from biomass) such as renewable diesel/hydrotreated vegetable oil (HVO)
- Power-to-liquid produces e-fuels such as e-methane, e-kerosine and e-methanol
- Sun-to-liquid produces solar fuels such as hydrogen, ammonia

Bio-fuels and bio-mass

Bio-fuels can be produced by agricultural waste, food waste, manure and sewage. There are liquid and solid bio-fuels. Examples of liquid bio-fuels are bio-gas, bio-methane, bio-LPG. Charcoal, biochar and biofuels pellets are examples of solid bio-fuels. The bio-fuel production is categorized into four generations based on the type of feedstock used. First generation bio-fuels primarily utilize crops that are high in sugar, starch, or oil content. Second generation bio-fuels are derived from lignocellulosic biomass. This can be from agricultural residue, waste or dedicated biomass plants. Third generation bio-fuels are produced from microalgae such as bio-diesel and seaweed, mainly for bio-ethanol. Fourth generation bio-fuels are generated from genetically modified microalgae. Burning sustainably resourced wood is carbon-neutral as the CO2 emissions emitted during burning are equal to trapped emissions during the growth of the trees.

Biogas is produced by the breakdown of organic matter. It is a mixture of methane, hydrogen and carbon dioxide. The methane content of biogas typically ranges from 45-74% by volume, with most of the remainder being CO2 (see **here**). The precise composition of bio-gas depends on the type of feedstock and the production pathways.

Bio-methane is a biogas from which the carbon dioxide, hydrogen sulfide and water have been removed. It Is also known as renewable natural gas. As a result of the purification process, the bio-methane has the same characteristics as natural gas. So bio-methane is the purified form of raw bio-gas. The combustion of these creates CO2 emissions, but since the bio-gas is derived from plants (which remove CO2 from the atmosphere) the CO2 emissions are generally considered carbon neutral.

Bio-LPG (Liquified Petroleum Gas) is produced from renewable sources including biological oil and fats and the fermentation of glucose by microorganism. It has a lower carbon footprint than conventional LPG (up to 80% lower). It is identical in its chemical structure to conventional LPG. It can be used as drop-in fuel and in existing gas boilers.

Power to liquid fuels

Next to bio-fuels and bio-mass also power-to-liquid fuels could be used. These are synthetically produced liquid hydrocarbon. Renewable energy is the key energy source, and water and carbon dioxide are the main resources. First renewable electricity is generated, which then drives an electrolyser that splits water into hydrogen and oxygen. Next, the hydrogen is mixed with carbon dioxide and turned into syngas via the reverse water gas shift (RWGS) reaction – a process that is conducted at high temperatures and driven by electricity. The mobility sector will likely use a lot of these fuels in the future for the hard to abate sectors like shipping.

Sun-to liquid fuels or solar fuels
Solar fuels are synthetic chemical fuels produced from solar energy. Solar fuels are fuels made from common substances like water and carbon dioxide using the energy of sunlight. Options for solar fuels include making hydrogen as a fuel by using solar energy to split water, or producing alcohols such as ethanol and methanol by using solar energy to reduce carbon dioxide with hydrogen, or creating less-conventional fuels such as ammonia and hydrazine by using solar energy to reduce nitrogen with hydrogen (see **here**).

Emissions
Low carbon fuels emit less carbon than fossil fuels. Renewable diesel, bio-diesel, hydrogen/methanol/ammonia when produced using fossil fuels with carbon capture and storage are examples of low carbon fuels. Renewable diesel's CO2 emissions are highly dependent on the feedstock used. Often, this results in life-cycle emissions above zero. The higher the blend-in percentage, the higher the CO2 reduction. The National Renewable Energy Laboratory (NREL) indicates that renewable diesel reduces the carbon intensity level on average by 65%. According to the NREL pure bio diesel (100%) reduces carbon dioxide emissions by more than 75% compared to petroleum diesel. The graph above shows emissions reductions of renewable fuel produced in the US.

Carbon neutral fuels are fuels that do not increase or decrease the amount of carbon in the atmosphere through their life-cycle. Power-to-liquid fuels e-methanol and e-kerosine are carbon neutral fuels. They are considered carbon neutral if renewable resources are used in the production process and the carbon captured from the atmosphere is later released back into the air.

Zero-carbon fuels are fuels that do not release carbon at the time of usage. For example hydrogen when produced by electrolysis and renewable electricity and ammonia when produced by renewable electricity and green hydrogen as the source are zero-carbon fuels.

Challenges
To replace fossil fuels by synthetic fuels is not an easy task. There are numerous challenges. First, prices for synthetic fuels are considerably higher than for fossil fuels. For example, the costs of producing bio-gas today lie in a relatively wide range between USD 2/MBtu to USD 20/MBtu. There are also significant variations between regions; in Europe, the average cost is around 16/MBtu, while in Southeast Asia it is USD 9/MBtu (see **here**). To make synthetic fuels a viable solution from price point of view, prices have to come down significantly and prices for fossil fuels need to increase which will most likely happen due to ETS 1 and 2. Second, synthetic fuels are less efficient. According to ICCT 48% of the energy from renewable electricity is lost in the conversion to liquid fuels. Manufacturing synthetic fuels is very expensive and energy-intensive. Third, synthetic fuels could be low carbon or carbon neutral. Low carbon fuels could emit up to 90% less CO2 during the life cycle than fossil fuels but this depends on what feedstock is used and the blend-in rates. Carbon-neutral fuels are fuels where during the production process the carbon is captured from the atmosphere and the same carbon is released during burning the fuel. However, the production process also needs to be done with renewable energy to qualify them as green. Fourth, the availability of synthetic fuels is limited. This is because there is currently limited production capacity. Of course this can be built but this takes time. For example global natural gas production was in 2022 4.09 trillion cubic meters. The total bio-gas production in 2021 was 15.38 billion (see **here**). Even though production has most likely increased the gap remains enormous.

Sources of heat - sun

The sun as heat source

Next to burning a liquid or a mass it is also possible to absorb heat from a source. It can be absorbed from the sun, from the air or water around us or from the heat deep in the ground or rest heat. We start with technologies that are able to absorb heat from the sun. In the subsequent sections the other technologies are discussed.

Solar thermal technology converts sunlight into heat, which is then used to produce hot water, heat or even cool buildings. Most solar thermal systems work in combination with a heater. For example, a condensing boiler or a heat pump, which operates when heat demand is too high for the solar system alone. On average, a single family house can satisfy up to 60% of its heat demand for domestic hot water with solar energy. A solar heating system is composed of: solar collectors, roof-mounted elements that collect energy from the sun, a hot water tank to store the water heated by the system, a circuit, and a heat exchanger to transfer heat from the collectors to the hot water storage tank. Installation costs of a solar thermal heating system are generally quite expensive as you have to factor in scaffolding, plumbing, and the required moderations to your roof. An example is solar thermal roof panel. There are two closed circuits with a heat exchanger. In the primary circuit, the cold heat transfer fluid passes through the solar panels. Radiation from the sun heats it and goes to a heat exchanger to transfer thermal energy to the secondary circuit and repeat the cycle. In the secondary circuit, the heat transfer fluid goes to the storage system. Inside the storage system, it gives up its thermal energy to the water stored inside. There are several solar thermal technologies: unglazed solar collectors, transpired solar air collectors, flat-plate solar collectors, evacuated tube solar collectors, thermodynamic solar panels and concentrated solar power.

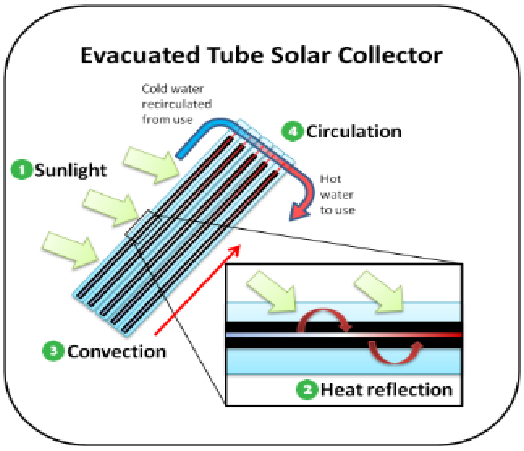
In unglazed solar collectors a heat conducting material absorbs sunlight and transfers the energy to a fluid passing through or behind the heat-conducting surface. It doesn't have a glass covering for the absorber. The collectors work best for low-temperature applications (small or moderate) that require a temperature below 30 degrees celsius such as swimming pool heating and space heating.

Transpired solar air collectors typically consist of a dark-coloured, perforated metal cladding material mounted on an existing wall on the south side of a building. A fan pulls outside air through the perforations and into the space behind the metal cladding, where the air heats to as much as 30°F-100°F (up to 38 degrees Celsius) above the ambient air temperature. The fan then pulls the air into the building, where it is distributed through the building's ventilation system. The transpired solar collector is a proven but still an emerging solar heating technology. This type of technology is best for heating air and ventilating indoor spaces (see **here**).

In glazed flat plate collectors consist of copper tubing and other heat-absorbing materials inside an insulated frame or housing, covered with clear glazing (glass). Glazed flat-plate collectors can operate efficiently at a wider temperature range than unglazed collectors. They can be used for applications of up to about 80 degrees celsius. Flat-plate collectors are often used to complement traditional water boilers, pre-heating water to reduce fuel demand. The design of solar panel is, overall, slightly less compact and less efficient when compared with an evacuated tube system, however this is reflected in a cheaper price. This design of solar collectors can work well in all climates and can have a life expectancy of over 25 years.

Evacuated tube collectors feature thin, copper tubes filled with a fluid, such as water, housed inside larger vacuum-sealed clear glass or plastic tubes. Evacuated tubes use the sun's energy more efficiently and can produce higher temperatures than flat-plate collectors for a few reasons (up to 120 degrees Celsius). First, the cylindrical shape of evacuated tubes means that they are able to collect sunlight throughout the day (from many different angles) and at all times in the year. Second, the tubes also have a partial vacuum within the clear glass enclosure, which significantly reduces heat loss to the outside environment - it reduces conduction and convection energy transfer losses. It is one of the most popular solar thermal systems in operation. The tubes can be replaced individually if one becomes faulty, avoiding the need to replace the whole collector. The system is an efficient and durable system with the vacuum inside the collector tubes having been proven to last for over twenty years.

How evacuated tube solar works

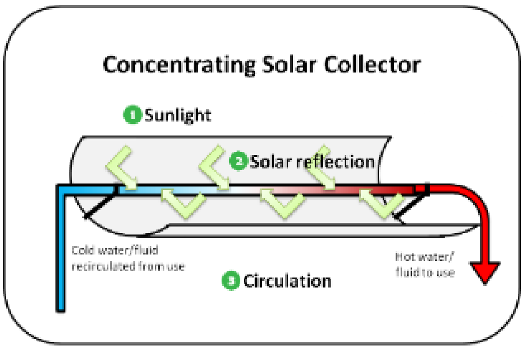


1. **Sunlight:** Sunlight hits a dark cylinder, efficiently heating it from any angle.
2. **Heat reflection:** A clear glass or plastic casing traps heat that would otherwise radiate out. This is similar to the way a greenhouse traps heat inside.
3. **Convection:** A copper tube running through each cylinder absorbs the cylinder's stored heat, causing fluid inside the tube to heat up and rise to the top of the cylinder.
4. **Circulation:** Cold water circulates through the tops of the cylinders, absorbing heat.

Source: www.epa.gov

Thermodynamic solar panels are a new development (and need more research and development). They are solar-assisted heat pumps. They are a hybrid between a solar thermal panel and a heat pump. They can create power from not only direct sunlight but also from heat in the air. They may resemble solar panels, but their function is more like a heat pump. They are deployed on the roof or walls and they don't have to be south facing. These panels work by circulating an extremely cold liquid refrigerant throughout the veins within the panel. As the refrigerant enters the system, it typically has a temperature of around -22°C. The panels absorb heat from the surrounding air, transferring the energy to the cold refrigerant. In this process, the refrigerant's temperature increases, ultimately turning it into a gas. The gas is then compressed which raises its temperature and it will then be passed on to a heat exchanging coil that is located within a hot water cylinder. The hot gas then passes through a heat exchanger, transferring its thermal energy to the water supply, heating it for domestic use. Finally, the refrigerant returns to its original liquid state and re-circulates through the system, starting the process again. The advantage of thermodynamic panels is that they can operate in various weather conditions, even at night or during cloudy days. They absorb heat from direct sunlight, but can also pull heat from ambient air. This is due to their ability to extract heat from the air, similar to how ground source heat pumps work. They can be used for domestic hot water production and underfloor space heating.

How concentrated solar collector works



1. **Sunlight:** Sunlight hits a reflective material (i.e., a mirrored surface), usually in the shape of a trough (shown here) or a dish.
2. **Solar reflection:** The reflective material redirects the sunlight onto to a single point (for a dish) or a pipe (for a trough).
3. **Circulation:** Cold water or a special heat transfer fluid circulates through the pipe, absorbing heat.

Source: www.epa.gov

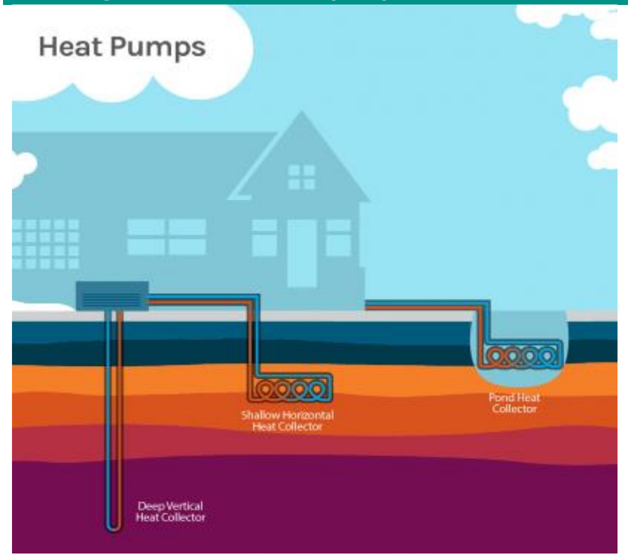
Concentrated solar power (CSP) is an approach to generating electricity through mirrors. This technology uses mirrors to reflect and focus sunlight onto a thermal receiver. The intense CSP energy heats up the fluid (heat-transfer fluid or HFT) in the receiver to high temperatures. This heat or thermal energy is used to turn a turbine and thus generate electricity (see **here**). The thermal energy contained in the fluid can be stored for later use. CSP energy also has direct industrial applications in water desalination and food processing. Concentrated solar power also has a high energy output, which makes it suitable for large-scale electricity generation. One of the main drawbacks is its high capital and maintenance costs. CSP installations require significant upfront investments, Additionally, the technology is still relatively new, and there's a lack of experienced professionals in the field.

Sources of heat - ground

The ground as a heat source

Another source where heat can be absorbed from is the ground. This is done by geothermal or ground-source heat pumps. A geothermal heat pump system includes an underground heat collector, a heat pump and a heat distribution system. It uses the earth as a heat source and thermal storage, using a series of connected pipes buried in the ground near a building. When ambient temperatures are colder than the ground, a geothermal heat pump removes heat from the collector's fluids, concentrates it and transfers it to the building. When ambient temperatures are warmer than the ground, the heat pump removes heat from the building and deposits it underground. So it can be used to heat and cool a house, business or community.

How a ground source heat pump works



Source: www.energy.gov

They can operate in any climate because of the earth's constant underground temperature. The temperature rises in about 25-30 degrees/km of depth near the surface in most of the world due to the heat flow from the much hotter mantle. The effect of weather, the sun and season only reach a depth of roughly 10-20 m (see **here**).

Geothermal heat pumps need some electricity to run. They can be connected with solar panels. Then these heat pumps have zero-emissions. Heat pumps are very efficient. For 1 kWh electricity used it produces around 4 times as much heat. But heat pumps are only a good option for thermally efficient homes. They heat a home not as fast as gas boilers and they are very expensive to buy and to install.

Sources of heat – air or water

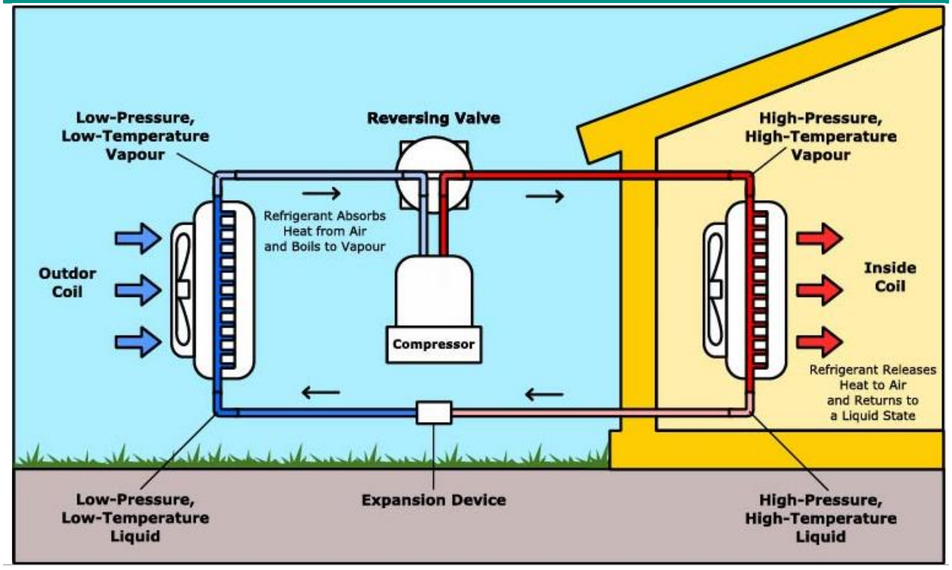
Air or water as heat source

There are not only geothermal heat pumps but also heat pumps that use air surrounding us or water close by as a source of heat. Heat pumps are able to absorb this heat and transfer already existing heat from the environment into a building. They mainly use the energy stored in the groundwater, or air for space heating, domestic hot water, ventilating, and cooling. There are water-water heat pumps and air-to-air (air source) heat pumps.

Water-source heat pumps use the energy stored in ground water, surface, or sea or sewage water. The heat pump takes heat from the water and makes it available for heating, cooling and preparation of hot water. Water source heat pumps are particularly efficient because water is a very good energy carrier.

Air-source heat pumps absorb heat from the air into a fluid. The fluid then passes through a heat exchanger into a heat pump, which raises the temperature and then transfers that heat to water.

How air source heat pump works



Source: www.energy.gov

Air source and water source heat pumps are very efficient. For 1 kWh electricity used it produces around 3 times as much heat. They have some of the same disadvantages as geothermal heat pumps. They work well with well-insulated buildings; distribution systems working at low temperature, i.e. underfloor heating and large radiators (see **here**). But they need some electricity to run. They can be connected with solar panels. Then these heat pumps have zero-emissions. Thermodynamic solar panels are a combination of thermal solar panels and a heat pump.

The heat pump challenge

A large number of heat pumps are using fluorinated gases or F-gases as refrigerant. Fluorinated gases are man-made gases that are used in for example heat pumps and switchgear. These F-gases are used sparsely but they are extremely powerful: F-gases are between 1,400-22,800 more potent than CO_2. Today, F-gases account for 2.5% of EU greenhouse gas emissions. The heat pump sector has pledged to support the shift from F-gases to natural refrigerants whenever possible and has already achieved significant progress in the monobloc outdoor unit segment. The current EU regulation aims to reduce F-gas emissions by two thirds of the 2014 level by 2030.The European Commission is targeting a reduction of F-gas emissions by 90% until 2050 compared to 2015. On 21 July 2023 EU deal on F-gases was delayed. Three issues created the stalemate: heat pumps, switchgear – the boxes that regulate electrical flow – and Annex IV, which sets out rules for when various kinds of products will be banned. There are already heat pumps on the market with natural refrigerants with lower global warming potential (GWP) such as air, CO2, ammonia, hydrocarbons and water).

Global warming potentials: F-gases in orange

Gas	GWP (AR4, 100yr)
CO_2	1
Methane	25
Nitrous Oxide	298
HFC-134a	1,430
R-404A (HFC blend)	3,922
R-410A (HFC blend)	2,088
HFC-125	3,500
PFC-14	7,390
SF_6	22,800

Source: climate.ec.europe.eu

Sources of heat – rest heat

Rest heat

Rest heat is the heat released as a by-product of industrial processes or electricity generation or the heat released from the burning of waste/rubbish. In many cases this heat is wasted. The heat can be used to heat water and produce steam for homes and local businesses. Using rest heat is becoming more common. It contributes to more efficient energy use, reducing the need for energy sources. Heat recovery refers to the process of reclaiming a portion of the energy wasted by the use of heating, venting and air conditioning systems. There are several ways to use rest heat.

- Combined heat and power or cogeneration
- District heating

Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. Cogeneration is a more efficient use of fuel or heat, because otherwise-wasted heat from electricity generation is put to some productive use. This involves the concurrent production of electricity or mechanical power and useful thermal energy (heating and/or cooling) from a single source of energy (see **here**). Combined heat and power (CHP) it is a highly efficient process (over 80%) that captures and utilises the heat that is a by-product of the electricity generation process. The electricity could be generated from renewables as well. By generating heat and power simultaneously, CHP can reduce carbon emissions by up to 30% compared to the separate means of conventional generation via a boiler and power station. The heat generated during this process is supplied to an appropriately matched heat demand that would otherwise be met by a conventional boiler.

Another way to use rest heat is in district heating. District heating involves generating heat in a centralized location and then distributing it to residences, businesses, and industry in a local area. District heating is the distribution of heat from large scale generation and waste heat sources around large areas, usually within cities, connecting community heating schemes together. Typical central energy sources: power stations, EfW (energy from waste), gas fired combined heat and power units, biomass combined heat and power, industrial heat pumps, solar/geothermal sources. The primary benefits of district heating are threefold: lower energy costs, environmental (through the reduction in carbon emissions) and security of supply. According to the IEA in 2022 district heat production remained relatively similar to the previous year, meeting around 9% of the global final heating need in buildings and industry. District heating offers great potential for efficient, cost-effective and flexible large-scale integration of low-emission energy sources into the heating energy mix.

Sources of heat - electricity

Create heat from electricity

The last source to generate heat is from power or converting electrical energy into heat. This is called in short power-to-heat. Renewable energy sources can produce electricity and this electricity is converted into heat. There are several ways to do this and the applications differ for households and industry. This form of heating is only zero emissions if electricity comes from renewable sources such as for example sun and wind.

Heating for households

For households the main heaters are electric resistance heaters (baseboard heaters, panel heaters, underfloor heating and wall heaters), infrared heaters or a combination (electric fireplaces). Underfloor heating provide radiant warmth that is transmitted upwards from the floor. Baseboard and panel heaters are convection heaters and electric fireplaces are a combination of infrared radiation and convection. The heating temperature is lower for households than for industrial processes.

Heating for industry

For industrial applications very high temperatures are necessary if used for industrial processes. There are the following forms of heating: resistance heating, induction heating, infrared heating, microwave heating, graphene heating and carbon nanotube heating. We now explain in short, these different industrial heating technologies (see **here**).

Resistance heating is a common heating technology that involves passing an electric current through a material with high resistance, such as a metal wire or an alloy. They are controlled with a thermostat. The resistance generates heat, which is used to heat up the material. Resistance heating can be used for temperatures up to 1200°C.

Induction heating is the technology that involves using electromagnetic induction to heat up a material. It is a non-contact technique for heating metals or other electrically conductive materials by electromagnetic induction. An alternating magnetic field is generated around the material, which induces an electric current in the material, producing heat. Induction heating can be used for temperatures up to 2500°C.

Infrared heating uses infrared radiation to heat up a material. The infrared radiation is absorbed by the material, which heats up. Infrared heating can be used for temperatures up to 1000°C.

Microwave radiation is used to heat up a material. Microwaves are non-ionizing radiation. This means they don't alter atoms and molecules and damage cells like ionizing radiation does. The microwaves penetrate the material and excite the molecules, producing heat. Microwave heating can be used for temperatures up to 3000°C.

Graphene heating is a relatively new heating technology that involves using graphene to generate heat. When an electric current is passed through graphene, the resistance of the material generates heat. Graphene can be used in electric underfloor heating but also in industrial processes. Graphene heating can be used for temperatures up to 2000°C.

Carbon nanotube heating is another new heating technology that involves using carbon nanotubes to generate heat. When an electric current is passed through carbon nanotubes, they heat up, generating heat. Carbon nanotube heating can be used for temperatures up to 3000°C.

Pro and Cons and challenges of the heat sources

In the previous paragraphs various sources of heat and technologies have been discussed showing that each technology has its pros and cons. The table below depicts an overview of the pros and cons per technology. Some of the technologies are only applicable for low temperature applications such as unglazed solar collectors for warming the pool to nanotube heating for industrial processes. Households have several options in heating their homes in a more sustainable way. They could replace gas boilers by boilers that can burn synthetic fuels or retrofit existing boilers to burn bio-fuels. The most important adjustment is the burner, due to the different burning temperatures of different fuel mixes. Fitting a bio-fuel burner will ensure that your boiler performs at the best possible efficiency for the fuel source. Some of these boilers are not commercially available yet, for example boilers that use hydrogen as fuel. Generally these alternative fuels are more expensive. Another option would be to install thermal solar collectors or heat pumps. Both technologies need a significant upfront investment/installation costs. Heat pumps are very efficient but they need more time to heat a home and are only an option for thermally efficient homes. Finally household could have the option to use district heating, which reduce energy costs and emissions.

Pros and cons of heating technologies

Sources of heat	Cycle life	Temperature	Application	Pros	Cons
Burning fuel or mass					
A-rated gas boiler	10-15 years	up to 70°C	Boiler	Fast heating Small radiators Low installation costs New boilers already higher efficiency (90%) Max flow temperature consistent 70°C Sufficient production	215 gr CO2 per kWh
Synthetic fuels			Boiler/burner	Fast heating Lower or no CO2 emissions	Limited production Efficiency challenge Expensive
Sun					
Unglazed solar collectors		Up to 30 °C	Swimming pool, space heating	Zero-emissions Relatively cheap	Less efficient versus evacuated Lower temperature output
Transpired solar air collectors	25 years	As much as 38 °C > ambient air	Heating air, ventilating indoor spaces	Zero-emissions	
Flat-plate solar collectors	25 years	Up to 80 °C	Complement water boilers Pre-heating water	Wider temp range, zero- emissions Cheaper price Zero-emissions Work well in all climates	Less compacts Less efficient versus evacuated
Evacuated tube solar collectors	20 years	Up to 120 °C	Space heating Water heating Air heating	Lower heat loss Use sun's energy more efficiently Higher temperatures Tubes can be replaced individually Zero-emissions	More expensive More fragile than other solar collectors
Thermodynamic solar panels	25 years	Up to 60 °C	Hot water production Underfloor space heating	Operate in various weather conditions Absorp heat from sun or pull heat from air Works day and night, low operating costs Zero-emissions	Relatively new technology Expensive
Concentrated solar power	35 years	500-1,000 °C	Large-scale electricity generation Industrial process heat	High energy output Zero emissions	High capital & maintenance costs Lack experienced personel
Ground (+renewable electricity)					
Geothermal heat pumps	20+ years	60-90 °C deep heat pumps	For thermally efficient property	For 1 kWh electricty used 4x as much heat Zero-emissions with renewable electricity	Heat not as fast as gas boilers Very expensive
Air or water (+renewable electricity)					
Heat pump	10-20 years	max flow temp 35-45°C radiator max flow temp 50°C hot water	For thermally efficient property	2 to 4x more heat than direct electric heating For 1 kWh electricty used 3x as much heat Zero-emissions with renewable electricity	Heat not as fast as gas boilers Expensive Need of larger radiators
Rest heat					
Combined Heat and Power		100-180 °C Gases above 450 °C	Heating, centing and airco systems	Waste heat re-used Reduce carbon emissions up to 30% Lower emissions	Development of system can be expensive Not truly being sustainable
District heating		80-100 °C		Lower energy costs Lower emissions Security of supply	Need larger infrastructure
Electricity (renewable)		1,200 to 3,000 °C	Heating home and industrial	Electric heating is 100% energy-efficient Zero-emissions with renewable electricity	Consumes a lot of energy Production generates losses; not 100% efficient

Source: IEA, NRDW, heatable.co.uk, energy.gov, upc.edu

For industries heat with higher temperatures is needed for industrial processes. They are currently mostly on fossil fuels. Replacing fossil fuels is more challenging for industries as not all alternative ways of heating are suitable for industrial processes. Concentrated solar power and heating with green electricity as well as using synthetic fuels are the main options. But these options are currently very expensive. For office heating the use of rest heat, heat pumps and some thermal solar collectors are also possible options.

Conclusion

Heating is mostly generated by burning fossil fuels. Alternative ways of heating only take a small share. To reduce emissions and even reach net-zero in 2050 for heating is an enormous challenge. There are several ways to approach this. We can continue to burn something. But then the fuel or mass needs to be replaced by a more sustainable and low emission fuel or mass. The availability and the production of these fuels are still limited and not enough to replace fossil fuels. Moreover these fuels are more expensive. There are also other sources to generate heat namely the sun (via thermal solar collectors), the ground, air and water (via heat pumps). The possibilities are available but the costs are still high compared to burning fossil fuel. There is another challenge concerning heat pumps. It is likely that the EU will further strengthen the regulation to reduce the use of fluorinated gases (F-gases) which are used as a refrigerants in heat pumps. This could hamper the roll out and/or acceptance of heat pumps. Rest heat is another source of heat that is mainly been wasted. The potential of rest heat for industry and district heating are substantial. Last but not least, renewable electricity could be converted into heat for household and for industry, but for households there are more efficient technologies available such as heat pumps. So all the alternatives have their pros and cons. To move towards more sustainable form of heating these alternative heating technologies need to become more affordable, supply/availability needs to increase and the use of fossil fuels needs to become more expensive.

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