

SOLAR THERMAL APPLICATIONS IN MINERALS PROCESSING IN SOUTH AFRICA

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Abstract

Globally, the interest in solar thermal applications in minerals processing is increasing as the potential value of this technology is recognised. From the point of view of energy supply companies, there is interest in possible applications of this technology, but a lack of knowledge on how to identify such opportunities. This paper describes results from Mintek's roadmap for research in solar thermal applications in minerals processing (STAMP) in South Africa. Mintek is investigating opportunities for solar thermal process applications to promote local beneficiation of minerals and metals as well as to support the local ferroalloy production sector. The roadmap was developed as an extension to the Solar Energy Roadmap for South Africa, where the need for research into solar thermal industrial process energy applications is foreseen, but not identified. The paper also presents insights from an industry analysis and the macro environmental factors influencing the market for STAMP in South Africa and details results from Mintek's pursuit of the strategy detailed in its roadmap. The intended audience of the paper includes policy makers in the solar industry sector, researchers and the South African mining and minerals processing community.

The purpose of the paper is to provide a motivation for solar thermal applications in metallurgical applications in South Africa. The paper invites collaboration on solar thermal projects with application in the minerals processing field and details several fields of interest.

Keywords: minerals processing, solar thermal process energy

1. Introduction

Currently it is estimated that global mean surface temperatures are elevated by 1 °C above pre-industrial levels. The cause of global warming is attributed to the increase of greenhouse gases in the earth's atmosphere due to the use of fossil fuels as primary energy source since the start of the industrial revolution. Fossil fuels include coal, oil and natural gas as well as petrochemical fuels derived from oil such as diesel, petrol and paraffin. Fossil

fuels are seen as non-renewable as they have formed over geological time periods and cannot be replenished naturally. Fossil fuels are therefore finite resources. Key statistics on carbon dioxide emissions and energy use by source and country are readily available [1].

To reduce the amount of greenhouse gases from industry the following interventions are usually recommended to meet sustainable development goals (SDG) as agreed upon by 193 countries (including South Africa) in 2015 [2]:

- Direct avoidance of CO₂ emissions by using renewable electricity, bioenergy or alternative materials
- Minimising process energy requirements through energy efficiency to reduce fossil fuel demand
- Using fossil fuels, but adding carbon capture, utilisation and sequestration (CCUS) to prevent CO₂ emissions to atmosphere

Although energy efficiency is necessary to meet the global goal of reducing industrial greenhouse gas emissions by between 60 and 91% [3], it is not sufficient and other approaches need to be considered as well. Changing electricity supply to renewable electricity is certainly an option and can reduce indirect greenhouse gas emissions significantly. The challenge is to reduce direct greenhouse gas emissions currently produced from use of fossil fuels for heating and/or as process reductants. Although carbon capture and sequestration has found some applications, the uptake of this technology has been slower than expected and other ways of reducing emissions are needed [4], [5].

The possibility of renewable energy sources to replace fossil fuels and/or electricity as the source of process heat is discussed in this paper. Currently most of industrial heat requirements are met by fossil fuel combustion in the form of coal, natural gas or liquid petroleum gas (LPG) and oils (diesel). Biogas and solar thermal technologies can replace heating by fossil fuels in many applications. With an industrial energy demand of 85 EJ of which 41 EJ is needed for material transformation processes above 400 °C, the possible market for solar process heat is significant [3]. Discussions around the South African market for

solar process heat mostly concentrate on low temperature applications [6] but may be expanded to higher temperatures as the technology develops.

2. Industry analysis

An industry analysis was conducted to identify the main influences on CST research and application in minerals processing in South Africa. The industry is seen as mines and minerals processors operating in South Africa, the South African government - as Mintek's main stakeholder - and potential CST companies wanting to provide services to mining and minerals processing as process heat. The analysis also considers entrepreneurs that might want to start new businesses in this industry. The analysis is not exhaustive as it only provides the main influences rather than an in-depth analysis of all influences.

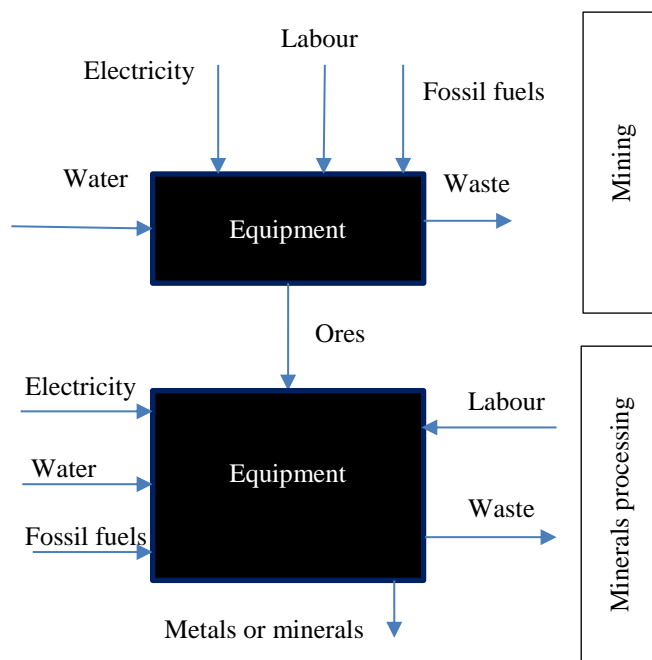


Fig.1. A simplified production map showing the main inputs and products from mining and minerals processing

2.1 New entrants

Although many new mines have opened in South Africa, the mining industry is still dominated globally by a few companies [7]. Some of these companies are vertically integrated and beneficiate ores to metal, but the South African industry is still predominantly exporting unbeneficiated ore. The barriers to entry in the mining and minerals beneficiation value chain are high. Large amounts of capital is needed to enter the industry. Other barriers to entry are political in nature, with some resources located in politically unstable regions or begin

threatened by nationalistic legislation. The South African government is encouraging new foreign direct investment by marketing South Africa's mineral resources. President Ramaphosa [8] said, "As government we regard the mining industry as a key player in the future growth and development of our economy, with huge potential for exploration, production and beneficiation."

2.2 Suppliers

The mining industry uses labour, equipment, water and energy (mostly in the form of electricity) to liberate ores. These ores can then be further beneficiated to concentrate the valuable minerals, and processed to produce metals. All process routes require more resources and these resources once again include equipment, labour, water and energy. Energy may be needed in the form of electricity and/or process heat. Highly energy intensive processes are often located to take advantage of low energy costs and South Africa's electricity crisis has moved it from a preferred location for such processes to a threatened one [9].

South Africa's national electricity supply is currently monopolised by ESKOM, a state owned enterprise. Ever increasing electricity prices has led to ESKOM introducing an incentive for large electricity users [10]. It is unclear how much of industry is benefitting from this incentive. ESKOM's precarious financial position is public knowledge and many users are investigating imbedded generation as an alternative. This may lead to the "utility death spiral" where lower demand leads to reduced revenue which necessitates higher electricity prices which leads to a further reduction in demand [11]. In the state of the nation address [12] it was announced that ESKOM will be split into 3 entities concentrating on electricity generation, transmission and distribution. This will also level the playing field for independent power producers (IPPs) to supply electricity to the grid. South Africa's updated IRP (Integrated Resource Plan) is awaiting finalization.

The uncertainties in the electricity sector are causing renewed interest in reducing electricity consumption through energy efficiency, and preheating of feed materials when smelting. Current state of the art preheating technologies use furnace off-gas and fossil fuels (coke, diesel and natural gas) as energy sources for preheating. There are multiple suppliers for fossil fuels, although the market is sometimes quite volatile.

These uncertainties are also promoting renewable energy as a viable option to reduce exposure risk. Renewable energy (for both electricity and process heat) has predictable costs, dominated by capital repayments. Capital repayments are negotiated at the start of the project before project implementation begins. Operational costs for renewable energy projects are usually low compared with fossil fuel alternatives

and can be attractive if the payback period is shorter than the planned business lifetime. Renewable electricity generation may be owned by the user or obtained through a power purchase agreement. Harmony Gold (a gold mining and exploration company) has announced that it has signed an agreement for 30 MW embedded generation which will supply them with electricity below ESKOM costs [13]. Similar agreements may be considered for the supply of process heat.

2.3 Buyers

Significant buyer pressure is starting to change the way commodities are supplied. With almost all countries being signatories of the Paris accord, supply chains are being scrutinized to ensure that commodities are produced sustainably and with lower environmental footprints than before. This demand for “green” commodities has led to CODELCO’s green copper program where they are certifying the environmental footprint from producing their copper and using differential pricing based on environmental attributes such as carbon footprint and water footprint [14]. South Africa can build on its renewable energy resources to start similar initiatives to differentiate products from greener production routes.

2.4 Substitutes

Despite the growth of the circular economy, global demand for commodities is still rising, indicating that primary production of ores and metals will still be needed. The recycling industry may indeed be included as possible users of renewable process heat. Specific applications may be found in separation of low boiling point metals by fuming, e.g. cadmium recovery via distillation from Ni/Cd batteries, which takes place at 900 °C.

For solar thermal process heat, the main substitute remains coke and other fossil fuels. Without price adjustments (such as an expensive carbon tax) coke and coal are likely to remain a more affordable energy source than solar thermal on a kWh basis. Data for calorific values of fuels [15], the cost of electricity [16] and cost of fuels are presented in Table 1. The cost of metallurgical coke is highly variable with the value of R2000/t used for illustrative purposes only. The cost of coal is estimated as R830/t [17]. Solar thermal process heat costs are location dependent but can provide cost advantages when compared to diesel and electricity in countries with good solar resources such as South Africa. Over large parts of South Africa with DNI levels above 2500 kWh/(m²a), the levelised cost of solar thermal process heat can be estimated as between R0.53/kWh and R0.61/kWh [18]. The comparison of prices for solar thermal process heat per energy unit is given in Table 1.

Heat source	Price R/kg	Energy content*, kWh/kg	Cost R/ kWh
Diesel	17.46	8.4	2.08
Electricity	N/A	N/A	0.78
Solar thermal	N/A	N/A	0.53
Metallurgical Coke	2.00	7.2	0.28
Anthracite Coal	0.83	9.06	0.09

Table 1. Estimates for process heat costs per kWh

*Energy content values from [15]

2.5 Competition

Competition exists amongst mining and minerals processing entities to achieve the highest through-put for the lowest production cost. The use of renewable energies should not jeopardise production cost competitiveness in any way.

In the renewable electricity space, the auction environment has become the dominant model for independent power producers, encouraging fierce competition on pricing of electricity. This has led to several innovations reducing the cost of concentrating solar technology. An overly competitive environment does bring about the risk of under-pricing and only the future will tell if recent low bids are a fair indicator of technology costs. Similar fears were raised when solar PV technology costs decreased but this has proven unfounded and solar PV technology costs has stabilised at a low level.

3. Macro environment analysis

The macro environmental analysis was done to identify some factors external to the industry that have significant impact on future industry development.

3.1 Global policies

Although 195 countries agreed to the COP 25 Paris accord in 2015, details on how developed countries will support developing countries are still one of the aspects to be finalised. The Clean Development Mechanism previously established by the Kyoto protocol enabled the trading of certified emission reductions (CERs). The market for CERs has been depressed due to changes in European Union regulations and uncertainty over the future of carbon trading. CERs traded at €0.35 in July 2018 [19].

The move to greener technologies is no longer driven by incentives however, as electricity and process heat has been

demonstrated as the more cost effective option in Chile [20], Canada [21] embraces electrification of mining, and for international companies such as RioTinto [22] it has become part of their business strategy.

3.2 Local policies and incentive

The South African electricity sector is guided by the Integrated Energy Plan (IEP) and the Integrated Resource Plan (IRP) and includes provision for increased renewable energy electricity production. At the time of writing, the updated IRP is still under review [23]. The National Energy Efficiency Strategy, along with the National Energy Efficiency Action Plan and the Biofuels Industrial Strategy are also of relevance to renewable energy sources, although they respectively focus on solar water heating and encouraging investment in the biofuels sector.

In the New Growth Path (NGP, 2011), targets were set to generate 300000 direct jobs by 2020 to green the economy, with 80000 in manufacturing and the rest in construction, operations and maintenance of new environmentally-friendly infrastructure. The Green Economy Accord (2011) realised the development of the South African Renewable Energy Council. Signatories to the accord included government departments, organised labour and business. No further report on progress towards these goals could be found..

Industrial Policy Action Plan (IPAP, 2014) from the Department of Trade and Industry (dti) supports renewable energy and energy efficiency as a priority for South Africa's industrial policy.

The South African government has levied a carbon tax of R120/t CO_{2e} in the Carbon Tax bill implemented by parliament from June 2019. The bill is generally seen as forgiving of industry with between 60% and 95% tax free emission allowances on the basic price of R120/t CO_{2e} [24]. The state intent is however to reduce allowances gradually until the full tax will be applied.

3.3 South Africa's commitments with regards to global warming and greenhouse gas emissions

“South Africa's nationally determined contribution (NDC) contains a target to limit greenhouse gas (GHG) emissions including land use, land use change and forestry to between 398 and 614 MtCO_{2e} over the period 2025–2030. This target is equivalent to a 19–82% increase on 1990 levels. South Africa's NDC is consistent with its pledge under the Copenhagen Accord, which proposed emissions reductions below business-as-usual (BAU) levels by 34% in 2020 and 42% in 2025. This represents a 17–69% increase in emissions in 2020 and a 17–78% increase in 2025 on 1990 levels.” [25] Current projections see South

Africa following the maximum NDC target and possibly exceeding it in 2030 [25]. Change is needed to reach the stated goals and new goals will be needed in line with global emission targets for 2060.

3.3 Economic landscape

Most solar thermal technologies have low operating costs, but require a significant amount of capital investment. Interest rates are therefore very important to financing solar thermal projects in particular and renewable energy projects in general.

South Africa's prime interest rates over the last ten years remained high (at 8 % to 10 %) compared to international benchmarks. International financing may reduce loan costs and lead to lower project costs. Demonstration and application of new technologies reduce their financial risk profile and can also lead to lower interest rates on loans for project financing.

South Africa's economic growth rate in contrast has been low, with the economy showing slow growth and several periods of recession.

3.4 Social Environment

Poverty, inequality and unemployment are three challenges facing South Africa. Fear of losing jobs has led to protests against the introduction of more renewable energy to the grid [26], [27]. However, the development of new business and growth of the green economy is seen as a possible solution to improving South Africa's employment rate in the long term as stated in the National Development Plan (NDP) [28].

3.5 Technological landscape

Worldwide electricity generations from solar photovoltaic (PV) and wind turbine technologies has become cost competitive with fossil fuel electricity generation. The focus has moved to managing the integration of these resources rather than debating their inclusion. Energy storage technologies are being developed and include different battery technologies, chemical storage and thermal storage. Fuel cells, electrical vehicles and the hydrogen economy are predicted to transform the transport industry.

The fourth industrial revolution is leading to innovation in plant management, control and optimization technologies and data processing. These developments may lead to more sophisticated systems that can manage variable resources incorporated in new, low carbon process flowsheets.

3.6 Environmental landscape

In October 2019 the United Nations released a report on the difference in impacts and risks associated with 2 °C global warming as compared to 1.5 °C global warming. The summary in Figure 2 is based on this report [29].

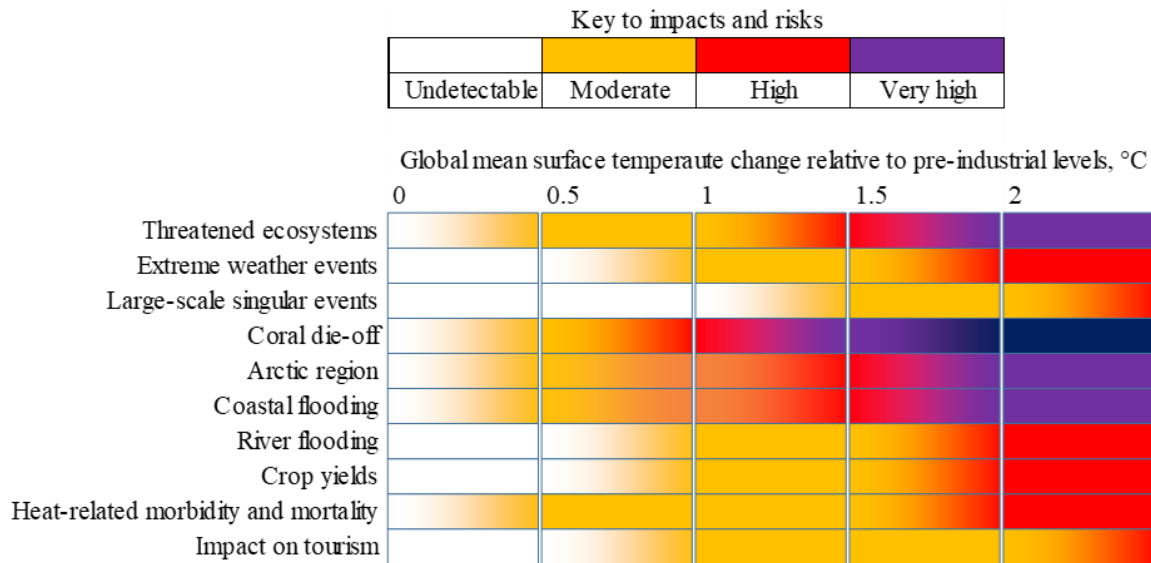


Fig. 2. A summary of global warming impacts and risks with increasing global mean surface temperature

To maintain global warming to below 2 °C, global CO₂ emissions for electricity generation needs to reduce to zero and industrial emissions of CO₂ need to reduce by between 60 and 90% by 2060 [3].

4. Future research opportunities

South Africa has the Solar Energy Technology Roadmap (SETR) [30] circa 2010, but it considers mostly electricity production and only low temperature solar thermal applications. Its research recommendations for concentrating solar systems are as follows:

“CSP systems for power and thermal applications: Optimise receiver system technologies for products and manufacturing (central receivers); expansion of existing system design, simulation and optimisation capabilities, including receiver structure and tracking systems, and dry and hybrid cooling in the power block; development of appropriate education and training programmes; and establishing R & D facilities for improved and new generation absorber and storage technologies.”

“Thermal applications: System optimisation research projects for specific applications, especially for process heat where a significant contribution can be made.”

This paper proposes that minerals processing and beneficiation may allow suitable applications for solar thermal process heat. From Figure 3 it can be see that South Africa has minerals resources of manganese, iron, zinc, copper and lead in areas with very good solar irradiance.

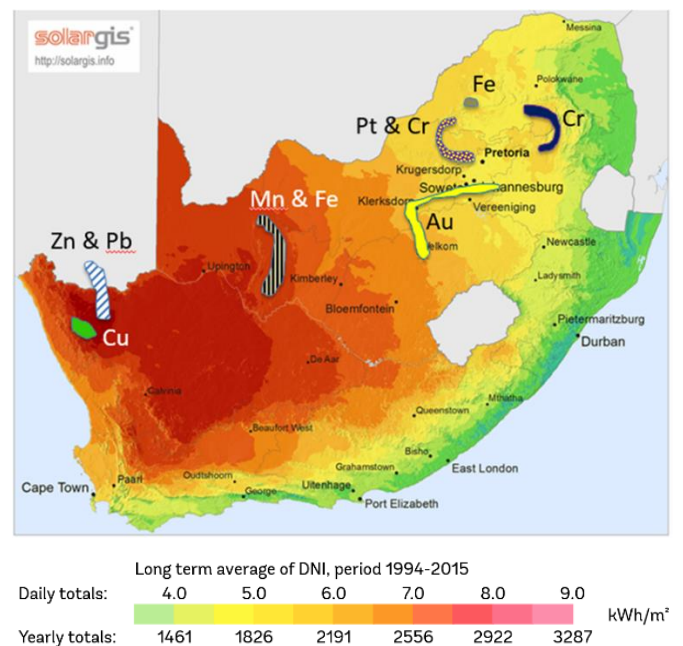


Fig.3. An overview of South African solar resource (DNI) and selected mineral resources.

DNI data by SolarGIS [31]. Mineral resource data from Council of Geosciences [32].

Beneficiation of these ores in South Africa are limited and exports currently dominate the sales of these commodities, see Table .

Commodity	Exports as a % of total sales*
Copper ore	49.0
Iron ore	89.6
Manganese ore	94.7
Zinc ore	100.0

Table 2. Exports of commodities

*Based on data from the Minerals Council South Africa [33], [34]

When analysing the beneficiation routes of these metals the following opportunities are options for solar thermal process heat applications:

4.1 Preheating with solar thermal to reduce electricity and fossil fuel demand when smelting.

For copper production energy consumption in smelting can be reduced by 50% [35] when integrating preheating with solar thermal energy. This concept can be further investigated using technology concepts developed for manganese ore preheating, which estimate a 20% reduction in electricity consumption when manganese ores are preheated to 600 °C [36], [37]. Similar studies may be done for iron and steel production and for Mintek's Enviroplas process for zinc production. In fact, solar preheating technology could be applied to most pyrometallurgical processes for preheating purposes, including ilmenite smelting and chromite smelting.

4.2 Scrap re-melting and casting for low melting metals.

Pure aluminium (Al) has a melting point of 660 °C, lead (Pb) has a melting point of 328 °C, tin (Sn) has a melting point of 232 °C and zinc (Zn) has a melting point of 420 °C. Re-melting and casting of these metal scraps are feasible with concentrating solar thermal heat and will advance the circular economy. The direct re-melting of aluminium with concentrating solar has previously been investigated on small scale [38], [39].

4.3 Hot dip galvanisation

Hot dip galvanization requires a bath of molten zinc at 450 °C in which parts can be dipped to provide a protective coating. Zinc dipping provides better bonding between the zinc and the iron or steel part than electrolytic zinc plating or zinc spray coating and therefore superior corrosion protection. Currently zinc kettles are heated by gas burners – a concentrating solar thermal alternative would be an interesting development.

4.4 Hydrometallurgical zinc production

Hydrometallurgical zinc production can be performed using many different process routes. Most require low temperature

heating (from 40 °C to 200 °C) to remove iron content from the electrolyte before zinc can be produced by electrolysis from the aqueous solution. The iron hydroxide precipitation route requires hot acid leaching at 95 °C, iron removal by the Jarosite process may be done at 185 °C or at 95 °C with different acid concentrations, the Goethite process requires temperature control between 70–90 °C and the hematite process requires autoclave treatment at 200 °C and oxygen pressure of up to 15 bar.

Zinc production from the solvent extraction route will be investigated in the near future.

4.5 Zinc distillation

Zinc distillation is used to produce zinc of very high purity (Special High Grade zinc). As zinc boils at 907 °C, a solar boiler for zinc operating at around 1000 °C may be an attractive alternative to zinc boilers heated by fossil fuels (The New Jersey Process) or electricity (Zincref process). This technology would have synergies with Mintek's Enviroplas technology which provides a pyrometallurgical route for the production of Prime Western Grade zinc from the Gamsberg deposits in the Northern Cape.

4.6 Copper electrolytic refining

Copper electrolytic refining is used to refine most of the world's copper production. The electrolyte needs to be maintained at 55 – 65 °C. This process heat requirement is easily met with non-concentrating solar thermal and examples of this has been very successful at the Gabriela mine in Chile [40].

4.7 Electrowinning of manganese metal

Electrowinning of manganese metal requires the electrolyte baths to be at 35 °C to 45 °C. The process also requires a higher temperature calcine preparation step to ensure that all manganese is reduced to MnO to enable maximum extraction of manganese from the leaching process. The incorporation of renewable energies into electrolytic manganese production is already being advanced in Australia [41], but further opportunities may be available.

In summary, for all these studies care should be taken that the solar share of process energy is maximised while the necessity for complimentary energy sources are acknowledged and included in the business case. For process heat applications below 100 °C commercial technologies are readily available and demonstrated and basic research is no longer imperative. For medium temperature process heat from 200 °C to 400°C, commercial technologies are available but demonstrations have been few. Large scale demonstrations would likely lead to more implementations of these technologies and should be pursued. For high temperature process heat above 400 °C, some

technologies have been developed, but they have not been commercially implemented and research as well as demonstration is required in this temperature range.

With an abundance of opportunities in the zinc production and purification flowsheet, it is noted with interest that Vedanta is undertaking a feasibility study for a greenfield smelter and refinery at the Gamsberg mine [42]. Also of interest is the statement of the International Zinc Association of South Africa (IZASA) that the solar power industry is becoming a big market for zinc coated steel [43], indicating that future utility scale solar PV and concentrating solar infrastructure is also driving demand for galvanised steel.

Although the Black Mountain copper, zinc and lead project is scheduled to stop in 2020, Exxaro is undertaking extensive brownfields exploration in the region [44]. Orion resources has also announced that they plan to restart mining for copper, zinc and lead at Prieska [45], [46].

5. Conclusion

Solar thermal applications in minerals processing has great potential to reduce reliance on fossil fuels and promote the greening of minerals processing. On its own or combined with renewable electricity generation, solar thermal process heat can significantly reduce operating costs, specifically where it can reduce diesel and electricity consumption.

A preliminary scoping of opportunities generated by overlap of mineral and solar resource concentrations has identified opportunities in the manganese, copper and zinc production processes specifically and in smelting operations (including steel and ferrochrome production) in general. Future analysis may widen the geographic area to lower solar radiation areas where more opportunities may become apparent. In general, research for solar thermal applications are recommended in the fields of metal recycling, the preheating of smelter feed and the galvanization of steel. Further opportunities may arise as global and local incentives to promote lower greenhouse gas emissions increase in line with 2060 targets.

Acknowledgements

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