BARRIERS TO SOLAR PROCESS HEAT APPLICATIONS

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Abstract

In this work, barriers to solar process heat (SPH) applications are described as experienced mainly in two German research and demonstration projects on SPH. Being aware of already published studies the authors focus explicitly on selected topics based on their observations and discussions with project partners from universities, research institutes and industry, instead of giving an overall view of possible market barriers.

The knowledge gained by monitoring and optimising solar process heat systems is documented. Two main findings beside others are, that solar process heat in comparison to conventional heat generation can only be applied successfully by developing standards and that the documentation and publication of well-operating pilot plants in the industrial sector must go on to serve as best practice examples.

In the frame of the project Solare-Prozesswärme-Standards (Solar Process Heat Standards, Sol-Pro-St), which is funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) e.g., simulations of thermal processes on a temperature above 75°C with the software MATLAB®/Simulink® and the toolbox CARNOT[1] showed specific solar yields of 400 kWh/m^{2}a for a SPH plant for an electroplating company. Such yields lead to payback periods of approximately 16 years and can be one of the main reasons for the industry not to invest in solar technologies. As a result, in this project three out of four industrial partners opted out of an investment in solar thermal systems and implemented measures of energy saving, installed a new and more efficient gas fired boiler or a cogeneration appliance instead. With the fourth partner negotiations are still in process.

1. Introduction

Studies of the IEA Task 33/IV–SHIP (Solar Heating for Industrial Processes) state a high potential for solar process heat applications. In the EU about 30 % of the industry's heat demand is used for processes with a temperature below 100 °C and approximately 57 % for processes with a temperature between 100 °C and 400 °C [1]. Many efforts have already been made by stakeholders and researchers to develop new strategies in order to open this immense potential and thus to strengthen the market for solar process heat. In dependence on the geographical location there is potential for a large share of the required process heat to be delivered by solar collectors. But the incentives for and activities of companies in Germany to install solar process heat are still very restrained. Referring to the results presented by various studies and publications, there are several main technical and non-technical barriers [2, 3].

[1] CARNOT: The "Conventional And Renewable eNergy systems OpTimization Blockset" was developed in 1999 at the SIJ and was designed as a complementary program library for MATLAB® / Simulink®. It is primarily suited for the simulation of thermal systems using renewable energy.

Technical barriers

- Unavailability of adequate space for the solar field, the buffer storage or the hydraulic piping between energy production and energy consumption.
- High process temperatures in combination with an inappropriate process strategy lead to low collector efficiencies and specific collector yields.
- The installation of solar plants may cause production downtimes, which are economically unacceptable.
- The integration of solar heat into an existing, steady operating process is technically complex, especially because the supply of solar energy is varying during the course of the day and year.
- Each process temperature range has a recommendable technology from flat plate collectors (FPC) over compound parabolic concentrator collectors (CPC) to vacuum tube collectors (VTC) to parabolic trough collectors (PTC). That means that the adequate choice is essential for the optimum of efficiency of a SPH-system.
- Alternative energy saving measures such as heat recovery or combined heat and power (CHP) can have technical and/or economical advantages compared to SPH-systems.
- Complex and individual production processes require a time and cost intensive planning of the solar plant, which includes preliminary and mostly cost-intensive data monitoring and simulations.

Non-technical barriers

- Missing information about technical options inhibit the interest of potential customers. Furthermore the number of qualified energy consultants with specific knowledge in SPH applications is not sufficient to meet the demand.
- The employment of plant designers and installers with insufficient knowledge of the technology may lead to different categories of faults and thus to bad examples and negative publicity.
- High investment costs on the solar part on one hand and low costs for fossil fuels on the other hand lead to long pay back periods for SPH-plants and thus lower their economic attractiveness.

In the next chapter, some of the listed barriers will be discussed on the basis of completed or ongoing SPH-research projects with the involvement of the Solar-Institut Jülich of FH Aachen and E²-Erneuerbare Energien und Energieeffizienz of FH Düsseldorf.

2. Experiences of two Solar Process Heat research projects

2.1 Experiences of the Project Sol-Pro-St

The project Solare-Prozesswärme-Standards [4,5] is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Universities, industrial partners of the electroplating industry, food industry and solar industry are involved. The definition and implementation of solar process heat standards are suitable to reduce investment costs. Because of the diversity of industrial processes requiring heat, standards must be introduced specifically to common processes. One aspect is, for example, the supply of heat at different temperature levels. A customized realization can reduce the return temperature and thus, increase the efficiency of solar collectors. Furthermore recommendations for system engineering and dimensioning are given in this research project.

Simulations of thermal processes on a temperature level of about 75°C using the software MATLAB®/Simulink® and the toolbox CARNOT showed realistic specific solar yields of approximately

400 kWh/m^{2}a. An example for such yields is given in the simulation results below. The simulation was carried out with the aim to design a solar process heat system for one of the participating project partners from the electroplating industry. The galvanic process requires approximately 340 MWh of thermal energy annually for heating the electroplating baths. The required target temperature is 75°C. Below this temperature, no further heat sinks are available. Furthermore, there is no production on weekends. The simulated system consists of a collector field which is connected to a buffer storage by means of a heat exchanger. The collector field is aligned in south-west direction with an angle of 45° and the location is Velbert, Germany. The collector type is a vacuum tube collector from Buderus (Model CPC12) with an aperture area of 2.56 m². The solar heat is directly supplied from the buffer storage to the heat load. A backup system is connected to the storage, which provides the required residual energy in the case that there is not sufficient solar energy available and ensures that the target temperature is kept on 75 °C in the upper area of the storage. In the simulation, collector energy is directly fed to the storage whenever the current collector temperature exceeds the storage temperature.

Several simulation runs were performed to analyse variations of collector area and storage volume.

Tab 1: Solar heating provision as a result of the parameter variations

collector area / storage volume	100 m²	125 m²	150 m²	175 m²	200 m²	225 m²
5 m³	12.9 %	15.9 %	18.9 %			
7 m³			19.0 %	22.0 %	23.7 %	
10 m³				22.1 %	24.4 %	26.5 %

Tab. 2: Efficiency of collector circuit as a result of the parameter variations

collector area / storage volume	100 m²	125 m²	150 m²	175 m²	200 m²	225 m²
5 m³	44.1 %	43.7 %	43.1 %			
7 m³			43.8 %	43.5 %	42.6 %	
10 m³				43.7 %	42.7 %	41.1 %

In table 1 and table 2 the simulation results for the optimal combination of storage volume and collector area are highlighted in green. A combination is considered optimal, if stagnation can be avoided. In the case of stagnation the solar system has been oversized (red figures). To prevent serious damage to the collectors one has to reduce the collector area or increase the storage volume. For the remaining values the system can be regarded undersized, which was realized in the simulation by increasing the collector area or reducing the storage volume.

The solar heating provision is defined as the annual collector yield fed to storage divided by the total annual energy (collector yield + backup energy) fed to storage. The efficiency of the collector circuit is defined as the annual collector yield fed to storage divided by the annual global irradiation on the collector surface.

In order to calculate the efficiency of the collector circuit the annual global irradiation of 986.54 kWh/m²a was calculated on the basis of the simulated weather data. Further simulation results for the respective optimal combinations are listed in table 1 and 2.

- Collector area 125 m² and storage volume 5 m³

Collector yield:	53.889 kWh
Backup energy:	285.035 kWh
Energy demand:	338.924 kWh
Spec. collector yield:	431 kWh/m²a

- Collector area 175 m² and storage volume 7 m³

Collector yield:	75.100 kWh
Backup energy:	266.263 kWh
Energy demand:	341.363 kWh
Spec. collector yield:	429 kWh/m²a

- Collector area 200 m² and storage volume 10 m³

Collector yield:	84.262 kWh
Backup energy:	261.960 kWh
Energy demand:	346.222 kWh
Spec. collector yield:	421 kWh/m²a

For the industrial project partners the calculated payback time of a SPH-system is crucial when investments have to be decided. In the case of the electroplating company mentioned above which is currently producing their process heat by a gas boiler, a SHP system would be paid off after 16 years. The payback period has been calculated with a gas price of 5 ct/kWh, investment costs of 450 €/m^2, 30% subsidy, an interest rate of 3%, life cycle of 20 years and specific yields of 400 kWh/m^2a. Figure 1 shows payback times also for other technologies. A payback time of 3.6 years (self-consumption) or 11 years (feed-in the grid) is expected for a cogeneration system (CHP). After 3 years a wood chips heating system will be paid off. Although current financial support is about 30 % SPH is still not competitive. Subsidies of 30% are granted by the state North Rhine-Westphalia for CPC collectors producing process heat through the program progress.nrw. On the other hand it can be seen that energy price is an important factor when calculating the pay back time. When energy prices increase by 50 % for gas and electricity, as shown in figure 1, payback time of SPH will be reduced from 16 to 9.5 years. This is still a critical time period for investors to take up a loan. CHP (self-consumption) would be paid off after 2.5 years. A payback time of 10 years for CHP (in case CHP-electricity is fed in the grid) is calculated with an expected increase of feed-in tariff of 50 %. The feed-in tariff depends on policies and thus can vary in the future. It is about 6 ct/kWh_{el} today. With the current feed-in tariff and an energy price increase of 50 % CHP would not be economical. Higher energy prices reduce the payback time of SPH significantly, and make SHP more attractive, but nevertheless other technologies are found to be still more economical on the basis of the parameters used in this calculation.

Furthermore figure 1 shows the emission savings of the discussed technologies in comparison to SHP: Under ecological aspects solar process heat is a competitive option. The CO_2e savings of the different technologies are similar. But considering the TOPP (tropospheric ozone precursor potentials)-equivalents savings cogeneration is the most effective in comparison to wood chips, gas boiler and SPH. Emissions have been calculated with the software GEMIS (Öko-Institut).

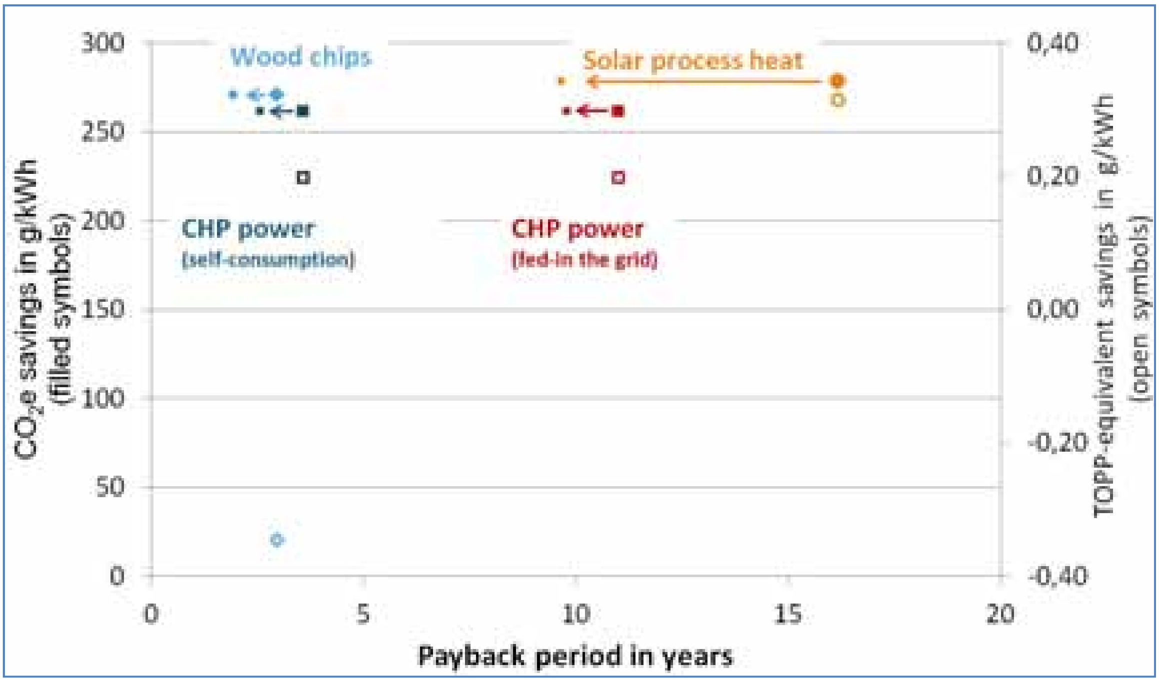

Fig. 1: Influence of energy prices on payback periods, exemplarily for an industrial partner

Independence on energy price developments and low operating costs are clear advantages of SPH systems compared to the other mentioned technologies. Costs of fossil fuels are in the long run not predictable. In addition CO_2 savings have not only advertising appeal but help to slow down the climate change.

As a result of the calculated pay back periods for each company involved in the project, three out of four industrial project partners opted out of an investment in SPH systems and implemented measures of energy saving, installed an efficient gas fired boiler or a cogeneration appliance instead. With the fourth partner negotiations are still in process. Apart from long pay back periods and the lack of standards the project Sol-Pro-St has shown that current flat plate or vacuum tube collectors are not suitable for an economic operation above 75°C.

To sum up, SHP is currently not competitive. One possibility to open up the market could be a higher financial support for the investor. This could help to encourage stakeholders to build up more pilot plants. There are still not enough existing well-operating and well-documented pilot plants to serve as best practice examples.

2.2 Experiences of the Project P3

The research project P3 (Pilot Plant for Generating Process Heat with Parabolic Trough Collectors) [6,7] was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and coordinated by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) in Cologne. As co-operating partner the Solar-Institut Jülich of the FH Aachen (SIJ) was responsible for the monitoring and the data analysis of the P3 pilot plant. The plant with a collector area of 108 m^2 was built in 2009 and is located on the flat roof of the company ALANOD Aluminium-Veredlung GmbH & Co. KG in Ennepetal, North Rhine-Westphalia, Germany. The project partner ALANOD is a manufacturer of anodized aluminum coils and requires saturated water steam at a temperature of 143 °C and a pressure of 4 bar a for its productions line. The solar plant is connected to the company's existing steam infrastructure.

Figure 2 shows the hydraulic scheme of the P3 plant. The main components are twelve parabolic trough collectors (PTC1800, Solitem GmbH) and a steam drum. It is designed according to the recirculation principle whereby water is pumped from the steam drum through the parabolic trough collectors (PTCs) and back into the steam drum. The water is vaporized directly in the absorber tubes of the PTCs. When the fluid parameters in the steam drum equal those of the steam line, a check valve opens the connection and steam will be fed into the steam line. The test mode started in April 2010 and after some optimisations the plant is producing saturated steam since July 2010.

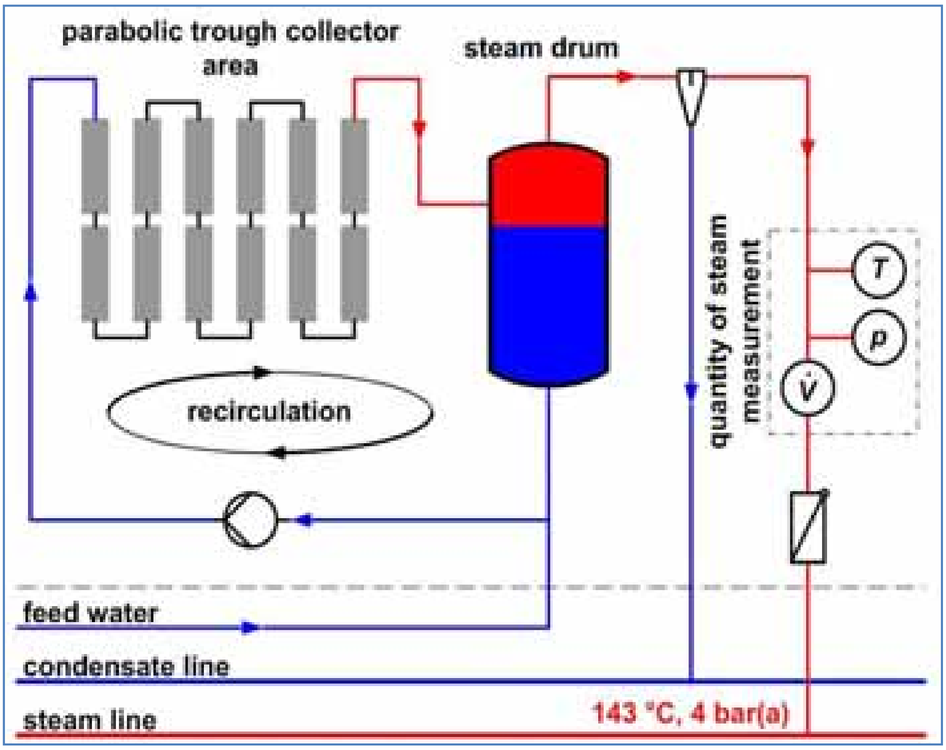

Fig. 2: Hydraulic scheme of the P3 plant

The main purpose of this pilot project was to demonstrate the feasibility of direct steam generation by PTCs and its integration in an existing steam infrastructure. The plant was planned by the DLR. Simulations were carried out to determine an optimal plant configuration, which included the collector orientation, the hydraulic lines, the interface between the solar field and the steam line. The installation was done by the company SOLITEM GmbH. Since there were no preceding experiences with this kind of SPH-plants, especially the planning of this plant was very individual and thus extensive. All components have been purchased from specialized manufacturers and retailers and showed no malfunctions at those exceptional temperature and pressure levels. As a general result of the monitoring performed by the SIJ, it could be proven, that the plant design is suitable for this type of application. With a simple check valve the directly produced steam can be easily fed into the steam line. Because of the automatic control of the existing conventional steam generator, the maximum fraction of solar steam compared to the total process heat production is restricted. The feeding of steam into the steam cycle has the same effect on the steam production as a varying heat load. Before the solar steam can be fed into the process steam cycle the whole system has to be heated up. The warm up time is dependent on the direct solar irradiance and the ambient temperature. The effect of low direct solar irradiance and of low ambient temperature on the warm up phase is illustrated in figure 3. In the diagram the water temperature at the inlet and outlet of the collector field as well as the temperature of the water and the steam inside the steam drum are shown. Before the plant starts to operate, the ambient temperature cooled down the water inside the collector tubes. On June 27th 2010, the plant reached the normal operating mode after about 2 hours at a direct radiation of close to 800W/m² on the aperture surface. The long warm up time is also caused by long hydraulic lines and a great steam drum so more water than the required must be heated before the normal operating mode can be reached. ALANOD staff members supported the test phase and are now able to maintain and operate the plant.

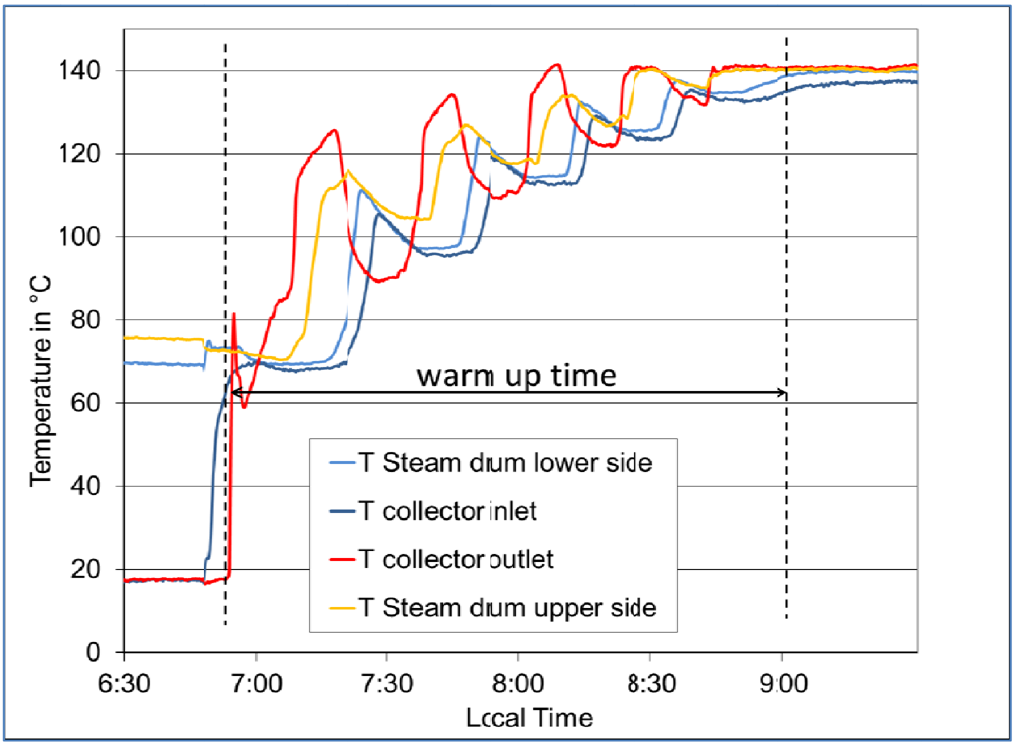

Fig. 3: Warm up phase on 27th of June 2011

In the P3 project, there was sufficient space to install the solar plant at the ALNAOD GmbH to serve as a demonstration object, but an upscale of the plant is not possible due to limited space. Long hydraulic lines had to be accepted, which leads to heat losses and long warm up periods. The chosen option to integrate the solar produced steam into the existing steam line turned out to be very reliable. Owing to the connection by means of a non-return valve, there were acceptable production downtimes during the installation.

For this plant the planning and installation phase has been time consuming. But it can be expected that for similar processes the future planning effort will be reduced and the integration of such a plant will become easier due to lessons learned. Locations with more direct solar radiation would lead to higher yields of a PTC plant so that a more economic operation could be achieved in comparison to the monitored yields at the location in Ennepetal, Germany.

3. Observations of a supplier for Solar heating components and systems

One of the project partners of the above mentioned project Sol-Pro-St from the industry is the company BOSCH Solarthermie GmbH in Wettringen, Germany. BOSCH STT is a supplier of solar process heat components and systems. Besides other factors such as low costs for fossil fuels they have identified two main barriers for solar process heat: the lack of standardization and qualification.

The company states that a standardization of plant sizes of 200 collectors and a mean collector area of about 400 m^2 already exists for apartment buildings. The standards have been established successfully in the last years. This is due to the well known typical heat demand and due to the standard operation strategies such as "heat consumption before heat storage". Thus, the supplier has to select the same or similar types of components, i.e. pumps, heat exchanger(s), the solar control unit and some safety installations. But when the demand characteristics deviate from the standardized layout and when the plant size is greater than 400 m^2 of collector area, then individual planning is needed. At these larger dimensions, standardization is still not existent. This can be regarded as a barrier to market growth. Therefore one best practice approach to successfully build and economically offer large scale solar process heat plants can be seen in the turnkey approach some European suppliers already have in their portfolio. Turnkey means that one single supplier is responsible for the installation of a complete plant. The lack of qualified or specialized staff is a second important factor for the relatively slow development of SPH market not only in Germany but also in some other European countries. In order to remedy this unbalanced situation some competence centres for solar process heat have been established in Germany recently. Their programs may help to close the gap between the standard technical education and the specific requirements needed to plan and install large scale solar thermal facilities for process heat.

4. Summary

The presented findings from the project Sol-Pro-St have shown that a major obstacle for the installation of a solar process heat system is the required temperature level. Current flat plate or vacuum tube collectors are not suitable for an economic operation above 75°C. Normally, specific collector yields of about 650 kWh/m²a (for example in case of solar heating) are expected for the type of collector (Buderus Model CPC12) used in the simulation. In the simulation, yields between 421 kWh/m²a to 431 kWh/m²a were obtained. The main reason for this deviation is the temperature level that has to be reached in the different applications. In case of the considered galvanic process the collector temperature has to be higher than 75°C. Because there is no use for energy below this temperature, the specific collector yields and also the solar heating provision is being reduced. The required temperature level for solar heating systems is normally between 35°C to 60°C. The lower temperatures have a direct effect on the operating time of the collector field and the expected collector yields. Among other aspects, the operating time of the collector field depends directly on the temperature level. The higher the target temperature is, the lower is the expected specific collector yield and, as a consequence, the lower the efficiency of the collector circuit.

The location of the solar plant has a major influence on the efficiency and the yield of SPH applications. Although there was no comparison carried out between different sites, it seems plausible that with increasing solar radiation and the same given temperature, a higher efficiency of the collector circuit can be achieved. The simulated yields from 421 kWh/m²a to 431 kWh/m²a of the collector field at the site Velbert, Germany, lead to an amortization of approximately 16 years. Beside the high investment costs this was mainly the reason for the industrial partners not to invest in solar technology. For all partners it applies that complex and individual production processes were identified, which required a time and cost intensive planning of the solar plant, including a foregoing data monitoring and simulations. In order to limit the investment and maintenance costs a SPH system needs simple hydraulics, fail-safe controllers, adequate monitoring and has to be properly designed. Recent experiences are proof to the contrary. Fault-prone solar process heat systems are still built. Such negative examples can delay the market penetration of a new technology by years.

In general, the PTC-technology used in the P3 project is appropriate for direct steam production at these temperature ranges. The used PTCs enable a reliable operation, but in comparison to flat plate and vacuum tube collectors there is still some development work needed to be done. However, to guarantee an economically working SPH-plant, it should be installed at a location with high direct solar radiation.

The previously stated barriers have to be determined individually for every considered SPH application. Beside these barriers, independency on energy price developments is a clear advantage of solar process heat systems compared to competing technologies. Energy costs of fossil fuel based systems are not predictable in the long run. In addition, CO_2 savings have an advertising appeal. These facts must be communicated with the investors and may lead to the decision to invest in a solar process heat system.

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