SOLAR PAYBACK: A REVIEW OF PRELIMINARY ENERGY AUDITS AND SOLAR INTEGRATION STUDIES

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Abstract

Solar thermal technologies have the potential to provide clean and low cost thermal energy to South African industries. Case studies of "real world" processes are critical to encourage the uptake of these solar thermal technologies and demonstrate the potential for cost savings and/or a reduction in the carbon footprint. This paper presents a case study for the integration of a solar thermal system, to provide hot water for a recycling plant at Mpact Polymers in Gauteng. This plant was selected by the Solar Payback project to receive grant funding of 30% for a pilot scale solar thermal system. Simulations show that a solar thermal system can be deployed with a simple payback of between 4.1-4.5 years (with a 30% subsidy assistance), with a solar fraction in the order of 35% for the plant wash module. Technical tendering for the development of a pilot plant at the Mpact Polymers plant is scheduled for January 2020.

Keywords: solar, thermal, PET, recycling, case study

1. Introduction

Thermal energy accounts for over two-thirds of industrial energy consumption in South Africa [1]. A sizeable fraction of this thermal energy demand is required for temperatures below 400 ºC, which can be supplied by solar thermal technologies. Solar Payback is multi-year research project aimed at stimulating the deployment of solar heat for industrial processes (SHIP) in South Africa, Mexico, India and Brazil. In a previous paper [2], the results of a SHIP potential study for South Africa were presented, which highlighted the food and beverage sector in particular as having a high potential for SHIP deployment.

Case studies and pilot scale projects are required to stimulate the deployment of SHIP systems and build confidence amongst companies in the technology. One of the key objectives of the project is the development of a pilot SHIP plant at a South African manufacturing company. In 2018 and 2019, three South African companies underwent feasibility studies to determine the potential for SHIP integration. Through an extensive evaluation process, the company Mpact Polymers was selected as the preferred company for the demonstration plant. Mpact will be awarded a grant of 30% of the project CAPEX by Solar Payback, upon the successful completion of a technical tendering process.

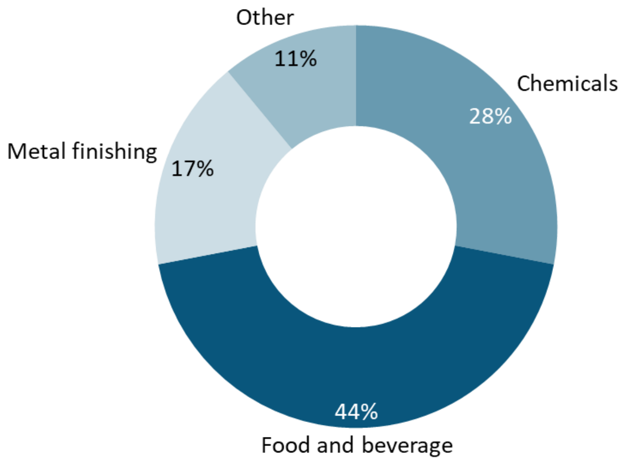
This paper presents a high-level summary of the results of the feasibility study that was conducted by the Solar Payback partners on behalf of Mpact. An outline of the methodology that was employed to develop the pilot plant is provided, along with a summary of the results.

2. Methodology to find companies to potentially deploy a SHIP plant

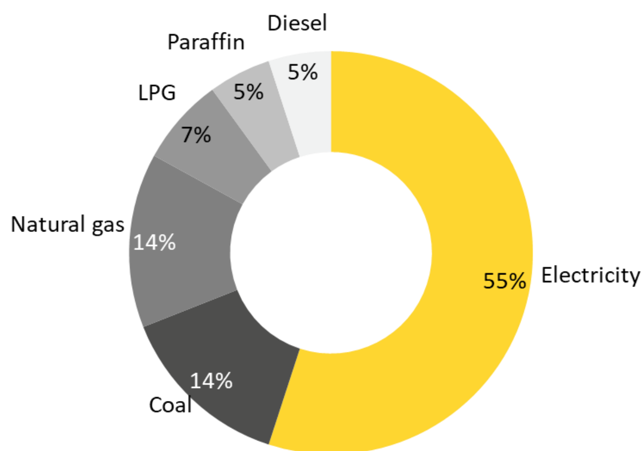
2.1. Initial contact with potential companies

Information on the Solar Payback funding for a SHIP plant was initially distributed to over 3000 contacts by CSIR, SANEDI and AHK. Key industry associations within the food and beverage, textiles, chemicals, metal finishing, and automotive sectors were also approached to identify members that could be suited to a SHIP system. Initially, one of the key challenges that was faced was a lack of awareness of SHIP systems. Therefore, a number of information dissemination sessions were held to highlight the technical and economic potential of SHIP systems.

Preliminary data was collected from 19 companies that expressed an interest in a SHIP demonstration plant. Companies were requested to complete a high level online questionnaire that aimed to establish basic company information and energy usage. As shown in Fig. 1, 44% of the companies that responded to the initial Solar Payback call were from the food and beverage sector, whilst 55% of all companies that responded utilise electricity for heating. The data indicates that companies that utilise electricity are more motivated to pursue alternative energy sources for process heating, which is likely due to the rapidly rising cost of electricity.



(a) Breakdown of industry sub-sectors



(b) Breakdown of the energy sources used

Fig. 1: Analysis of 19 companies who expressed an interest in pursuing a SHIP plant with Solar Payback

2.2 EINSTEIN energy audit tool

The companies that responded to the online survey were each invited to complete the EINSTEIN energy audit tool, with support from the Solar Payback partners. EINSTEIN stands for the Expert-system for an Intelligent Supply of Thermal Energy in Industry. This tool is aimed to collect detailed information on the following topics:

1. General company data
2. Annual energy consumption and costs
3. Processes that require thermal energy in the plant
4. Production schedules
5. Heat generation equipment
6. Cold generation equipment
7. Details of heat distribution system
8. Details of heat recovery equipment being utilised
9. Potential for solar and biomass onsite
10. Building information (roof area and structure)
11. Economic data from the plant

Populating the extensive EINSTEIN tool with detailed energy data proved challenging. In many cases companies did not have access to the required data or the plant engineers did not have enough time available to complete the tool, despite assistance from the local Solar Payback partners. Initially a target of 10 completed EINSTEIN tools was set, but only four were completed by the deadline.

2.3. SHIP feasibility and integration studies

Of the four companies that completed the EINSTEIN tool, the top three companies that showed the highest potential for a SHIP plant were chosen to proceed to the feasibility study stage. These companies included a cheese producer located in the Western Cape, a large brewery in Gauteng and a PET recycling plant in Gauteng. In order to determine the potential for SHIP integration at each plant, a series of site visits were conducted. The objectives of the site visits were to:

1. Get an overview of the production process at each plant, including process flow diagrams
2. Identify key processes that utilise thermal energy, and establish the temperature level required
3. Gather technical data of heat generation equipment
4. Gather hourly thermal energy generation and consumption data, as well as production schedules
5. Collect current energy cost data
6. Identify opportunities for waste heat recovery
7. Determine the available area for solar thermal collectors
8. Assess the motivation to implement a SHIP plant.

This data was collected by the local Solar Payback partners SANEDI and CSIR and compiled into a report for each of the three companies, which was sent to Fraunhofer ISE (FISE) in Germany. FISE then conducted system modelling using their in-house simulation tool COLSIM, to determine the optimal system size based on common system costs in order to minimize the Levelised Cost of Heat (LCOH). Based on the results of the modelling Mpact was chosen as the company with the best potential for a SHIP demonstration plant. This was primarily due to the extensive use of large electric water heaters in the recycled PET (rPET) plant. As electricity is a costly energy source for heating, the payback periods for a SHIP system were most attractive for Mpact. This company was also highly motivated to pursue alternative energy sources to reduce their dependence on electricity.

3. Mpact rPET plant overview

3.1. Company profile

Mpact Polymers operate a state of the art PolyEthylene Terephthalate (PET) recycling plant in Johannesburg South Africa, which is an important strategic asset to the company and its customers. Recovered recyclable materials such as paper and used PET bottles are sourced by Mpact Recycling through pre- and post-consumer programmes. Materials are sorted and baled and used by Mpact's paper mills and Mpact Polymers as raw materials.

Mpact Polymers is selling rPET, branded as "Savuka" to Mpact's plastics business, where it is blended with virgin material for the manufacture of beverage bottles and other products, and to external customers. Mpact is well-positioned to offer high quality rPET to local and international food retailers, who are determined to increase the composition of rPET in their packaging product, with some already increasing rPET from 10% to 20%.

3.2. Process description

An overview of the rPET production process is presented in Fig. 2. The plant consists of a front end section, a wash module, and two decontamination processing lines. In the front end of the plant, bales of PET material are sorted in order to remove metal, sand and labels from the bottles, which are then ground into PET flakes and sorted by colour. Within the wash module the PET flakes are cleaned through a number of washing steps before being dried and moved to the decontamination (deco) lines.

The deco lines include pre-crystallising, heating, PET decontamination, extruding and pelletizing, AA removal and cooling and bagging steps. The process is continuous and operates 24 hours per day and 365 days a year

3.3. Energy consumption

Resistance heating and heat pumps are used in the wash module, whilst resistance heating is used in the deco units. A high level diagram of the wash module and deco-plant is shown in Fig. 3. Hourly electricity consumption was provided by Mpact for 2016-2018 (up to November 2018). The following thermal generation equipment is sub-metered with data available:

- 3 heat pumps for wash module hot water
- Resistance heater for wash module hot water
- Caustic heater for the wash module
- Thermal dryer
- Decontamination lines 1 and 2 (overall only)

Fig. 4 presents the breakdown in electricity in the rPET plant. The mechanical and thermal loads in the two decontamination lines account for between 44-50% of electricity consumption.

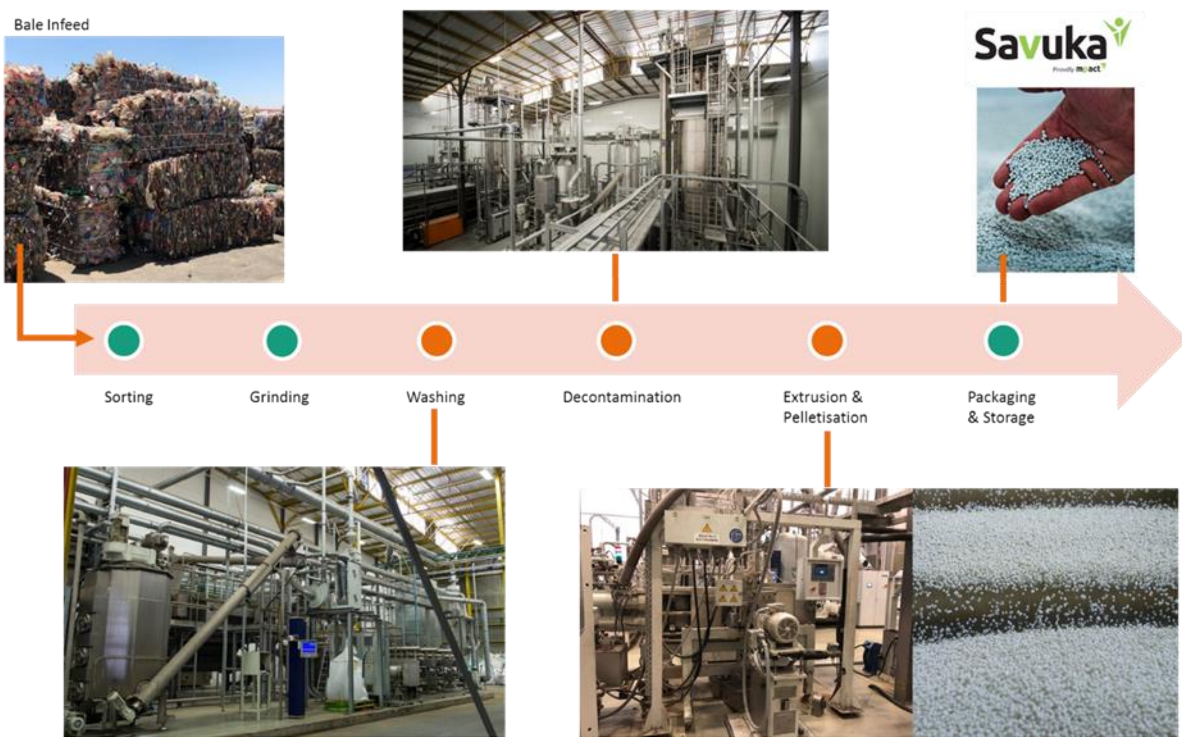


Fig. 2: Process diagram of rPET production at Mpact Polymers (orange: process using heat/cooling, green: no heating/cooling)

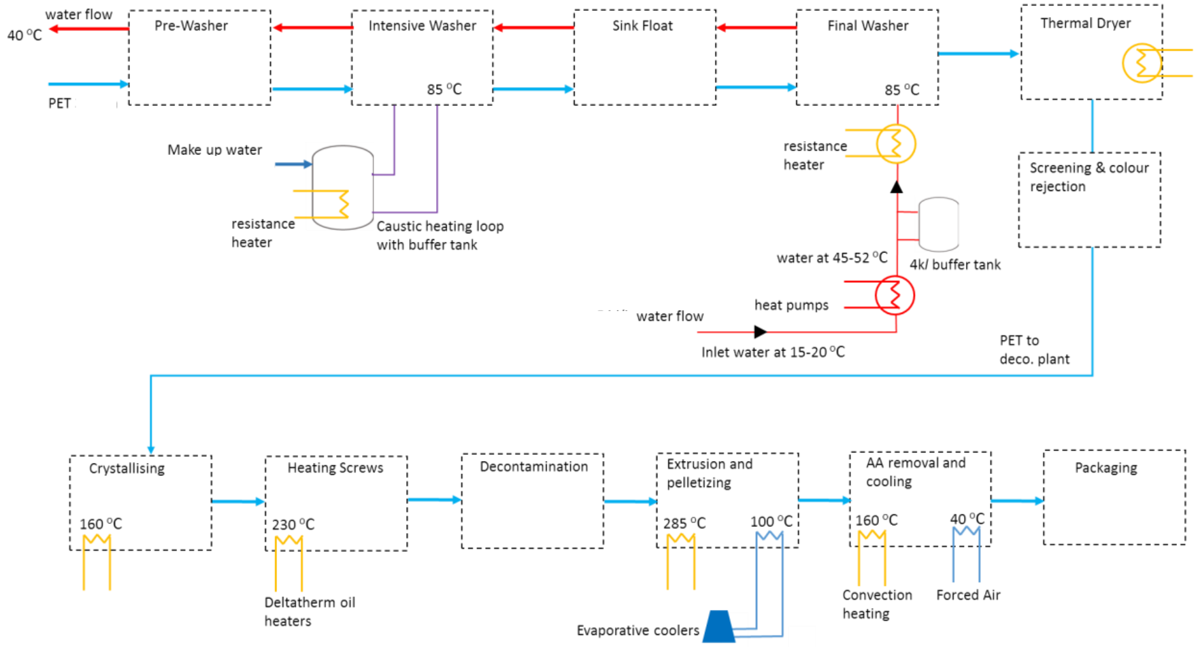


Fig. 3: Wash module and decontamination plant process diagram, indicating thermal loads

The thermal loads on the wash plant account for 19-26% of total electricity consumption. During the site visit it was noted that the electric heating within the deco lines is closely integrated into the plant machinery, and thus it is difficult to integrate the heat from a solar thermal system. Unfortunately the overall energy consumption values and installed capacity of equipment within the plant is confidential.

The temperatures required by various process in the deco lines range between 160 °C and 280 °C, which are significantly above the 85 °C required by the wash module. For this reason it was decided that the wash module presents the best opportunity for the integration of a solar thermal system, and the deco lines were not considered at present.

3.4 Waste heat recovery

As shown in Fig. 3, the plant currently utilises evaporative coolers to remove heat from the extrusion and pelletizing process. During the site visits by the Solar Payback partners, it was identified that there is a potential to recover thermal energy from the pelletizer and use this to pre-heat the inlet water into the wash module. Mpact is currently exploring the technical potential of this opportunity in terms of heat recovery.

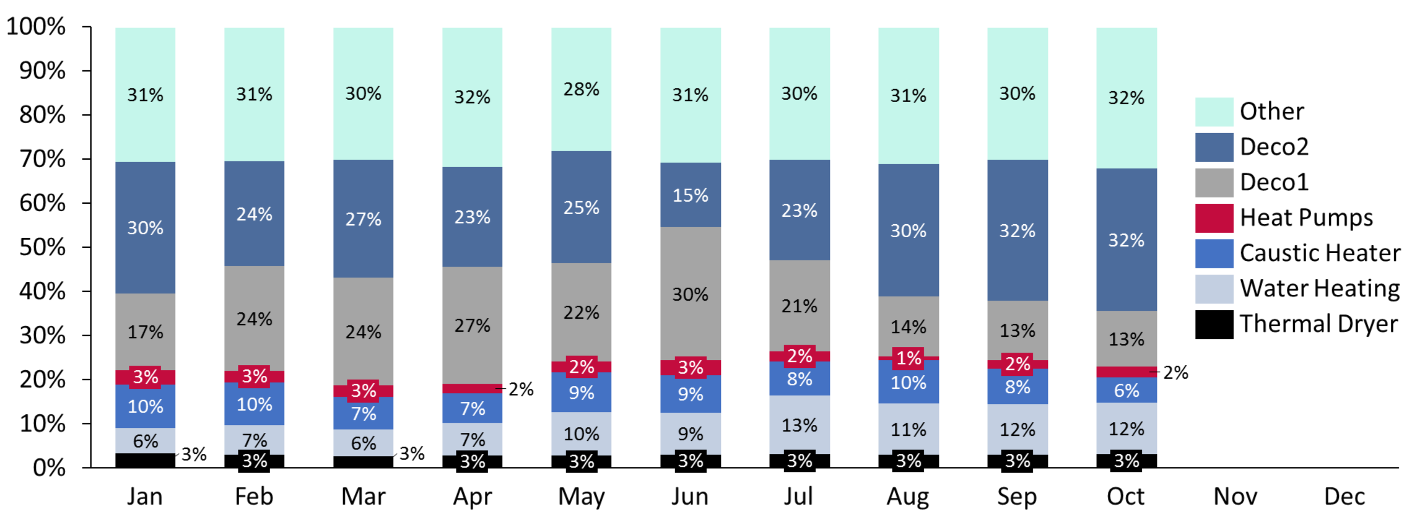


Fig. 4: Breakdown of monthly energy consumption on the Mpact plant

4. Thermal modelling

4.1 Methodology

Thermal modelling of a SHIP plant was conducted using ColSim CSP, which is FISE's in-house solar thermal system simulation tool. Input weather data into the model is taken from *Meteonorm* for the Mpact plant location. The ColSim model allows for dynamic system simulations, with an operational time-step of 1 minute. The resulting annual yield of thermal energy for different integration points and system configurations, along with assumed financial parameters and system costs feed into the calculation of LCOH, simple payback, NPV, and IRR.

4.1 Modelled integration points and load profiles

In this work two different solar thermal integration options were modelled. Integration point 1 (IP1), assumes no heat recovery is possible from the pelletizer. In this system, the hot water requirement is diverted through the heat pumps where it is heated to 33 ºC. This water is then indirectly heated to 85 ºC using a non-concentrating solar thermal system. Under these conditions the assumed load profile for the simulations is given by **Error! Reference source not found.** (IP1), based on the data collected at the plant. The installed capacity is confidential.

The second integration point assumes that the waste heat available from the pelletiser, can reduce the thermal load by approximately 60%. In this system configuration the inlet water is also heated by the heat pumps to 33 ºC. A parallel configuration with the heat recovery and solar thermal system is then utilised to raise the water temperature to 85 ºC. The load profile associated with this integration point is given by Fig. 5 (IP2).

Parametric simulations were conducted for both IP1 and IP2 to determine the performance and costs associated with the integration of the solar thermal system.

4.2 Economic parameters for SHIP system

The assumed cost parameters for the SHIP system are presented in Table 1. The costs are based on data collected by FISE, RENAC and DEG within the project. It should be noted that the actual costs that are received during the technical tenders could vary by up to 50% of these assumed values. Thus, only once the plant tenders are received can the final system be costed.

Table 1: Assumed cost parameters

Parameter	Unit	Value
Heat production costs	ZAR/kWh	1.1
Collector cost < 500 m²	ZAR/m²	7,079
Collector cost > 500 m²	ZAR/m²	6,371
Storage cost < 10 m³	ZAR/m³	32,180
Storage cost > 10 m³	ZAR/m³	24,135
Life time	a	20
Annual O&M costs	% of CAPEX/a	1
Incentives	% of CAPEX	30
Debt tenor	a	5
Nominal risk free rate	%	8.47
Credit margin	%	2.5
Liquidity spread	%	1
Corporate tax	%	28
Depreciation	a	1
Accelerated depreciation	a	1
Equity risk	%	7.62
General inflation	%	4.7
Energy inflation	%	9.89

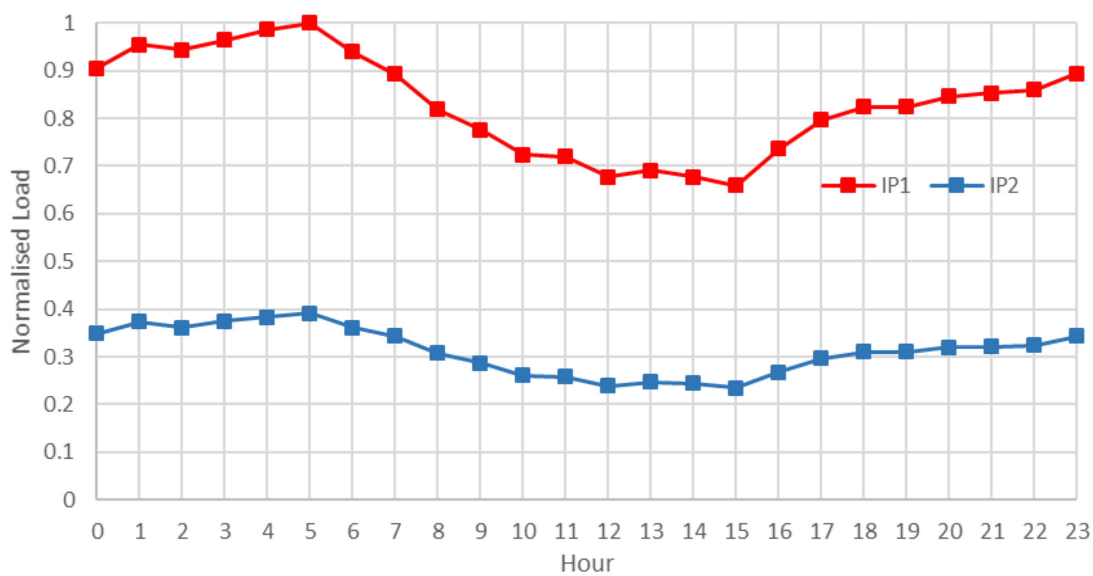


Fig. 5: Assumed load profile for IP1 and IP2 (normalised to maximum of IP1 to maintain company confidentiality)

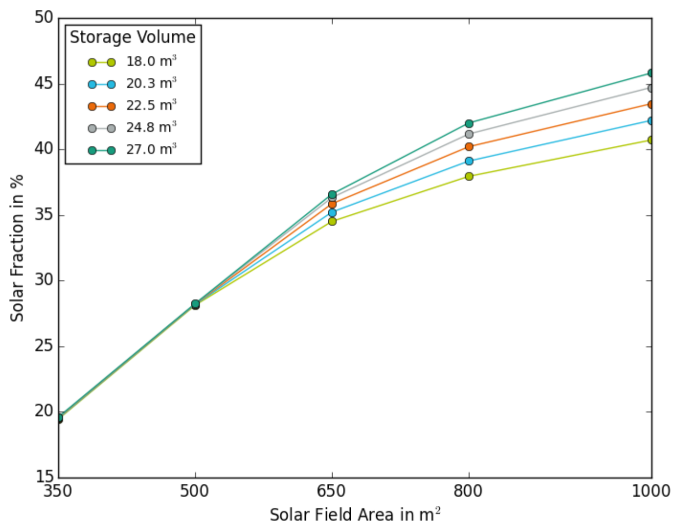
4.3 Solar fraction

The results of the simulations for varying system sizes for IP1 and IP2 are presented in Fig. 7 in terms of solar fraction. Solar fraction refers to the overall annual fraction of energy consumption that is met by the solar system. It should be noted that the given solar fraction is only based on the load profile in in Fig.5 and not for the overall plant.

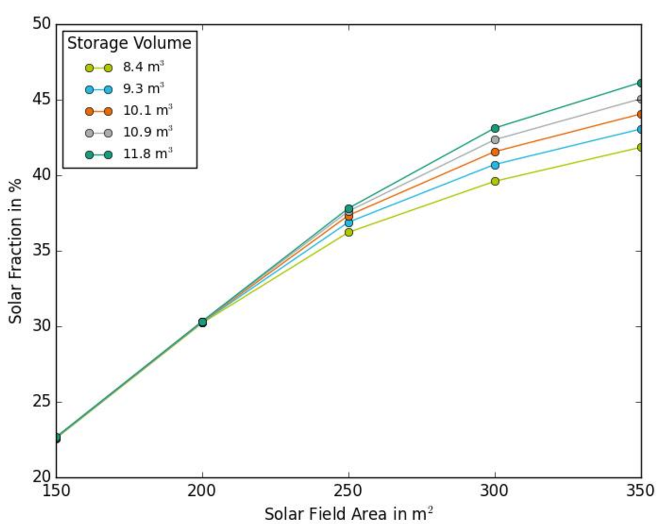
For each integration point, increasing the collector area and the storage capacity results in a higher solar fraction. For IP1 a solar fraction of 45% can be achieved with a 1000 m^2 collector area at 27 m^3 of hot water storage, whilst for IP2 a solar fraction of 45% can be achieved with a 350 m^2 collector area at 11.8 m^3 of hot water storage, whilst for IP2 a solar fraction

4.4 Levelised Cost of Heat

The Levelized Cost of Heat (LCOH) is a metric that relates the total costs of a system with the annual energy yield. This is a methodology that is commonly employed to compare different energy generation technologies or configurations to each other. The results of the LCOH calculations, based on the cost data in Table 1, are presented in Fig. 8. The minimum LCOH of the solar system (R0.78/kWh) is achieved at a collector area of 650 m^2 and storage volume of 24.8 m^3 for IP1. The minimum LCOH for IP2 is increased to R0.83/kWh due to the smaller system size and therefore larger specific collector costs. This excludes the significant savings from the waste heat recovery, which is recommended. The LCOH is minimised for a collector area of 250 m^2 and a storage volume of 10.1 m^3.

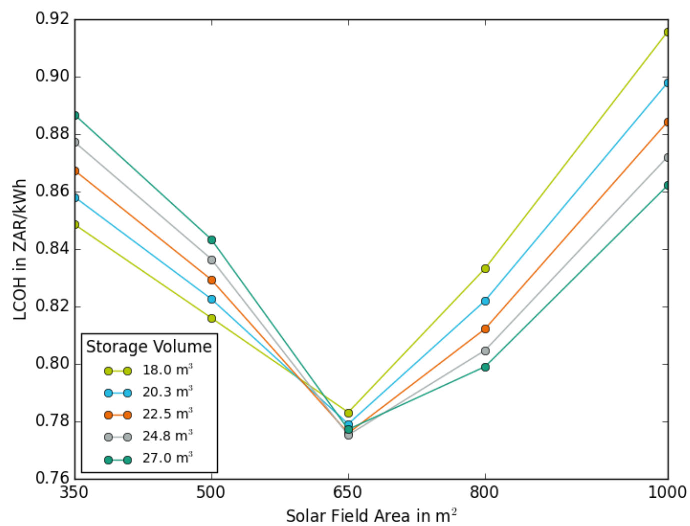


(a) Solar fraction simulation results for IP1

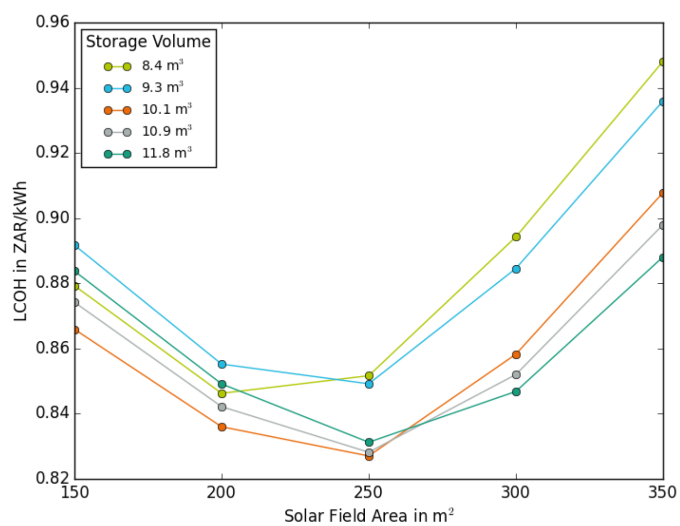


(b) Solar fraction simulation results for IP2

Fig. 5: Solar fraction for different systems



(a) LCOH from simulation results for IP1



(b) LCOH from simulation results for IP2

Fig. 8: LCOH for different systems

The system parameters at the minimum LCOH are presented in Table 2 for IP1 and IP2. The results show that attractive payback periods below 5 years can be achieved for both systems based on the assumed costs and thermal modelling. Thus, the modelling indicates that there is a good business case for Mpact to pursue a SHIP system. It should be noted that the payback period includes the Solar Payback grant finance that is available.

Table 2: Optimal system results

IP1: Parameter	Unit	IP1	IP2
Solar field area	m²	650	250
Process inlet temp.	°C	33	33
Process outlet temp.	°C	85	85
Storage temp.	°C	~85	~85
Storage volume	m³	24.8	10.1
Annual solar yield	MWh/a	862.4	331.6
Solar fraction	%	36.33	37.24
Efficiency solar system	%	65.15	65.12
Total investment cost	ZAR	4,73m	2.01m
Incentives IKI Payback	ZAR	1,42m	0.60m
CAPEX cost storage	ZAR	0.60m	0.24m
CAPEX solar field	ZAR	4,14m	1.77m
OPEX	ZAR/a	47,4k	20.1k
IRR*	%	39.5	36.4
Simple payback time*	a	4.1	4.5
LCOH conventional	ZAR/kWh	2.35	2.35
LCOH solar system*	ZAR/kWh	0.78	0.83
CO_2 emission savings	tCO2/a	788	303

*Note that all calculations include the 30% CAPEX subsidy provided by Solar Payback

5. Conclusions

This paper has presented an overview of a SHIP feasibility study that was conducted on Mpact Polymers. As the plant currently utilises extensive electric heating to produce hot water at 85 ºC, there is a good potential for SHIP deployment, using non concentrating collectors. The plant assessment highlighted a significant opportunity for waste heat recovery, which has the potential to reduce thermal energy demands by 40% on the wash plant, however, the technical feasibility of this opportunity is still under evaluation. Two plant integrations schemes were considered (including/excluding heat recovery). The results show that attractive payback periods of between 4.1-4.5 years can be achieved based on the assumed costs. The next phase of this project will focus on the technical tendering process.

6. Acknowledgements

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7. References

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