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Solar Systems for Industrial Process Heat and Power

INDHEAP

Optimal Solar Systems for Industrial Heat and Power

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Status of the methodology on integration of RES heat & power in industrial energy systems

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Executive Summary

The INDHEAP project investigates the integration of hybrid renewable energy systems (RES) in industrial applications, focusing on solar thermal and photovoltaic technologies. The project aims to overcome the limitations of single energy technologies by combining them to achieve higher efficiencies and meet diverse energy demands. Key objectives include identifying common strategies for integrating hybrid solar thermal and photovoltaic systems, gathering best practices, and understanding future research and development needs.

The technological overview covers various components such as:

- standard flat plate collectors (FP)
- evacuated tube collectors (ET)
- photovoltaic-thermal collectors (PVT)
- concentrating solar thermal technologies (CST)
- vapor compression (VC)
- heat pumps (HP)
- electric resistance heater (ERH)
- photovoltaic collectors – (PV)

Each technology's working principles, efficiency, and application potential are discussed.

Several integration concepts are explored, including:

- PV, TES and Heat Pump
- (Non-)concentrating solar thermal, TES and heat pump
- PVT, TES and Heat Pump
- CST, TES, PV with heat pump
- CST, e-TES and PV
- CST, e-TES, TES and PV
- PVT, ORC and TES
- CPVT, TES (and HP)

Best practice examples highlight successful implementations of hybrid RES systems, such as:

- Project FriendSHIP: Combining parabolic trough collectors with heat pumps and thermal energy storage.
- Project Linz Textil: Using PVT panels and heat pumps to replace gas boilers.
- Project Vossen: Integrating PVT, PV, TES, biomass, and heat pumps.
- Project Anton Paar: Implementing a solar ice storage system for heating and cooling.
- Project Henri Willig: Utilizing C-PVT collectors for cheese production.
- Project GreenTEC Campus: Developing the SunOyster technology for co-generation of power and heat.

The findings demonstrate the potential of hybrid RES to achieve significant energy savings, reduce CO2 emissions, and enhance overall system efficiency. The project provides valuable insights into best practices and future R&D needs, paving the way for more efficient and sustainable energy systems in the industrial sector.

Table of Contents

1. Introduction

In today's world, there are various energy concepts being researched and on the market. The single technologies are already on high technology research level (TRL) but are often facing limitations in their applicability. Either in an application case, there is more temperature needed, which the chosen technology cannot provide, there is also a need for electricity, or the efficiency is not feasible. For these cases hybrid renewable energy systems (hybrid RES) are the solution. These systems are combining different technologies, to get the most feasible solution in terms of efficiency and temperature level. Throughout the project INDHEAP a hybrid RES system, consisting of parabolic trough collectors (PTC), photovoltaic panels (PV) and a thermal energy storage (TES), shall be engineered and erected. In Work Package 2, Task 2.1. an overview of existing hybrid RES systems, with focus on solar technologies, will be provided in this report. This report is covering the objectives:

- Identify common strategies for the integration of Hybrid ST+PV systems in industrial processes
- Gather information on lessons learned, good practices, and future R&D needs from key stakeholders
- Broaden the understanding of hybrid ST+PV systems outside of INDHEAP approaches

Throughout this report we will analyse existing strategies and classifications of integration concepts for solar heat in industrial processes. We will gather best-practice examples (BPEs) of hybrid renewable energy source (RES) integration to identify common strategies. The SHIP database, which contains more than 500 documented SHIP plants hosted by AEE, will be screened for innovative examples that meet criteria such as hybrid RES systems (including combinations with other power-to-heat equipment), high solar shares for industrial systems, processes that require temperatures above 150°C, large-scale storage, and flexible solar/process target temperatures. Additionally, a separate database on photovoltaic-thermal (PVT) implementations is available at AEE for screening industrial applications. These criteria reflect the aim of achieving greater impact for industrial end-users and their goals of decarbonizing their energy sources. We will conduct short questionnaires with follow-up interviews with the key stakeholders of the BPEs to gather information on lessons learned, good practices, and future R&D needs to complete the status quo analysis. We will also actively reach out to similar Horizon projects. All information gathered will broaden our understanding of hybrid RES systems outside of INDHEAP approaches and ensure that novel ideas are well-communicated to relevant IEA Tasks (e.g. the SolarPaces Task IV or a possible future Solar Process Heat Task) as well as to Solar Heat Europe, the wider public, and the overall SHIP community. An overview of existing methodologies and best practice examples for hybrid RES integration will be given in and shared to T3.3.

2. Status of the methodology on integration of RES heat & power in industrial energy systems

The status of the methodology on integration of RES heat & power in industrial energy systems is described in this chapter. Firstly, a technical overview of the most important parts of one hybrid system is given. Following with the different hybrid systems, where to possible integration possibilities are outlined. Concluding this chapter is going to be the overview of researched best practice examples of hybrid systems which are capable of providing 150°C or more.

After this chapter the reader shall have a good understanding of various hybrid systems with their respective components, as well as the status quo of current erected, engineered or planned hybrid systems.

2.1. Technological overview

As hybrid RES can consist of various single technologies, this chapter shall give a short overview of possible single technologies, with focus on solar technologies, that can be used, engineering such a RES. Throughout the literature research and the internal knowledge of AEE INTEC, an overview graphic was designed and is displayed in Figure 1.

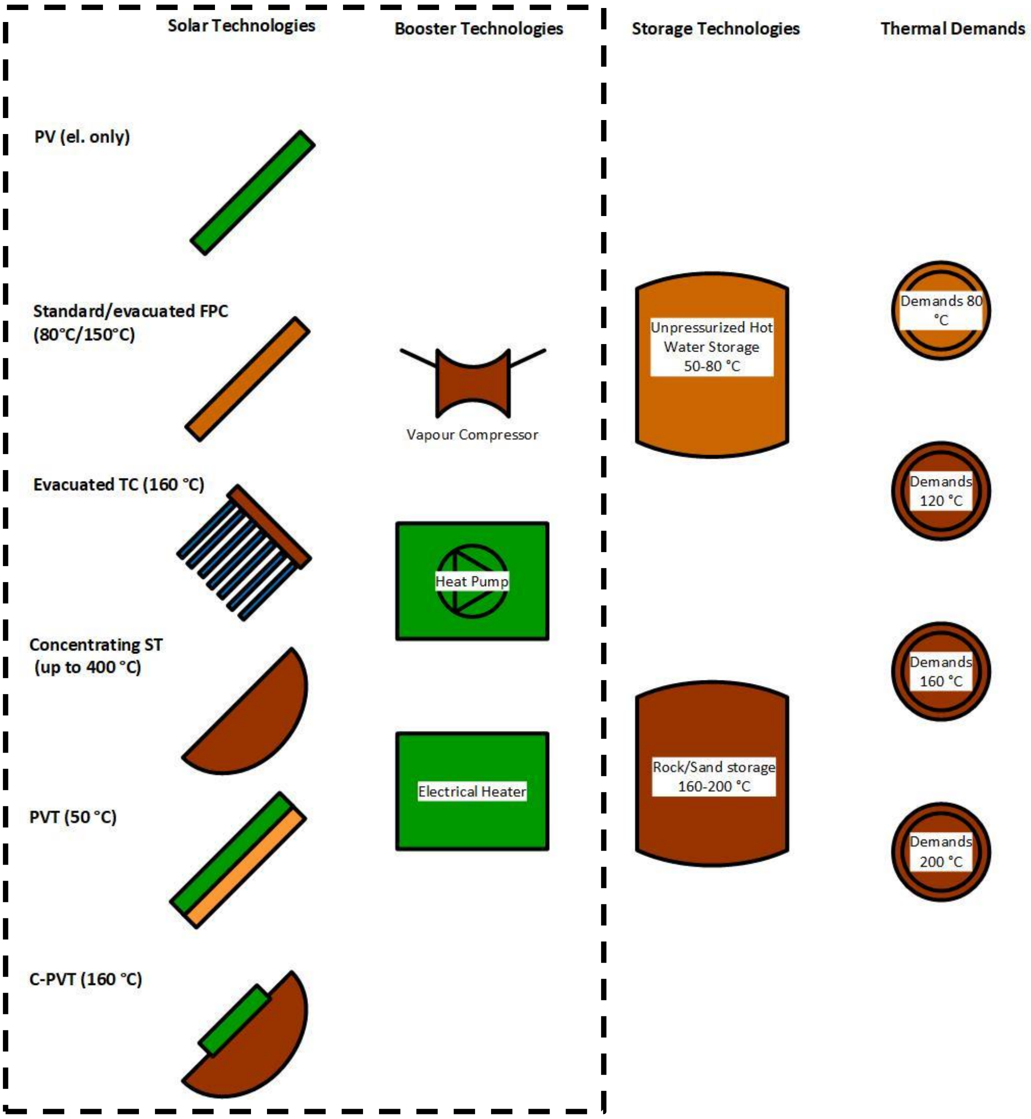

Figure 1 Classifications of RES concepts (own graph, AEE INTEC)

Each component shall be described shortly, to get a better understanding of the working principle of each technology.

2.1.1. Photovoltaic collectors (PV)

Photovoltaic collectors are a technology, which can convert sunlight directly into electrical energy. The sunlight consists of photons. When these photons reach the semiconductor, mostly silicon, electrons may get dissolved from the n-type layer and travel to the p-type layer, generating current and therefore electricity, as seen in Figure 2.

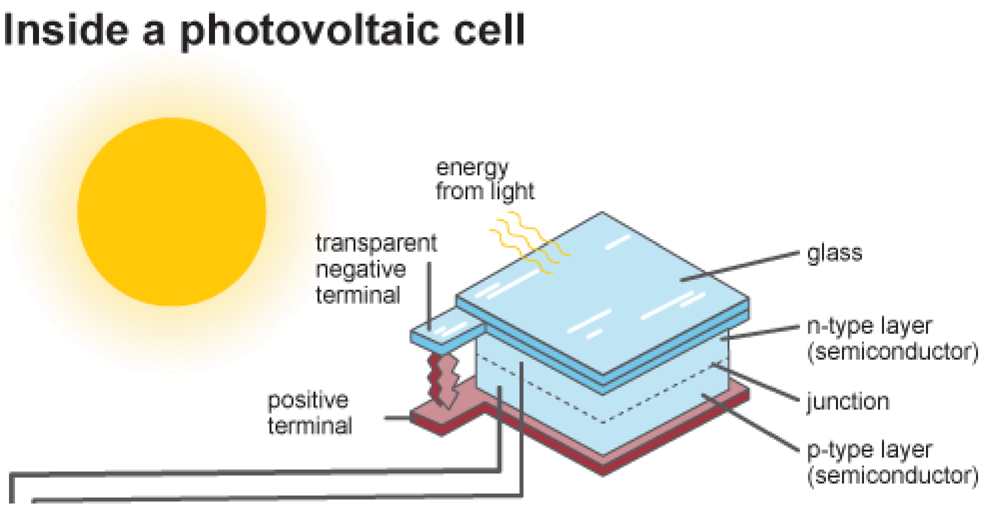

Figure 2 Photovoltaic cell [1]

This technology is very flexible in its usage, as the generated electricity has high exergetic value and can be used in different ways for electrical and thermal demands. The downside is the efficiency of the PV modules compared to other solar technologies. Until 2015 the max efficiency was 15% and is now approaching 25% for state-of-the-art modules. For niche products like for space travel, they already achieved around 50% efficiency cf. [1]. The ongoing research for PV modules is gradually reducing the price and rising the efficiency. Nowadays photovoltaic is experiencing way more growth than solar thermal applications, due to the consistent drop in price cf. [2].

2.1.2. Standard flat plate collector (FPC)

Standard flat plate collectors are widely distributed on the European market [2]. As they are the simplest and cheapest way, to convert sunlight into heat. Consisting of a transparent cover, which leaves the sunlight through, a dark, mostly selective, absorber which is collecting and transporting the heat to the flow-pipes and a rather simple hydraulic system cf. [3]. The set up can also be seen in Figure 3

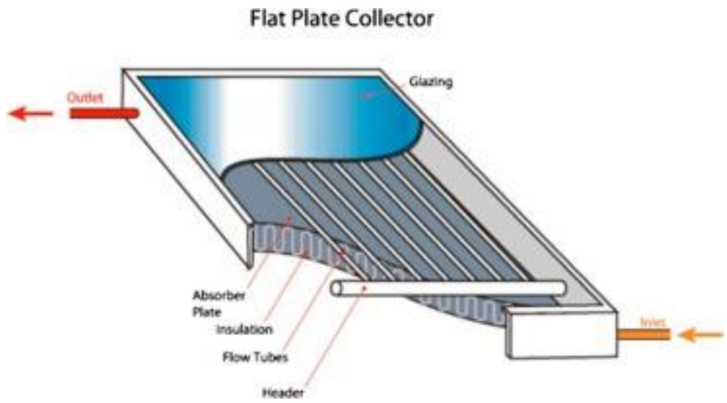

Figure 3 Flat plate collcector [3]

This collector is mostly used for domestic water supply, as it reaches only 80°C and is therefore on of the “colder” collector types. With special design, consisting of selective glazing of the transparent cover plate and evacuation between absorber and cover plate, the temperatures can reach up to 150°C cf. [4].

2.1.3. Evacuated tube collector (TC)

Evacuated tube collectors are most widely distributed in China [2]. The set up is different to that of a FPC, as this collector type consists of evacuated tubes, containing the flow-pipes. Each tube is like a mini-evacuated FPC, as they also consist of a glazed transparent cover, a dark selective absorber with the flow-pipes and evacuation inside cf. [3]. The set up can be seen in Figure 4

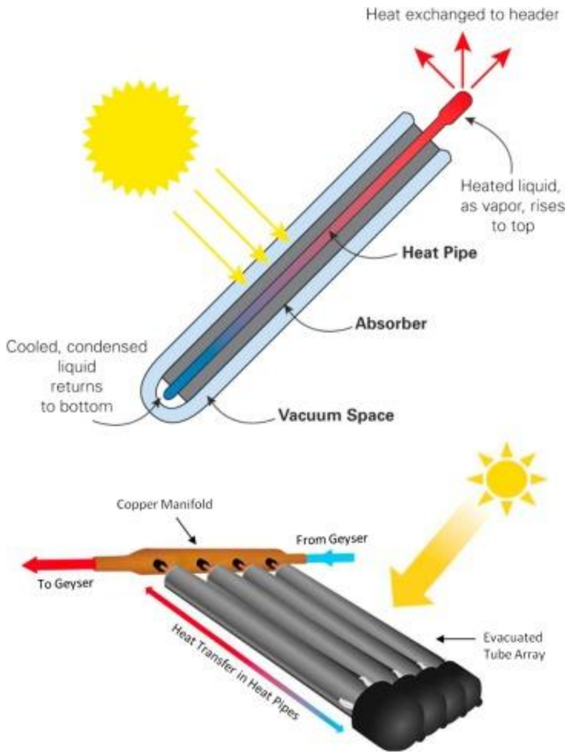

Figure 4: Evacuated tube collector[3]

Due to its evacuation, this collector has very little heat loss and can therefore supply higher temperatures up to 170°C and operate more efficient at lower temperatures (winter) cf. [3]. Nevertheless, this type of collector usually costs twice as much as the FPC cf. [5]. Furthermore, flat plate collectors have a higher area usage ratio, as the tube collectors must have empty spaces in between the tubes and therefore need more space for the same collector area cf. [3].

2.1.1. Photovoltaic-thermal collector (PVT)

Photovoltaic thermal collectors are a combination of PV and solar thermal. On top of the collector there is the PV layer, secured by a glass layer. Below the PV module there is the thermal collector, which transfers the unused or excess heat to water pipes, as see in Figure 5 With that system high overall efficiency can be achieved, combining >15% from PV and up to 60% through the thermal part of the TVP, resulting in an overall efficiency up to 65% [6]. Nevertheless, as with the evacuated TC, this technology is quite expensive compared to the individual technologies. Also on the thermal side, the temperatures cannot exceed around 60°C as the efficiency of the PV modules are dropping with rising temperatures. This temperature level is suitable for hot water production and are thus ideal application for e.g. hospitals with limited space availability cf. [7].

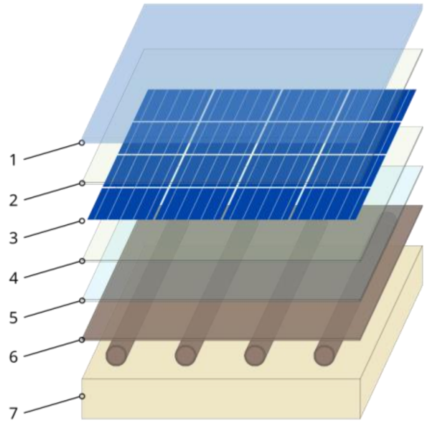

Figure 5: PVT collector [7]

2.1.2. Concentrating solar thermal

Concentrating technologies would be the concentrating vacuum tube collector, Fresnel collector, dish collector, concentrating tower applications and the parabolic trough collector. The most widely distributed concentrating technology is the parabolic trough collectors. The parabolic through is redirecting the sunlight to an absorber pipeline, which is mounted in the middle of the parabolic trough, as seen in Figure 6. Similar technologies are concentrating dish and fresnel collector cf. [8].

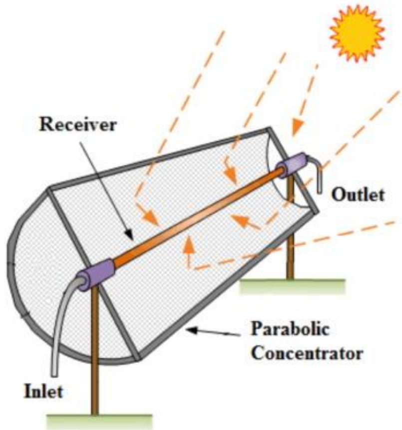

Figure 6: concentrating thermal collector [8]

As this type of collector is only using the direct irradiation, the destinations are limited to the sunnier and less cloudy parts of the world. To capture the sunrays throughout the whole day, the collectors are engineered as either one-axis or two-axis collectors, to follow the sun. The big advantage of this technology is the achievable temperatures up to 400°C. Therefore, steam, thermal oil or pressurized hot water can be produced and used directly in the industry or for powering a steam turbine. But higher temperatures also mean higher heat losses, that is the reason why this type of collector has a lower solar utilization efficiency cf. [8]. In INDHEAP a small parabolic trough collector by Absolicon will be considered.

2.1.3. Concentrating PVT collector (C-PVT)

This type of collector is combining the concentrating technology with the photovoltaic technology. The TRL level is still low for this technology but shows great potential. The combinations and placements of the PV modules varies from study to study. Nevertheless, the PV-module should rise the overall efficiency of the parabolic collector cf. [9].

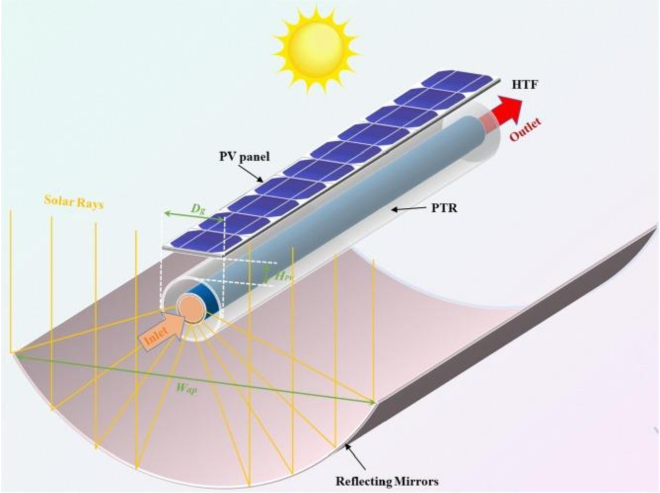

Figure 7 parabolic trough C-PVT collector with topped PV-panels [9]

In Figure 7 a C-PVT can be collector seen, which has PV-panels above the absorber pipe. The structure of the collector can be described as a standard parabolic trough collector, on which PV-panels have been mounted. Therefore, it is possible to generate a small amount of electricity. The sunlight received by the PV-panels is non concentrated and therefore underlying the same efficiency as standard PV panels cf. [9].

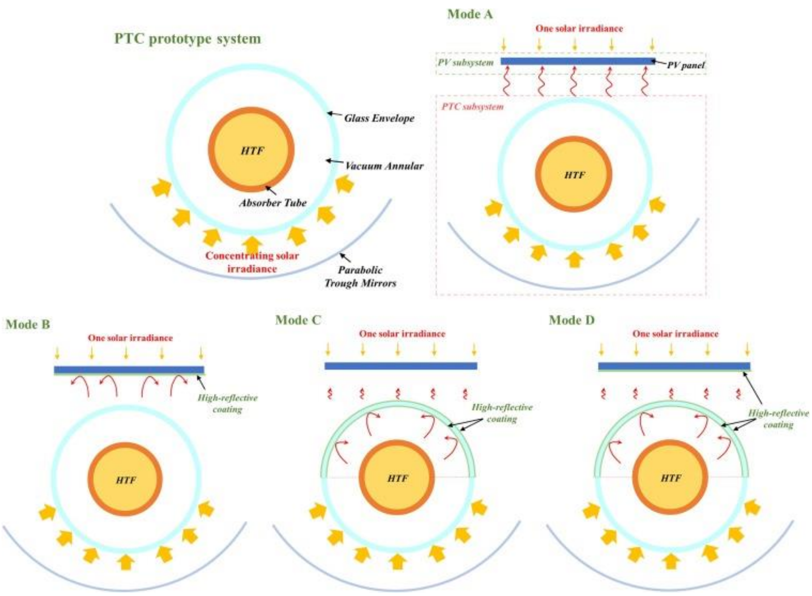

Figure 8 Variations of parabolic through C-PVT collectors [9]

Figure 8 is describing the same technology as the paragraph before. Additionally, this figure is showing what additional variations concerning the coating or reflecting spheres can be done. Due to that, higher efficiencies in both the parabolic trough and the PV-panels are achievable cf. [9]

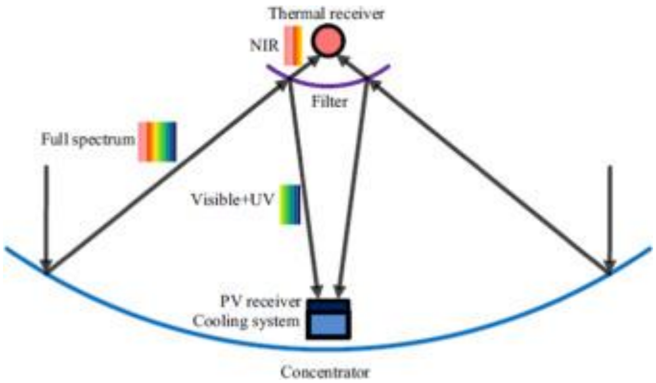

Figure 9: System concept of concentrating dish C-PVT collectors [Type 1] [10]

Comparing to Figure 7, Figure 9 is showing a combination of a concentrating dish and PV-panels in the bottom of the concentrating dish. The advantage hereby is that PV-panels are receiving concentrated visible light, with less infrared light. Therefore higher efficiencies and less overheating, due to concentrated light, are possible cf. [10].

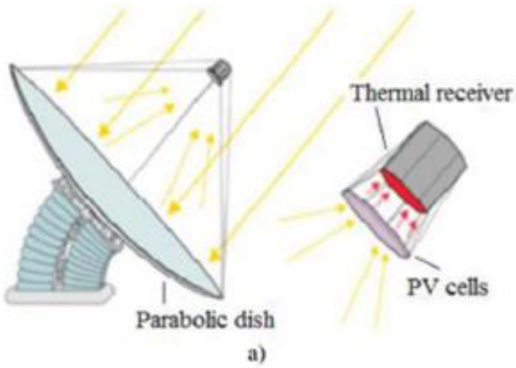

Figure 10 System concept of concentrating dish C-PVT collector [Type 2] [10]

Figure 10 is showing a different approach of concentrating dish C-PVT collectors. In this case, all the irradiation is concentrated in one point. In this point, the irradiation is passing firstly through the PV-cells and then are being received by the thermal receiver. The advantage is the even higher efficiency due to the greater concentrating. Disadvantages can be risk of overheating the PV-cells due to a malfunctioning of the thermal receiver, resulting in lower efficiency or damage cf. [10].

Concentration PVT technologies are a promising variation, as they can achieve high temperatures with combined electrical production, in areas with limited space. Nevertheless, much research must be done, in order to bring a suitable technology to the market cf. [10].

2.1.4. Vapor Compression

Vapor Compression is used to boost the lower-exergy energy coming from the solar technologies. If, for example, the parabolic trough is producing steam at 2bar and the process needs 6bar, a vapor compressor can recompress the steam and feed it to the equivalent process. Vapor compressors can be designed as steam injectors, piston compressor, screw compressor, as seen in Figure 11, or turbo compressor. The combined approach could optimize the utilization of solar radiation by operating collector fields at lower temperatures while still achieving the required process parameters.

Figure 11: Vapour compressor [11]

2.1.5. Heat pumps (HP)

Heat pumps, the concept can be seen in Figure 12, are commonly used in space heating and domestic water heating, as HP can easily substitute the fossil oil boilers. The principle of the heat pump is to convert low temperature heat to higher temperatures by means of electrical compression and make it usable again. This is very relevant in the industry as a lot of low-grade excess heat is occurring in the daily production. Quite often excess heat needs to be actively cooled with chillers to fulfill regulatory obligations. In contrast, with HPs the excess heat can be utilized if right temperatures can be achieved. The thermodynamic principle of the Carnot cycle is the same for Heat pumps and chillers cf. [12].

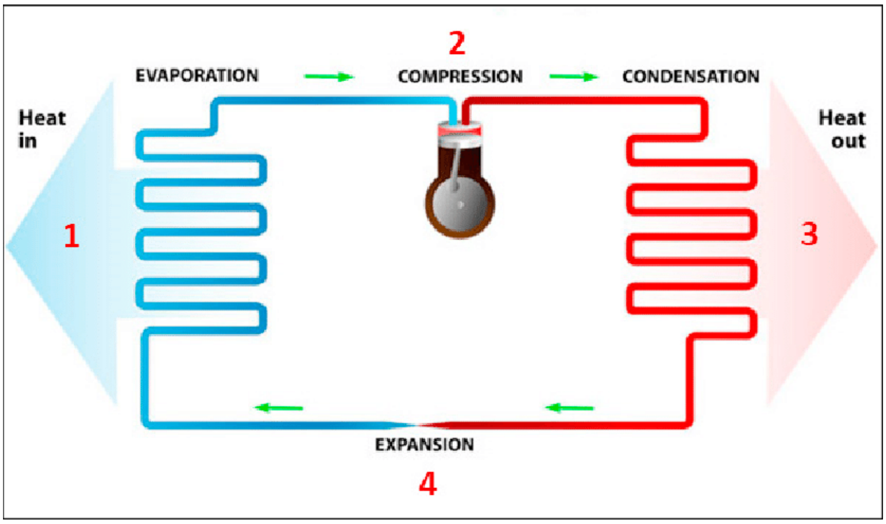

Figure 12: Heat pump concept [12]

In case that the temperature from the solar technology is too low for the process in the industry the heat pump can rise it to the needed temperature. For example: PVT is providing 60°C but the process needs 110°C. The HP can now use the 60°C and the electric energy to rise the temperature to 110°C. Heat pumps are widely used and are being researched extensively for higher temperatures. Today 160°C to 240°C of hot water or steam are achievable, depending on the quality of the heat supplier. HP can be a very useful addition to solar technologies to form a hybrid system but for higher temperatures concentrating solar technologies are still unbeaten cf. [12].

2.1.6. Electric heater

Electric resistance heater, see Figure 13, are converting 100% of the given electric energy into heat. Mostly they are used, to cover the peak load of various processes, as they do not need a start-up-time. With these heaters, the only limitation for the achievable temperature is the material-stress and the infrastructure supplying the energy. If the infrastructure is not capable of delivering such amounts of current, the electrical heater cannot provide enough energy.

Nevertheless, combinations with HP for peak coverage and over-heating applications are already settled in the market and widely distributed.

Figure 13: electrical resistance heater [13]

Single usage of this technology, like an e-boiler, is not the most efficient way, as the power generation is limited through the efficiency due to double conversion (steam turbines) or seasonal/environmental variations (solar, wind). Therefore, a combination of renewable technologies and electric heaters seems to be ideal.

2.2. Existing integration concepts of hybrid renewable energy systems

The different named technologies in the previous chapter, can be combined to form a hybrid renewable energy system (hybrid RES). These systems are advantageous as they can be combined in a way that disadvantages of the singe technology can be overcome. For example, on a cloudy day the solar thermal collector is not reaching the desired temperature, therefore the heat pump jumps in and boosts up the heat to the desired temperature.

Before giving an overview of the possible integration concepts found in the literature research, an overview of the integration process itself shall be given.

2.2.1. Introduction to the integration process

When integrating solar heat into industrial or commercial plant, the goal is to identify the most technically and economically suitable integration point and concept. Given the complexity of heat supply and distribution in industry, where numerous processes require thermal energy, this task is typically nontrivial. Understanding design factors related to solar energy integration in industrial process heating systems is crucial.

Therefore, an energy audit like analysis of the industrial or commercial plant must be done. An understanding of the different temperature levels and heat demands as well as the variability of the processes needs to be erected. When understanding these parameters one can start to define points of suitable temperature and loads, where the hybrid RES can be implemented. In the IEA SHC Task 49 a classification was developed and published, that allows a generalization of possible integration points on supply or process level.

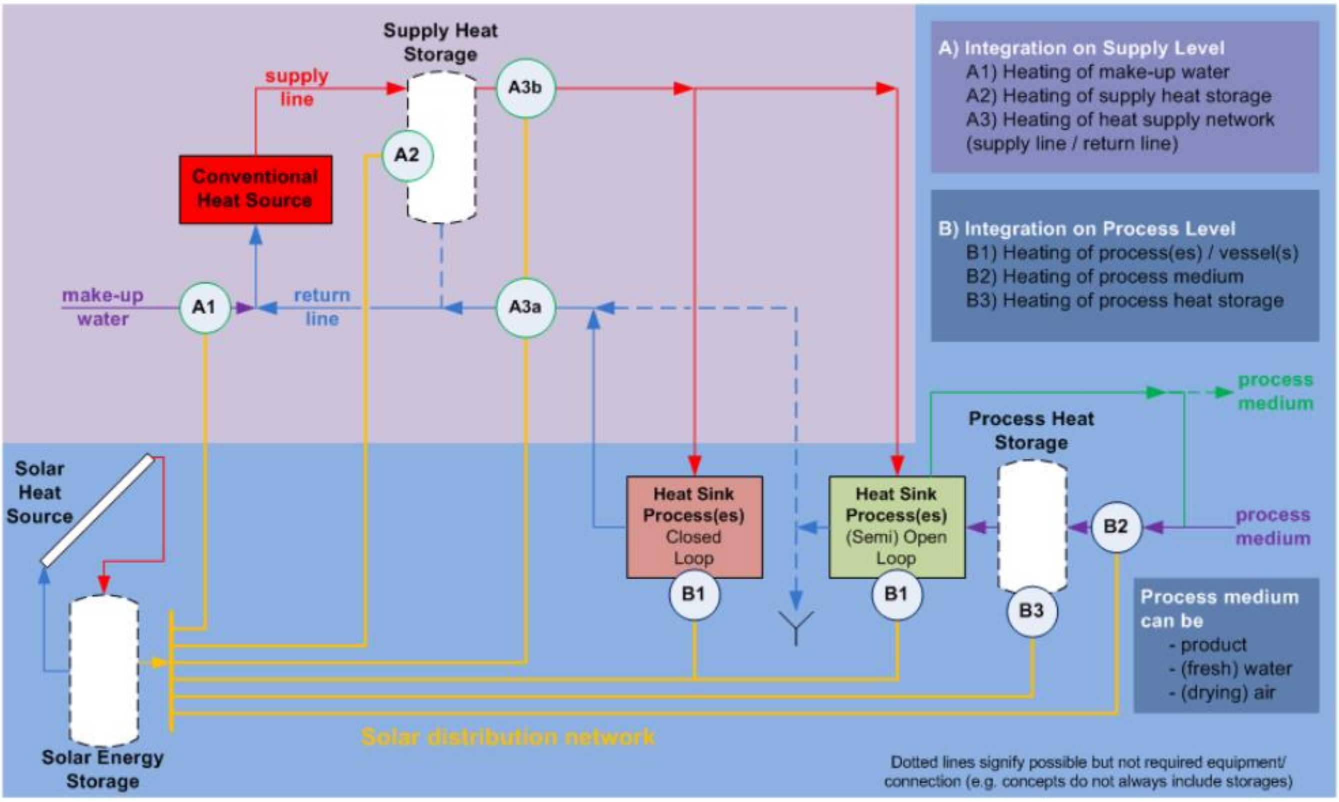

Figure 14 overview of integration points (own graph, AEE INTEC)

This graphic shall only be an overview, because as previously mentioned finding the best integration point is not trivial. However, throughout the literature and best practice examples, it can be said that most renewable energy systems are integrated on the supply level. Most of the time it is tried to use the same heat transfer medium, so no further adaptions need to be made. Basically, on the supply level, the boiler can be switched with the RES like a blackbox if the heat transfer medium stays the same (physically as thermodynamically).

2.2.2. Overview of hybrid renewable energy systems

During the literature research, various technology combinations have been found. This chapter shall give a quick summary of the found combinations:

- PV, TES and Heat Pump
- (Non-)concentrating solar thermal, TES and heat pump
- PVT, TES and Heat Pump
- CST, TES, PV with heat pump
- CST, e-TES and PV
- CST, e-TES, TES and PV
- PVT, ORC and TES
- CPVT, TES (and HP)

It can be said that the above-mentioned hybrid systems are just a general overview of possible systems as the integration points and concepts vary amongst the researched studies. The chosen concepts and in the following more detailed outlined ones, were the most interesting and/or furthest researched ones. This chapter shall only give an overview and does not provide any comparison or evaluation whatsoever.

2.2.3. PV with Heat Pump

As photovoltaics become increasingly efficient, their adoption in domestic settings is on the rise. This technology also offers significant advantages for industrial applications. PV has a lower efficiency/conversion factor but is producing electricity, which has high exergetic value. With this energy, the electrical consumers of one's plant can be supplied in parallel with the heat pumps. Therefore, even if the heat pump has a worse COP, with one's own PV-plant the electric consumption is no issue.

For a possible system integration, the heat pump can be engineered as the only heat supplier (inclusive back-up). The heat source used in the system shown in Figure 15 is environmental heat, providing mostly hot domestic water and space heating up to 80°C. However, waste heat or other heat sources may be applicable, resulting in higher temperatures. The electricity produced by the PV can be used directly in the plant, for the heat pump or can be fed into the grid cf. [14]. Figure 15 shows a possible concept with a PV and heat pump.

The advantage for this concept is the universal use of the generated electric energy. Additionally, the heat pump can also be used as a cooling device, also powered by the PV panels in the summer months cf. [14].

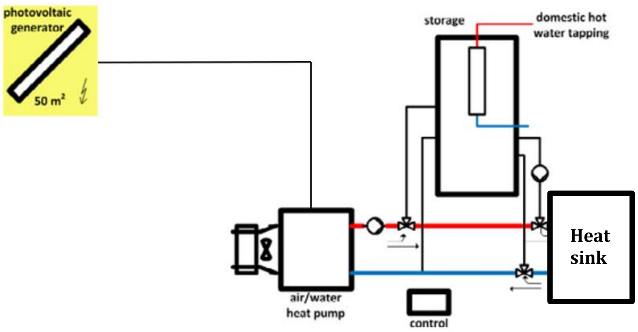

Figure 15: PV + heat pump [14,adapted]

2.2.4. (Non-) Concentrating solar thermal with heat pump

The use of unglazed, glazed and concentrating collectors can be combined with a heat pump and mostly a thermal energy storage. With this setup, two operations modes can be operated: parallel and serial.

Parallel

The parallel operation is using the heat from the thermal collector directly to heat up the storage or process. The heat pump is using environmental heat to generate heat for the process cf. [14]. This type of operation is shown in Figure 16.

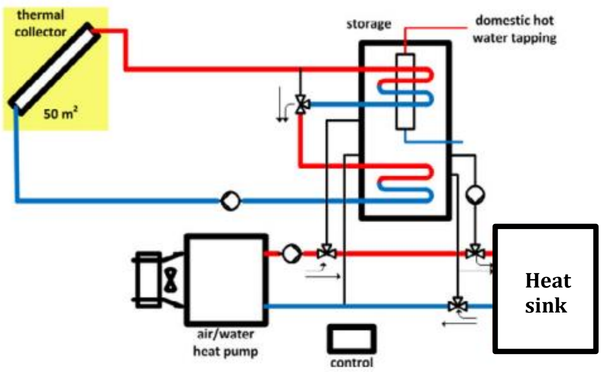

Figure 16: thermal collector + heat pump [14, adapted]

Usually with this operation mode, the heat pump is the backup for cloudy days or winter time when the solar thermal plant, is not able to provide the needed temperature. Nevertheless, with the non-concentrating technologies the temperatures are in the range of under 100°C. Concentrating technologies are achieving up to 400°C. Also, the heat pump is only operating feasible with environmental heat until around 80°C cf. [14].

Serial

For the serial integration, the heat pump is using the solar thermal heat as a source. Therefore, with a high temperature heat pump, high temperatures up to 250°C can be achieved. The issue is the demand on the solar heat and its seasonality. During summer, the heat pump can be skipped, depending on the needed temperature and collector technology, and be directly fed into the process or storage tank. During winter there is little to no energy produced and the heat pump has less source-temperature to be working with and may even cool down the circuit to a temperature where no more energy is able to be subtracted. Therefore, a dual source heat pump where it is also possible to gather energy from the environment or a suitable designed seasonal energy storage, shall be chosen for security. The back up boiler not mentioned cf. [14]. A possible integration concept is shown in Figure 17.

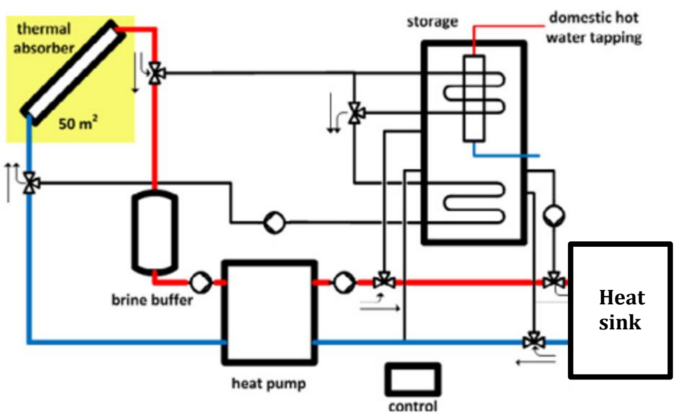

Figure 17: solar thermal + heat pump (serial)[14, adapted]

2.2.5. PVT with Heat Pump

An interesting technology is the photovoltaic thermal absorber. A combination of PV and solar thermal collector, fused together in one technology. As described earlier, the PV-panels can only make use of the visible light. The infrared light, which carries a lot of heat, cannot be processed and is therefore lost. The PVT collector is now using a thermal absorber on the back of the PV panels to collect the infrared irradiation and also making sure that the PV panels are always operating under their maximum temperature of around 60°C cf. [14]. That is the reason why PVT collectors are ideally used in combination with a heat pump with serial integration as shown in Figure 18.

The PVT collector is now providing medium tempered water as a source for the heat pump and simultaneously, with the same space usage, electricity for the HP or other processes. Of course the system has to be precisely designed, so the collector can provide the needed energy throughout the whole year or a seasonal storage or double-source heat pump for environmental heat usage, needs to be chosen cf. [14]. Even though the systems may be seen only for domestic use or space heating, two best practice applications for industry are shown in the following chapter.

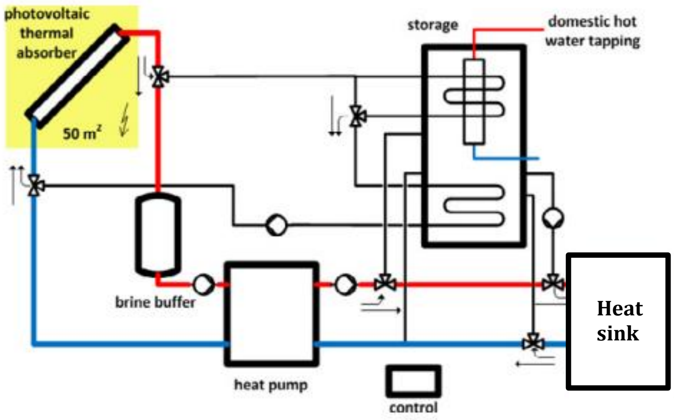

Figure 18: PVT + heat pump[14, adapted]

2.2.6. CST, TES, PV with heat pump

This hybrid system, shown in Figure 19, is using the quite same components as the (non-)concentrating hybrid system but with differences in operational mode and area of application. This system is additionally using PV-panels to generate extra electricity for the heat pump or the plant. The non-concentrating hybrid system is mostly used in domestic hot water supply or space heating. But when it comes to industrial processes, higher temperatures and energy quantities are needed cf. [15].

The system described in the title consists mostly of the following:

- A concentrating technology, mostly parabolic trough collectors but also Fresnel collectors, dish collectors or concentrating towers are possible.
- An energy storage, can be pressurized hot water, steam, salt or solid media.
- And a high temperature heat pump where the source can be environmental heat, but if available it would be more feasible to use waste heat.

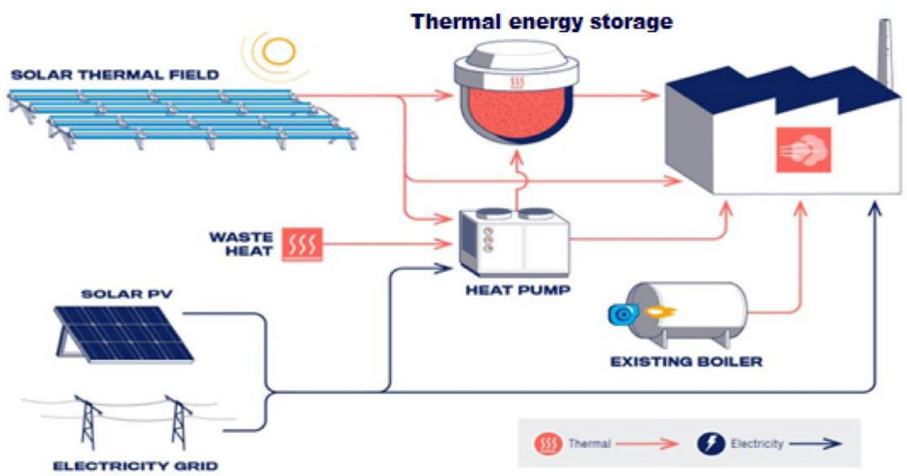

Figure 19: CST, TES, PV and Heat Pump [15]

With this system, average temperatures up to 200°C and above are possible. The peak temperatures may be up to 400°C from the parabolic through collectors. The parabolic through is delivering high temperature heat, which is then stored in the storage tank. The heat pump is supplying heat, when the solar yield is not enough to supply the process heat. Additionally, with the PV plant, internal electrical processes can be supplied with electricity, but also the heat pump can be fed with own produced electricity cf. [15].

Previous studies have shown that this hybridized concept of renewable energy system has the lowest levelized cost of heat (LCOH) compared when these technologies are used solely cf. [15].

2.2.7. CST, e-TES and PV

This concept, also proposed in the correlating project INDHEAP, is not using a heat pump but consist of a mix of non-concentrating and concentrating technologies, an electrical thermal energy storage and PV-panels. In INDHEAP case a parabolic trough, but also Fresnel collectors, dish collectors or concentrating towers are applicable, a dual-media storage with electrical resistance heater and normal PV panels are used cf. [16].

The project wants to combine the advantages of concentrating solar technologies (high efficiency and medium temperatures up to 200°C) and PV panels (universal usable energy) to supply heat to an industrial plant. The e-TES is used to store the heat from the solar thermal plant (when not fed directly) and to overheat or re-heat the heat transfer medium in the tank with the energy produced from the PV panels. With this concept low LCOH shall be achieved and as close to 100% renewable share is the target cf. [16]. The first concept design is shown in Figure 20.

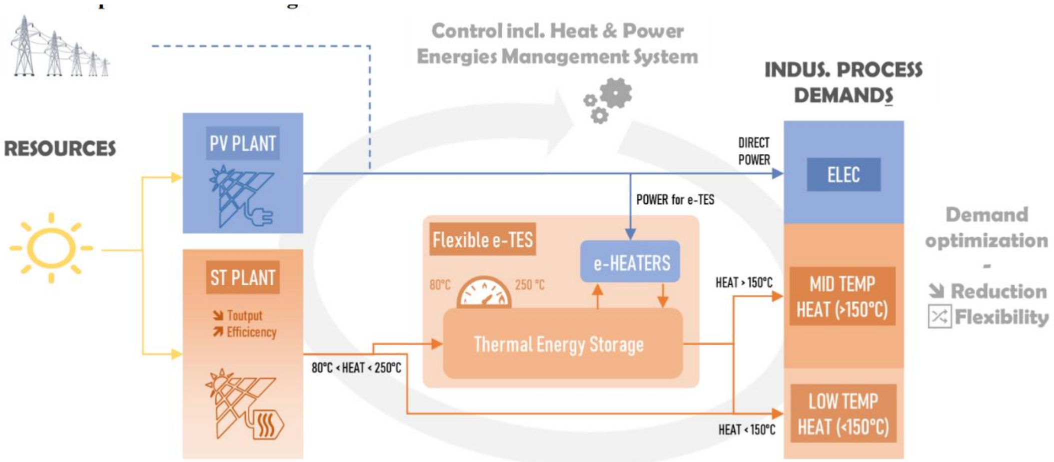

Figure 20: CST, e-TES and PV [16]

In this concept, both of the energy provider are feeding their energy in one common thermal energy storage. The storage is designed to be loaded up to 250°C even though the process needs around 170°C. This is due to the situation when the solar thermal collectors are feeding 200°C and the PV has also excess energy that needs to be stored in the tank. Therefore, the electric resistance heater would use the energy to heat up the e-TES up to 250°C. The e-TES has dual-media as a heat capacitor and can withstand high temperatures and flexible temperature supply or withdrawal cf. [16].

Interesting is the comparison with the next system concept “CST, e-TES, TES and PV” as they are using two thermal energy storages, as the use of only one TES had higher LCOH than splitting it into two TES cf. [16].

2.2.8. CST, e-TES, TES and PV

This concept is also not using a heat pump, to reheat or support the solar thermal collectors, but is using an electrical-thermal energy storage consisting of sand, which can be heated internally with an electrical resistance heater. In a researched study there has been made a levelized cost of heat (LCOH) analysis. Different system combinations have been analyzed and conclude that the following system, shown in Figure 21, has the lowest LCOH with the highest solar yield and energy output cf. [17].

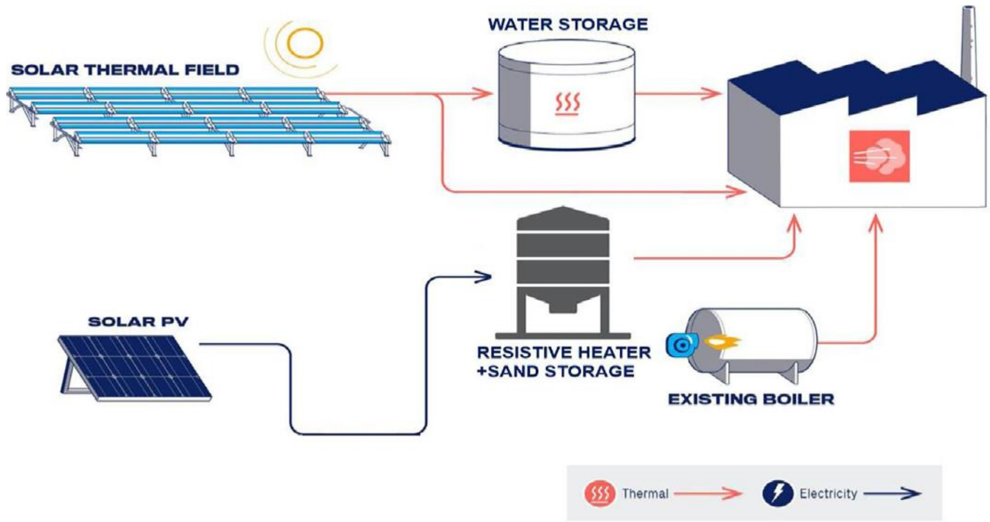

Figure 21: CST, e-TES, TES and PV [17]

If comparing this hybrid system with a system only consisting of PV and the e-TES, the study concluded a huge reduction in land usage and a lower LCOH of 83,5 €/MWh compared to 90 €/MWh cf. [17].

In this system there are two TES used. One for the smoothening and intermediate storage of the solar yield, and the other for the generation and long(er) storage of high temperature heat from PV panels. As with the PV panels, there is basically no limitation to the output temperature. The PV – e-TES system is used to support the parabolic trough when they are not reaching 200°C and also store in parallel the energy generated by the PV panels to supply the plant constantly with 200°C during night or in the morning or during cloudy phases cf. [17].

With this concept, a renewable share of 90% can be achieved with 83,5 €/MWh. The remaining 10% are being supplied by the existing natural gas boiler, as the LCOH are rising exponentially when trying to achieve 100% renewable share cf. [17].

2.2.9. PVT, ORC and TES

A study has shown that the combination of organic ranking cycles with PVT collectors, is a good solution for providing heat for space or swimming pool heating and parallelly generating electricity. A possible system design is shown in Figure 22.

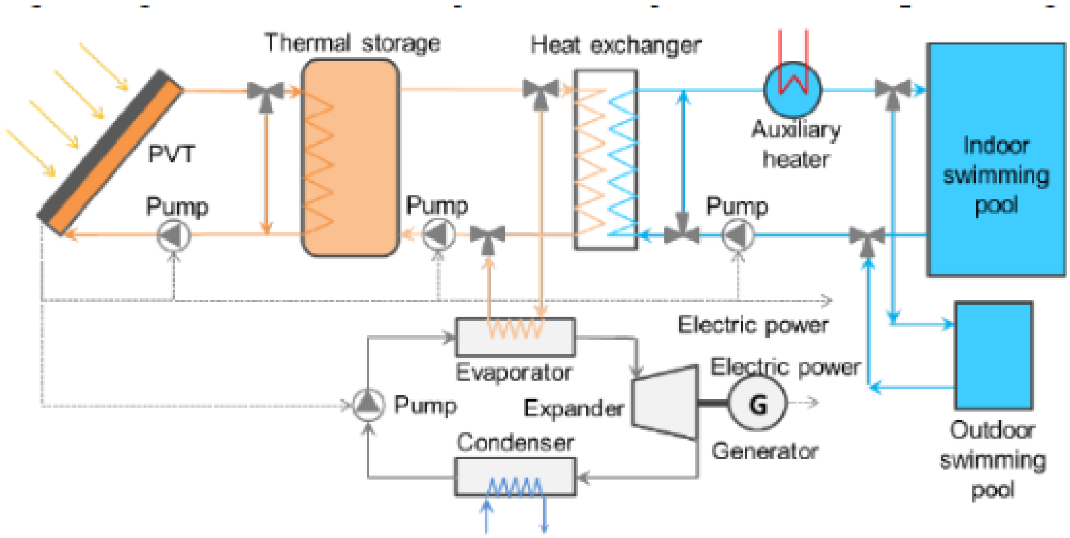

Figure 22: PVT and, TES with ORC [18]

A case study was conducted for the swimming pool at the University Sports Centre (USC) in Bari, Italy where the primary use of the thermal energy (hot water) produced by the PVT-water collectors was to satisfy the heating requirements of the swimming pool. Surplus heat at higher temperatures (above 70°C) was utilized by the ORC engine to generate additional electricity, complementing the electrical output from the PVT collectors. With a total installation area of 2000 m², the system meets 61% of the annual thermal demands of the swimming pools and generates 328 MWh of electricity annually. During the summer months, the coverage percentage ranges from 84% to 96%. The electricity produced by the ORC engine accounts for approximately 4% of the system's total electrical output. An optimized water tank volume of 125 m³ suggests a minimum payback period of 12.7 years for the proposed PVT-ORC S-CHP system in this scenario. cf.[18]

2.2.10. CPVT and TES

CPVT is an interesting concept as it is combining solar thermal and photovoltaics in one but also concentrating the solar irradiation. These systems consist of a concentrating collector, may it be Fresnel collectors, parabolic troughs, dish collectors or concentrating towers, with an integrated photovoltaic area.

For example, a combined CPVT as a parabolic trough, shown in Figure 23, is using a holographic lens to split the receiving light into the optimal spectral range for photovoltaics and redirecting them directly to the PV-module, whereas the rest is directed onto a thermal tube to generate heat cf. [19].

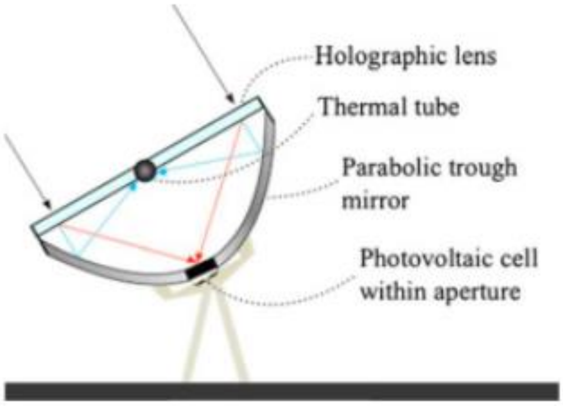

Figure 23: parabolic trough combined with PV [19]

Another possible combination is the concentrating dish collector shown in Figure 24. Here no holographic lens is used. The working principle is similar to a conventional PVT flat collector. The concentrating rays are being received by the CPV module. There, electricity is generated and the excess heat is delivered to the cooling fluid cf. [19].

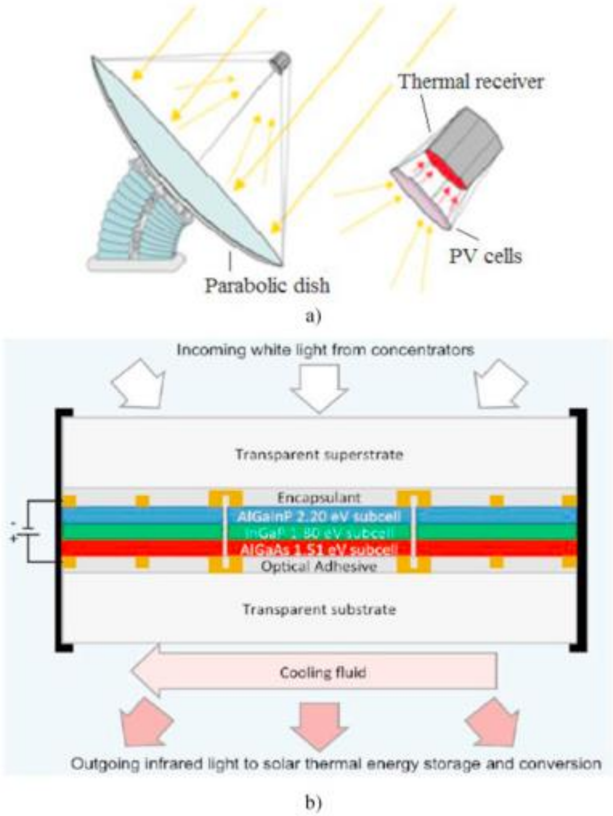

Figure 24: concentrating dish with PV [19]

A possible system layout is shown in Figure 25.

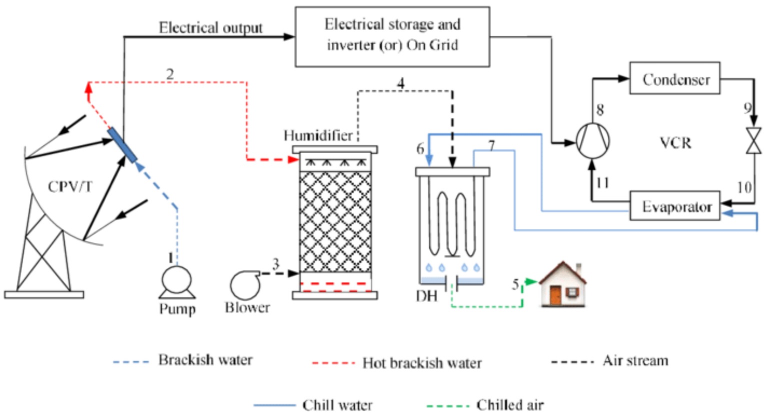

Figure 25: possible CPVT system layout [20]

CPVT (Concentrated Photovoltaic Thermal) collectors and systems continue to gain significant attention in both residential and industrial solar energy applications. This is due to their ability to deliver substantially higher thermal and electrical outputs compared to standalone PV (Photovoltaic) or hybrid PVT (Photovoltaic Thermal) systems. This is achieved through the use of energy-efficient concentrators that maximize solar energy capture within the collector cf. [10].

The study thoroughly analyzes system efficiency, operating temperature, and the coefficient of performance (COP) for different types of concentrators and concentration ratios. Key findings from the research include that CPVT systems that incorporate parabolic trough collectors can achieve an overall thermal efficiency of 70% and an overall electrical efficiency of 25%, depending on factors such as design, material quality, tracking level, and operating conditions cf. [10] .

The PV-CSP hybrid system offers several advantages over standalone PV or CSP systems:

1. **Improved Power Quality**: PV systems meet daytime demand, while CSP systems store thermal energy to generate electricity during cloudy periods or at night, ensuring a consistent power supply.
2. **Higher Efficiency**: Utilizing PV-Topping and SBS (solar beam selective) technologies, these systems achieve efficient energy distribution and cascade utilization, leading to an overall power generation efficiency of over 40% if used as a CSP system.
3. **Cost Efficiency**: Although the economics of PV-CSP hybrid systems are still debated, they offer potential cost reductions in solar power generation. High capacity factors (CF) make these systems cost-effective, especially under optimal operating and climatic conditions. Energy storage in the form of heat is also cheaper than electrochemical storage.
4. **Suitable for Large Solar Power Plants**: Unlike PV/T technology, which is used in small energy systems, PV-CSP hybrid technologies are better suited for large power plants that supply grid-demanded energy. Costs decrease due to economies of scale, and compact PV-CSP hybrid technology can also be used to develop micro solar power systems for remote areas.

cf. [19].

2.3. Best practice examples of implemented hybrid RES systems

In this chapter the status quo of the current erected, engineered or planned hybrid systems reaching 150°C is given. These hybrid systems are providing heat to an industrial process. As this report shall give an overview, please refer to the linked literature source for detailed information.

2.3.1. Project FriendSHIP: Concentrating ST with serial heat pump and TES

In the project FriendSHIP there has been a hybrid system proposed, where small parabolic trough collectors are generating heat at around 170°C and serial installed heat pump is rising it to 200°C cf. [21]. The system layout can be seen in Figure 26.

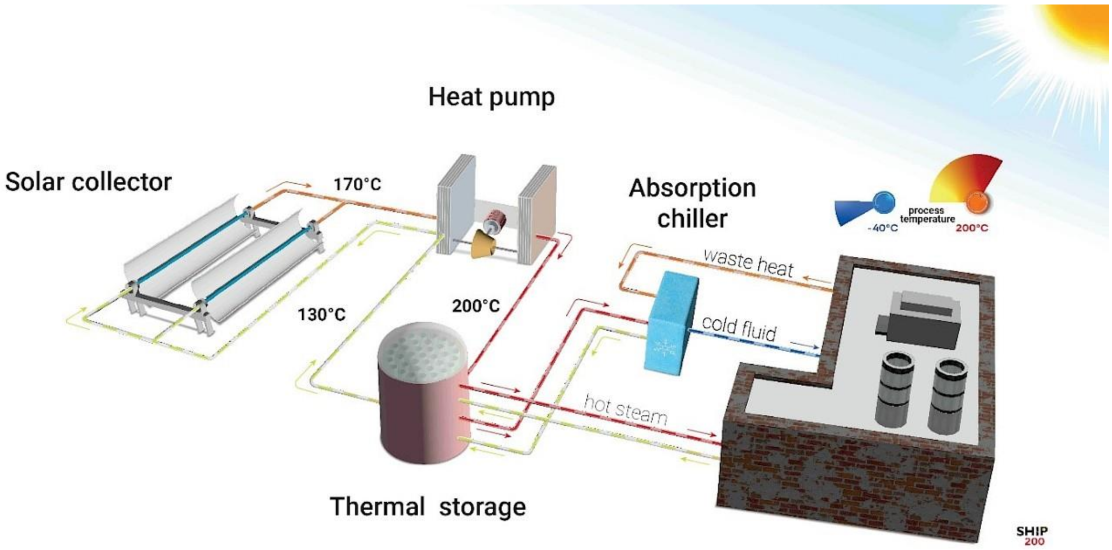

Figure 26: hybrid system friendship [21]

The generated heat shall then be stored in a thermal energy storage which is engineered as a latent heat storage based on PCM (Salt mixture) with a double fluid circulation loop. The advantage hereby is the possibility to also store excess heat from the process loop. Therefore, the thermal storage is working in both ways. Additionally to supplying the facility with process heat, a concept with an absorption chiller is supplying cold to the facility cf. [21].

Based on this hybrid concept, simulations based on real industrial data were conducted, ensuring real and accurate simulation results cf. [21].

The FRIENDSHIP project simulations revealed that the hybrid system combining heat pumps and parabolic mirrors can achieve up to 30% energy savings compared to traditional heating systems. It also demonstrated a reduction in CO_2 emissions by up to 40%. The system's overall efficiency, measured by a COP of approximately 4.5, indicates that for every kWh of electricity used, about 4.5 kWh of heat is produced. Despite higher initial investments, the system can pay for itself within 5 to 7 years, depending on specific conditions and usage. Additionally, it can reach temperatures up to 200°C, making it suitable for a wide range of industrial applications cf. [21].

2.3.2. Project Linz Textil Feasability Study: PVT, TES and serial Heat Pump

The initial system concept proposes replacing all gas boilers (low-temperature and steam boilers) with a high-temperature heat pump cascade. The design targets for the collector area and the long-term storage were based on ensuring sufficient regeneration. The schematic diagram is shown in Figure 27. The space heating supply is normally intended to come from the return flow of the first heat pump stage. During non-process times, space heating is provided by the first heat pump stage (dashed lines). When the provision of process heat does not require the full capacity of the heat pump cascade or during non-operational times (e.g., at night), the unused heat pump stage can increase the temperatures in the upper part of the long-term storage, thereby increasing energy density. This operating mode cannot be represented in the Polysun simulation tool due to the complexity of the remaining system. In reality, higher source temperatures are expected to result in higher coefficients of performance for the heat pump cf. [22].

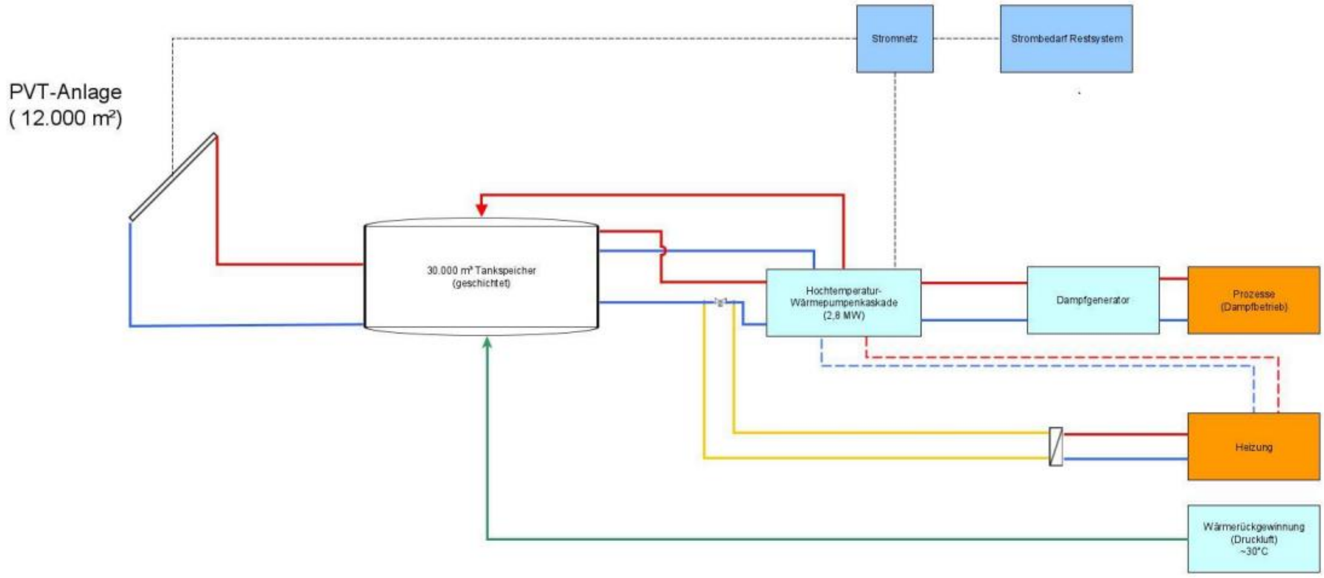

Figure 27: hybrid system Linz textile [22]

During the summer months the TES is loaded, and it is therefore possible, to transfer the heat into the end of February. The electricity generation from the PVT-panels are providing the whole energy for the heat pumps (2,8 MW) from April to mid of September, resulting in 56% coverage. The COP of the Heat Pump at 150°C supply temperature was simulated at 3.73 cf. [22].

This feasibility study was also comparing the PVT system with a combination of vacuum tube collectors and separate PV-panels system. It has been concluded that the PVT system is slightly favorable as the CO_2 reduction was higher and the costs was lower and more stable cf. [22].

2.3.3. Project Vossen Feasability Study: PVT, PV, TES, Biomass and serial Heat Pump

The developed supply concept is based on high-temperature heat pumps that use a long-term heat storage as a source. This long-term heat storage is regenerated by a large-scale solar thermal system with hybrid collectors on one hand and waste heat from various processes on the other. Additionally, a biomass boiler is linked to the PIT storage to cover for peak loads or missing irradiation. The heat supply for the space heating shall be on the return line of the first heat pump stage. The heat pump system (2,8MW) shall supply 130°C hot water to the processes. The existing gas boiler is providing the peak heating up to 150°C for the needed processes cf. [23]. The system layout is shown in Figure 28.

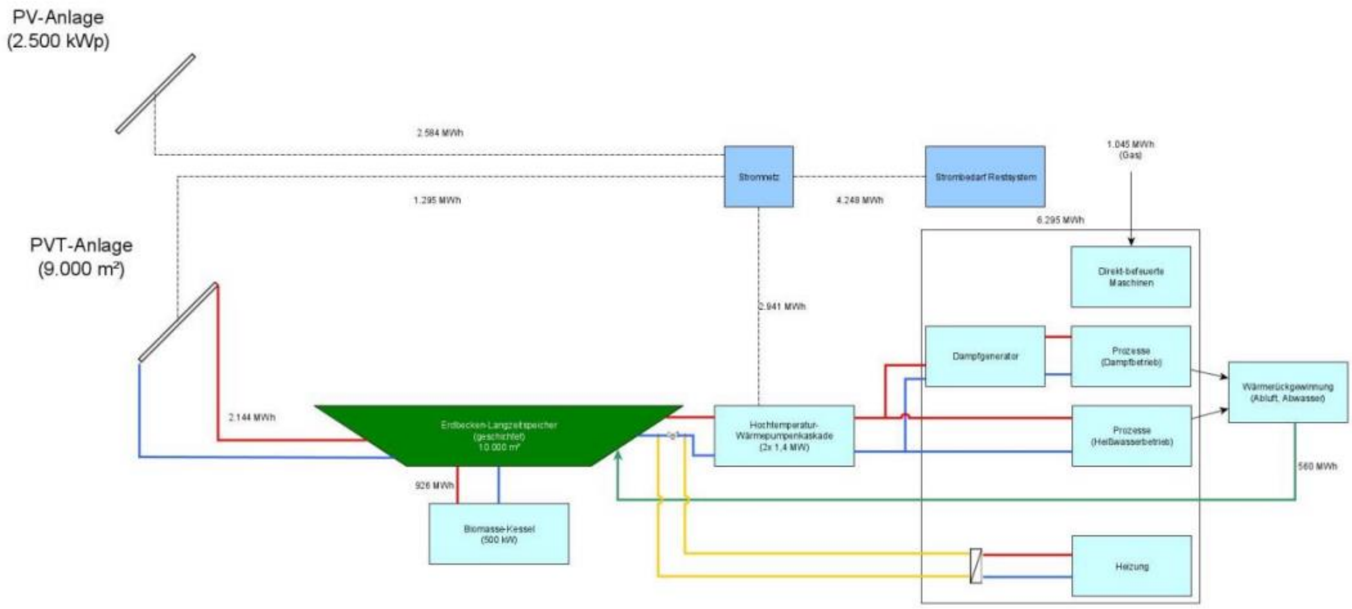

Figure 28: hybrid system Vossen [23]

The pit storage is designed as an earth pit water storage, delivering heat until the late of October. With fewer irradiation, the biomass boiler comes into action. Nevertheless the heat pump system has an overall efficiency of 3,76. Additionally, with the combined PVT and PV panels, the electrical consumption can nearly be covered over the whole year cf. [23].

2.3.4. Project Anton Paar: ST, Ice-Storage, HP and TES

The planned project involves the construction of a solar ice storage system for building heating and cooling. It consists of three brine-water heat pumps, each with a thermal output of 480 kW, an underground ice-water storage with a total volume of approximately 1,700 m³, 183 unglazed thermal solar collectors in a three-layer design, as well as comprehensive measurement, control, and regulation technology (MSRT) and hydraulic systems cf. [24]. This setup can be seen in Figure 29.

The ice energy storage, filled with water, acts as a seasonal energy storage and is regenerated using unglazed solar collectors and low-temperature waste heat from active cooling in the building. The ice energy storage (low-temperature latent storage) and solar collectors form the energy sources for the brine-water heat pumps. The water-filled ice storage can store energy (solar, ground, waste heat from the building) and supply it to the heat pumps cf. [24].

The heat extraction by the heat pumps leads to a freezing process and thus the "release of crystallization energy", whereby a large part of the stored heat is released at a constant temperature. The water-filled ice storage has internal, spiral-shaped plastic tube heat exchangers, which represent the system separation between the heat pumps and the ice storage cf. [24].

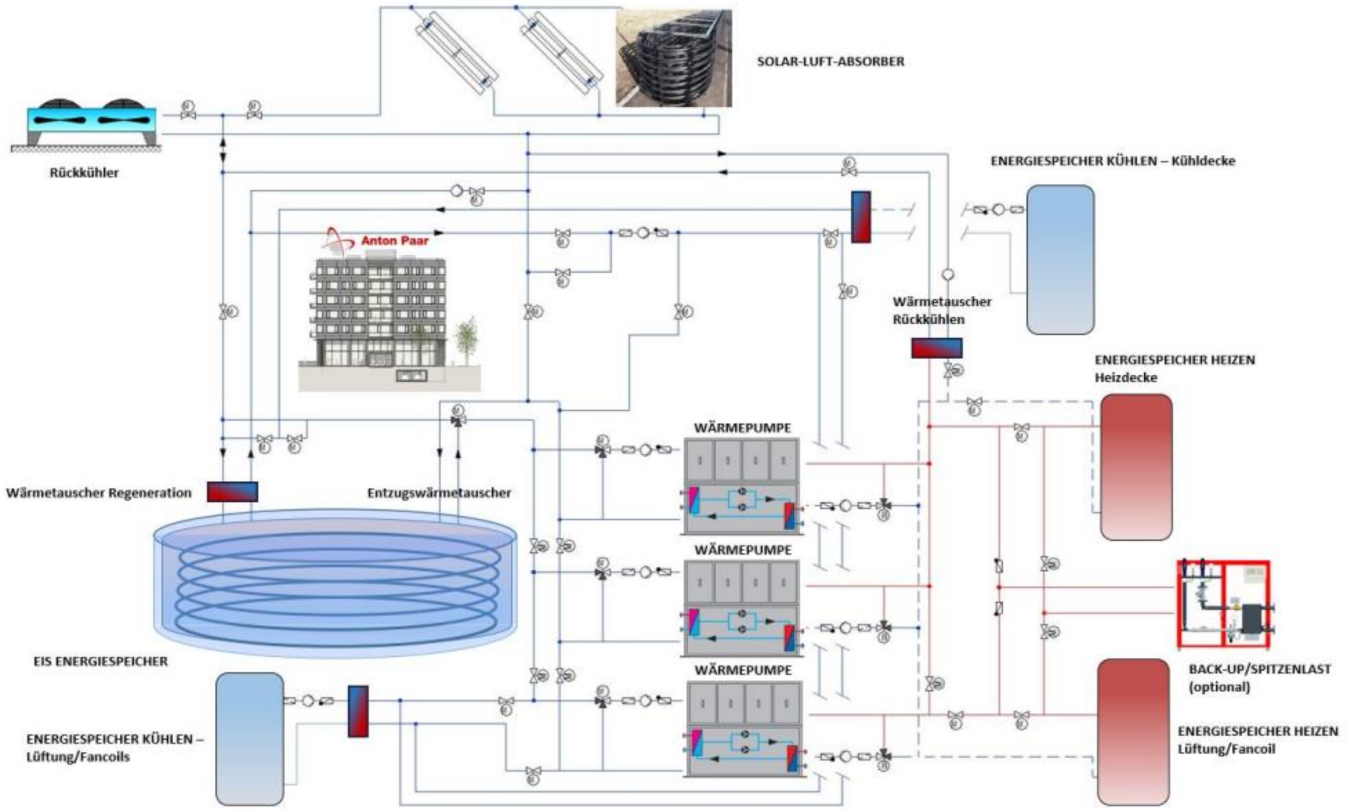

Figure 29: hybrid system Anton Paar [24]

The regeneration (melting process) and loading of the storage are carried out, on the one hand, by solar absorbers, which use the incoming solar radiation and air temperature, and, on the other hand, by the surrounding ground and waste heat from the building’s cooling operation cf. [24].

2.3.5. Project Henri Willig cheese factory: C-PVT with TES

The facility is a food industry factory located in Katwoude, the Netherlands. Since July 2017, the system has been operational, providing both heat and electricity to meet part of the factory’s daily demand, specifically around 8 m³ at 45°C. Hot water is required on average five days a week for the cheese production equipment. The project qualified for the SDE+ subsidy in the Netherlands for both heat and electricity generation. Eighty-eight low C-PVT collectors (Solarus PowerCollector™) were installed on the building’s flat roof, covering a total collector area of 226.2 m². These are divided into 22 kWp_{el} and 110 kWp_{th} cf. [25]. The modules are oriented southeast (20°) with an inclination angle of 10°. The design of the modules is shown in Figure 30.

Figure 30: figure of C-PVT collectors installed [25]

The heat supply system is illustrated in Figure 31. The 110 kWp system pre-heats the tank to 30°C in winter and 75°C in summer. An 8 m³ hygienic tank is positioned between the collectors and the inline gas boiler units to deliver heat. A mixing valve at the tank's outlet ensures water is delivered at approximately 45°C. Additionally, a 22 kWp electrical system with module-level optimization is connected, and the energy produced is utilized by the building. In 2018, the collectors provided nearly 54 MWh of heat and 15 MWh of electricity cf. [25].

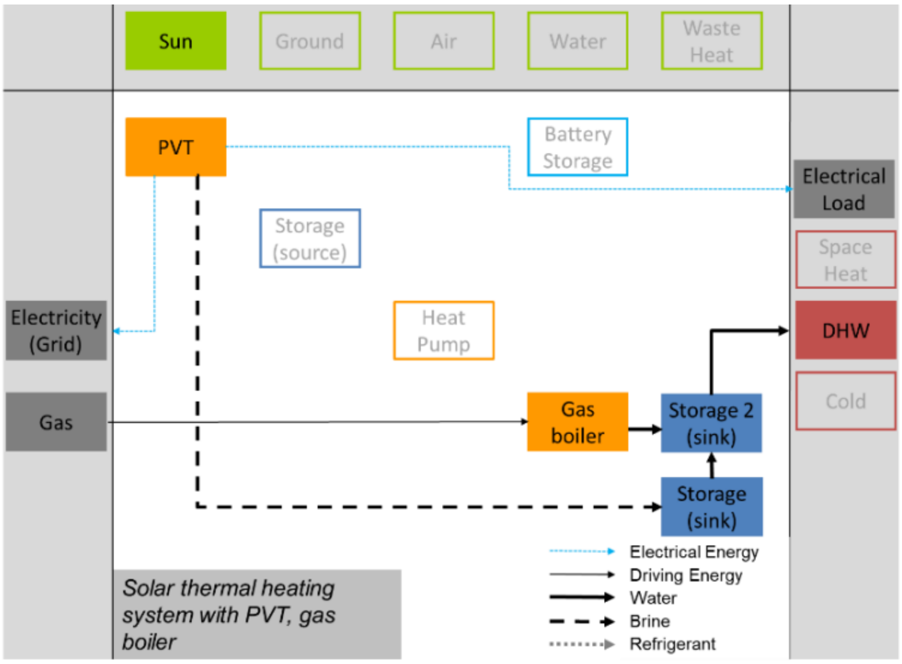

Figure 31: system layout C-PVT [25]

2.3.6. Project GreenTEC Campus: C-PVT with TES (heating & cooling)

SunOyster Systems GmbH (SOS) develops the SunOyster, a concentrating solar technology designed for the co-generation of power and heat (CPVT) at 170°C.[26] The primary concentration is achieved using standard parabolic mirrors, while the secondary concentration is done with custom-made lenses known as SunOyster Crystals, as seen in Figure 32.

The SunOyster 16 features two parabolic mirrors, each with a gross mirror surface area of approximately 8 m². These mirrors track the sun bi-axially throughout the day, focusing direct radiation onto a focal line. In the event of a storm, the SunOyster folds into a secure flat position, known as the Oystering position, which has successfully withstood various severe storms cf. [25].

In the focal line, two hybrid receivers from the pre-series simultaneously generate electricity and heat. The electric output is 3.2 kWp, while the thermal output is 6 kW. With further optimization, the serial production SunOyster 16 is expected to achieve 4.7 kWp and 7.5 kW of thermal power cf. [25].

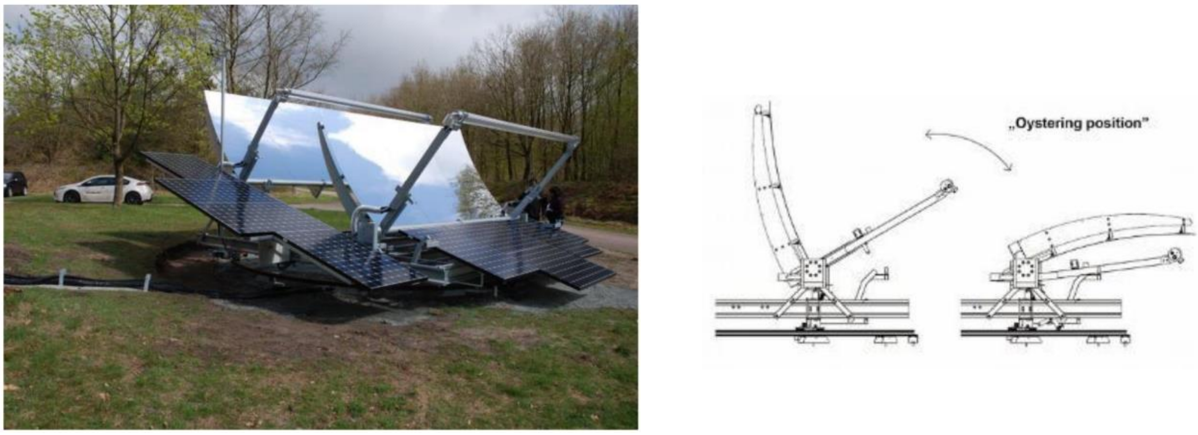

Figure 32: C-PVT collectors (version "pvplus") and oystering position [25]

To maximize space efficiency, the SunOyster mirrors of the pvplus version are surrounded by 12 PV modules that track the sun from east to west along with the SunOyster. However, their elevation remains fixed. These modules add an additional 3.8 kWp to the total electric output. The heat generated by the SunOyster is stored in a 1000-liter buffer tank. This heat can then be utilized by a thermal chiller, which converts it into cold and stores the chilled water in a smaller 200-liter tank. Below is a hydraulic diagram shown in Figure 33 cf. [25].

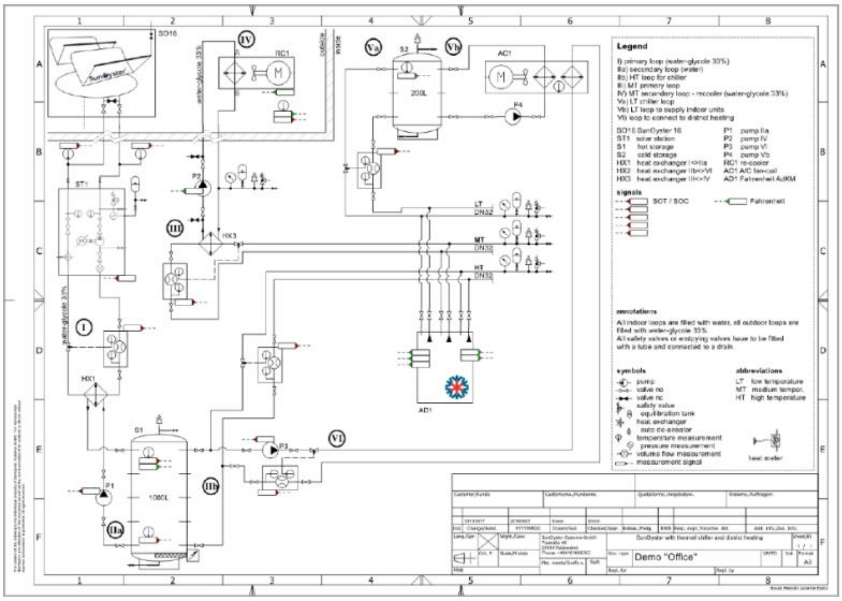

Figure 33: hydraulic system [25]

2.3.7. TCP SHC Task 60

Throughout the TCP SHC task 60 there has been a survey conducted where various PVT Systems were collected. Combinations with HP, Biomass, Gasboiler and Geothermal are listed. These systems can be found under the following link: https://www.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task60-A1-Existing-PVT-Systems-and-Solutions.pdf

3. Conclusions

The INDHEAP project provides a detailed analysis of hybrid renewable energy systems (RES) for industrial applications, with a focus on integrating solar thermal and photovoltaic (PV) technologies. While various classifications of these systems exist, they often lack the flexibility needed to adapt to diverse industrial needs and conditions.

Hybrid systems are deployed in several configurations but always included a thermal energy storage, such as solar thermal combined with photovoltaics (solar + PV) and solar thermal combined with heat pumps (solar + HP). The project primarily focuses on integrating solar thermal and PV systems with a thermal energy storage, while also considering the addition of heat pumps to enhance overall system efficiency and flexibility, as heat pumps are widely utilized in hybrid RES according to literature.

The research highlights that although there are some existing installations of hybrid RES, their deployment is still limited. This points to a significant opportunity for further development and scaling to fully exploit the benefits of these systems in industrial settings.

Looking ahead, the project aims to develop a comprehensive integration guideline that addresses current gaps and provides a structured approach for implementing hybrid RES in industrial environments. This guideline will emphasize optimizing the integration of solar thermal, photovoltaic, thermal energy storages and heat pump technologies to create more efficient and adaptable energy systems.

In conclusion, based on the research findings and evaluation of best practices, it is clear that flexible and integrated hybrid RES solutions are crucial. There is a strong need for a broader implementation and the development of comprehensive guidelines to support future integration efforts. Hybrid systems are poised to play a pivotal role in advancing the use of renewable energy in industrial processes, driving greater energy efficiency and sustainability.

4. Degree of Progress

This report covers the screening of best practice examples of Task 2.1. The findings will be integrated into the further work of WP2 towards developing an integration guideline.

5. Dissemination level

The deliverable is public and will be available through different channel of the project.

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