BX01 - Reduction of Bauxite Moisture Using Concentrated Solar Energy

Fernando Berlinck Dutra Vaz
CEO, SmartDry, Recife, Brazil
Corresponding author: ferberlinck@gmail.com

Abstract

Moisture in minerals impacts on logistics (dead weight) and processing (steals energy via evaporation) costs with direct link to GHG (green house gases) and pollution. Sustainable mining is at the top of the agenda for many, and societies, governments and investors are increasing pressure for a sustainable mining chain. We are developing solutions to use CSE (concentrated solar energy) to dry-reduce moisture in minerals and concentrates. Classical available solutions use a receptor and thermal fluid to collect and transfer CSE to a horizontal kiln. These are complex and CAPEX and OPEX intensive. Our solutions use double tracking heliostats to focus and inject CSE into an ore pile forming at the courtyards. As ore is dumped onto the pile, CSE is injected in the amount required to dry or reduce the moisture as defined by the customers. Our solutions are able to handle large daily amounts of ore with minimal operational changes. Our solutions require lower CAPEX and OPEX than other presently available solutions. By using CSE, drying-reducing moisture becomes a fixed cost.

Keywords: moisture, humidity, drying, concentrate solar energy, minerals, sustainable mining.

1. General Remarks

Moisture in minerals impacts on logistics (dead weight) and processing (steals energy via evaporation) costs with direct link to GHG emissions and pollution [1, 3]. Society, Governments and investors are demanding more sustainable and cleaner mining and processing. Present solutions use fossil fuels or biomass to dry-reduce moisture in minerals and concentrates. These are CAPEX and OPEX intensive operations with impacts on GHG emissions and pollution.

Available dewatering technologies utilize vacuum filters, pressure (hyperbaric) filters, thickeners, centrifuges, dewatering screens to reduce moisture to a lower value [1] and dewatering chemicals / surfactants [2]. These are mechanical and chemical solutions. Thermal solutions use a fossil fuel or biomass to produce thermal energy that is them used in kilns to dry minerals and its concentrates. These solutions contribute to GHG and pollution [1]. New technologies that use renewable energies (such as concentrated solar energy, CSE) for drying and reducing moisture in minerals have to be developed for a more sustainable mining, in the near future.

This paper shows possible direct CSE injection solutions for drying and reducing moisture in minerals. In their publication, Li et. al. [1] said: "*It should be possible to benefit from advances made in other industries. Use of solar energy, ambient air, and windmills is possible at vast mine sites.*"

1.1 The Challenges

Most mining operations use a feeder to dump ore onto a courtyard forming a so-called stockpile. As the pile grows, the ore dropping point moves in 3 axes (X, Y and Z). The CSE point (like the fixed receptor in a CSP - Concentrated solar power plant) should move along, so CSE focused on the ore dropping point. For this, you need a double tracking heliostat. Since tons of ore are involved, large amounts of CSE are needed. Harvesting it in a mine or port operation is challenging. Heliostats shadowing must be considered and solved.

CSE is a proven technology used for decades in CSP (concentrated solar power plants) to generate electricity. The quality of heliostats is high and prices are dropping making the financial viable with in a 6-7 years ROI depending on the required parameters.

1.2 Some of the Unknowns

If you ever went to a beach on a hot summer day, you felt on your feet what solar energy does to a mineral. By focusing CSE into a growing pile this will produce layers of hot ore that will speed up the evaporation. But how would evaporation take place in a 40.000-50.000 ton heated ore pile? How much will local air humidity and wind effects influence ore pile evaporation? How long will evaporation in a large ore pile take to reach a certain residual moisture target? What is the efficiency of direct CSE focusing onto minerals? How will different ores behave under the same processing conditions? These are some of the unknowns that our PoC (proof of concept) with Vale will try to answer for iron ore.

1.3 The Proof-of-Concept Project at Vale

To develop a PoC that could clarify the above unknowns at a low cost, was a challenge. So, we decided to use 30 kg samples and controls. Because Vale's daily ore volumes are so large using a solar kiln is not an option. Therefore, the PoC project focused on two alternative solutions, as follows:

1) Dry-reduce ore in courtyard pile forming
2) Focus and inject CSE onto ore being transported by conveyors.

Experiment 1) In order to simulate the ore being drop onto the pile at courtyards, we built an equipment that has in its center a funnel surrounded by heliostats. The heliostats focus the CSE on the center where the ore is dropping, hitting, heating it up in all layers. See Figure 1 for details.

Figure 1. Experiment 1 set up showing the heliostats, funnel and sand dropping being hit by CSE from all sides. (Flir E4 model thermal camera – Normal mode)

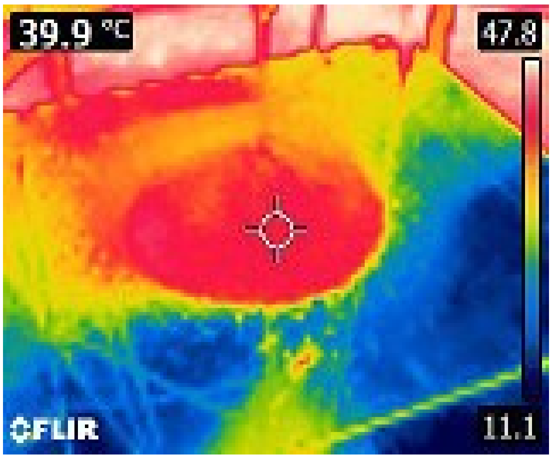

Figure 2. Experiment 1 Thermal image of the same set up taken at the same time. (Flir E4 model thermal mode).

Experiment 2) Ore is placed inside a tray. The tray is placed under the Fresnel lens. Above the lens, a reflective mirror beams down CSE. The same circular heliostats focus the CSE onto the reflective mirror. See figure 2 for details.

2. Our Solutions

To dry-reduce moisture in minerals water evaporation is the key. Heating is the primary method to speed up the evaporation process. By focusing the required amount of CSE (concentrated solar energy) onto the spot where the ore is being dumped to form a stockpile in the courtyard, solar energy can be used to heat up the ore in all layers of the pile. The CSE energy is transformed into thermal energy that heat up the water with the ore, thereby speeding up evaporation process. By injecting the CSE as the pile grows, the thermal transfer is "local", short distance as compare to focusing CSE on the sides of the piles. Typical stockpile sizes vary a lot, but in the case of iron or bauxite ores daily volumes are among the highest and piles can be over 20 m at the base and 15-20 m high with a typical mass of 40-50.000 tons per pile. A solution is being developed to work in conjunction with stockpile stackers to reduce the effect of heliostat shadowing.

The amount of energy required to dry-reduce the moisture is determined by the amount of ore (tons/day), the moisture (%) and the moisture reduction target (from X% down to Y% moisture). The total amount of heliostats (m^2) depends on site solar irradiation (Kwh/m^2/day). See in Table 1 below:

Table 1: Energy requirements and economics of bauxite dry-reduce moisture using CSE.

Initial moisture (%)	13.00%	
Final moisture (%)	3.00%	
Kg of water per ton of ore	100	
Energy necessary to evaporate (kJ)	257,394	
In kWh	71.50	
Site energy (average in kWh/m^2/day). Madeira Port, Maranhão, Brazil (http://www.cresesb.cepel.br/index.php#data).	5.10	
Heliostats (m^2) needed per ton of ore	14.02	
Assumed number of sunny days per year on site	200	
Heliostats (m^2) needed	280,386	
Cost per m^2 of Heliostat (US$/$m^2$)	$106,00	
Total CAPEX	$29,720,900	
Tons per day	20,000	
Freight Brazil-China per ton	**$20,00**	**$40,00**
Tons per Year reduced moisture	4,000,000	4,000,000
Ton of water removed per year	240,000	240,000
Value of water remove per year	$4.800.000,00	$9.600.000,00
ROI (Years)	6.19	3.10

CSE is a proven technology used for decades in CSP (concentrated solar power plants) to generate electricity. The quality of heliostats is high and the equipment prices are dropping, making an investment in this technology financially viable within a 3-7 years ROI depending on the overall project parameters. In economic terms, adopting CSE as the energy source means moving from a variable cost (other energy sources) to a fixed cost (renewable energy) in drying, since the finance contract has a fixed interest and the OPEX cost is well known and does not vary greatly over the years. Society, investors and governments are also increasing pressure for a more sustainable mining and processing sectors. These intangible values are expected to bear an increasing importance on the decision process in the mining and processing sectors in the next years.

2.1 Double Tracking Heliostats

Conventional heliostats track the sun and focus CSE on a fixed point, the receptor placed at the tower of a CSP (concentrated solar power) plant. Double tracking heliostats (DTH) tracks the sun and the discharging ore point on the pile as it moves and as the piles grows. So, the focal point of CSE is constantly moving with the ore, heating it up. This creates a hot zone that moves at the speed with which the point of where the ore is being dumped moves. The use of secondary reflective surfaces is also used to avoid heliostats shadowing. See Figure 3.

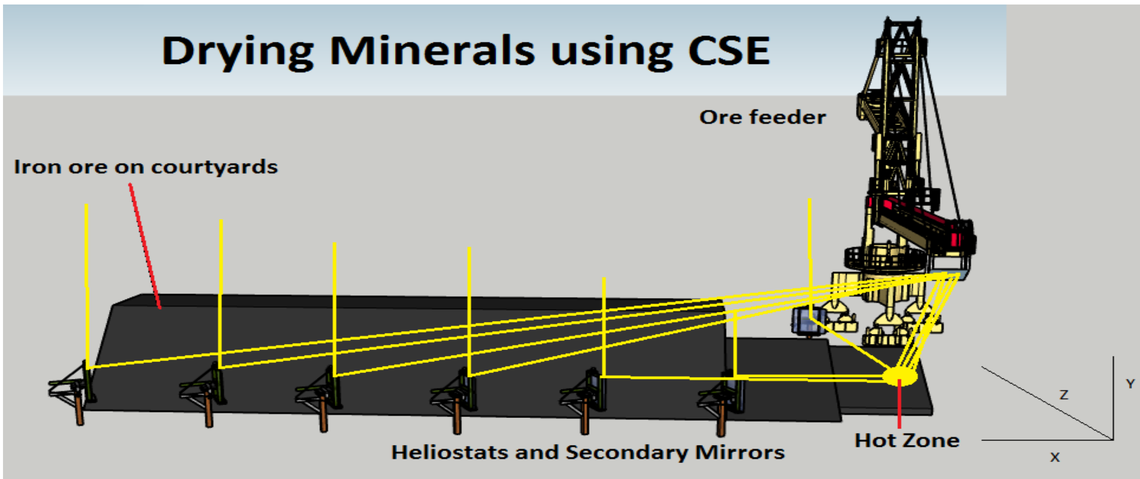

Figure 3. Double tracking heliostats and secondary reflective surfaces at an ore courtyard and ore feeder.

2.2 Injecting CSE onto Ore Being Transported by Conveyor Belts

Mining companies use various belts to transport ores, minerals and concentrates. Belts are good for CSE harvesting (long) but bad for focusing (narrow). Our solution is to use a Fresnel lens to focus and inject CSE onto the ore as it is being transported. The focal point is above the ore, so it creates a zone of CSE and not a spot/point. The use of a Fresnel lens also prevents CSE hitting the belt which could damage the belt.

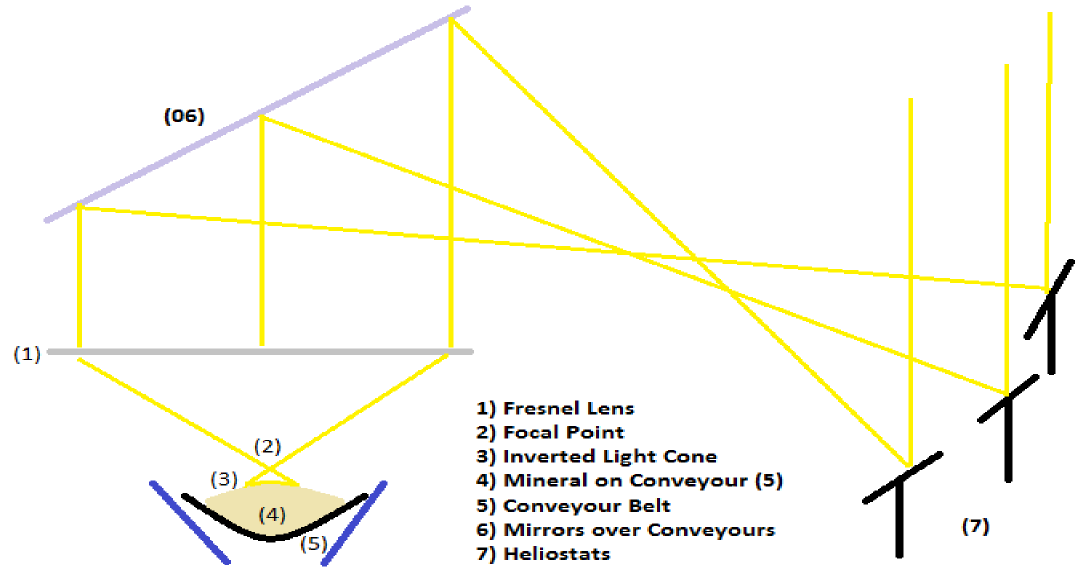

Figure 4. Injecting CSE onto ore being transported by conveyor belts.

2.3 Solar Kiln with Fresnel Lens

Our solar kiln solution differs in that this uses a Fresnel lens to focus and inject CSE into the kiln. A Fresnel lens can have multiple focal points with different amounts of CSE in each focal point. This allows for a simpler CSE distribution inside the kiln while avoiding thermal energy loss at the kiln entrance. In Figure 3, our solar kiln is shown with a 3 focal point Fresnel lens in front. A Fresnel lens can be made with its total lens area split into 3, zones (e.g. white 10 %, yellow 30 % and blue 40 %), with different focal points in each. The result is 3 focal points inside the kiln with its respective % of the total CSE in each. See Figure 5.

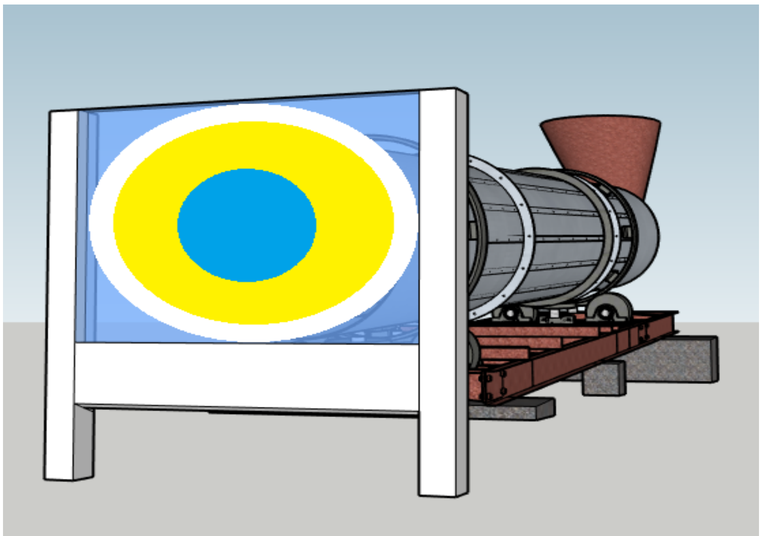

Figure 5. Solar horizontal kiln with a Fresnel lens with three focal points.

3. Equipment Used in Vale's Proof of Concept Project

Due to the very large volumes of iron ore required to be processed, Vale discarded the kiln-based solution. Therefore, only the pile forming and Fresnel lens-based conveyor belt focusing solutions were tested.

In Figure 6, the full equipment installed at the test facility for the pile forming experiment can be seen.

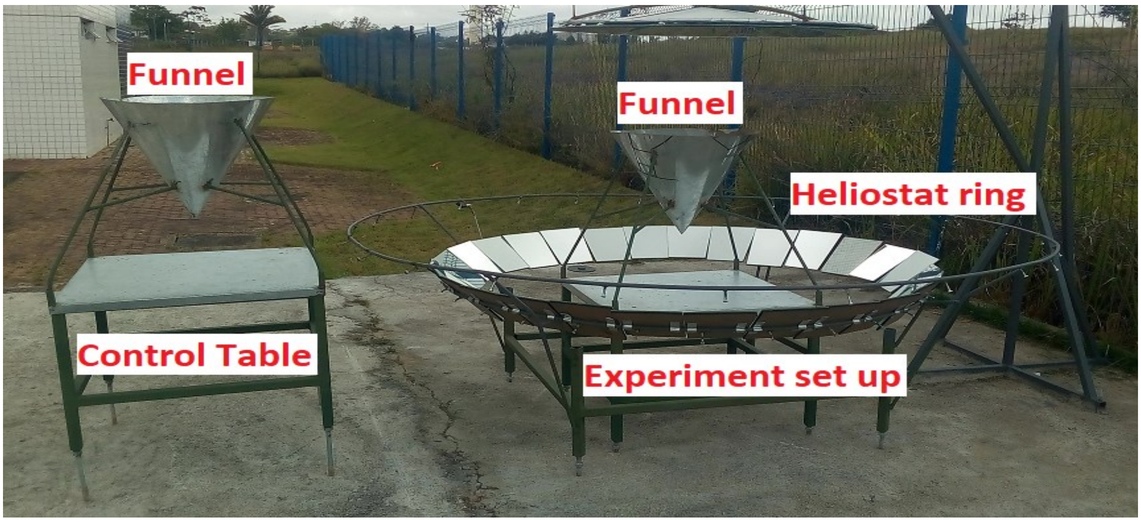

Figure 6. Equipment set-up for pile forming experiment.

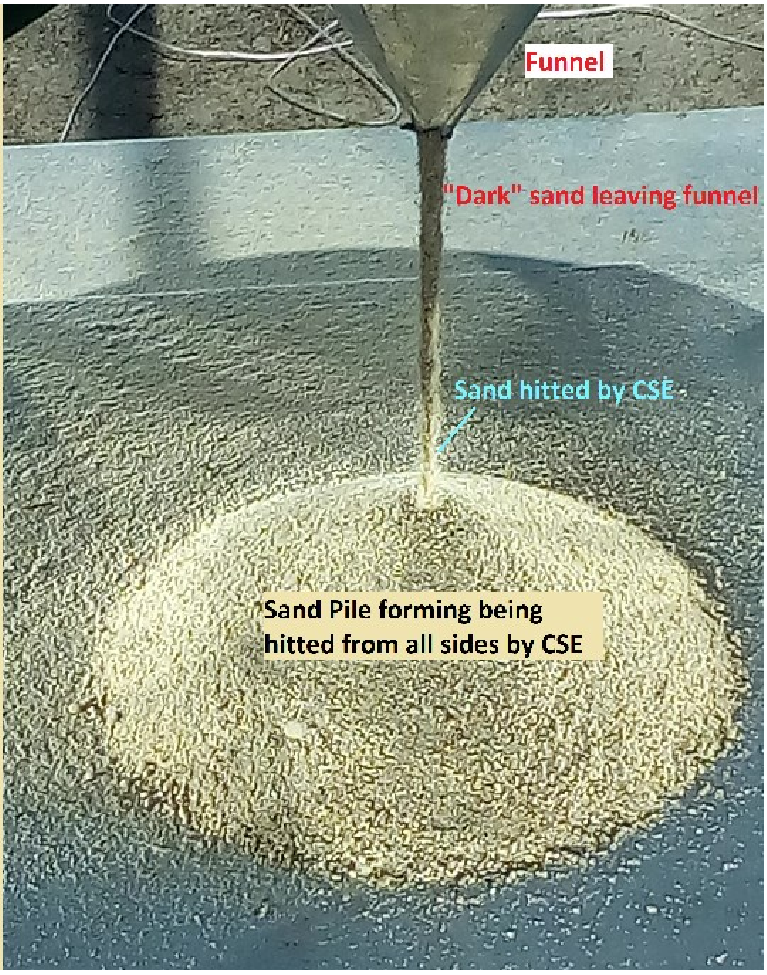

Figure 7. Detail of CSE hitting sand falling down from funnel.

In the experimental set-up, the ore is falling from a funnel forming a 30 kg pile). In the experiment the ore is hit by CSE and normal sun light in the control sample. The difference in surface and inner pile temperature (measured by thermal camera (Flir E4 model) and a probe thermometer (Incoterm) and moisture level (prior and after CSE injection) will determine the efficiency of the solution.

For the Fresnel Lens experiment, the CSE has to be focused perpendicular to the Fresnel Lens. To achieve this the equipment was adapted so that the sun light is reflected, first towards a concave secondary mirror and this focus the CSE towards the Fresnel lens.

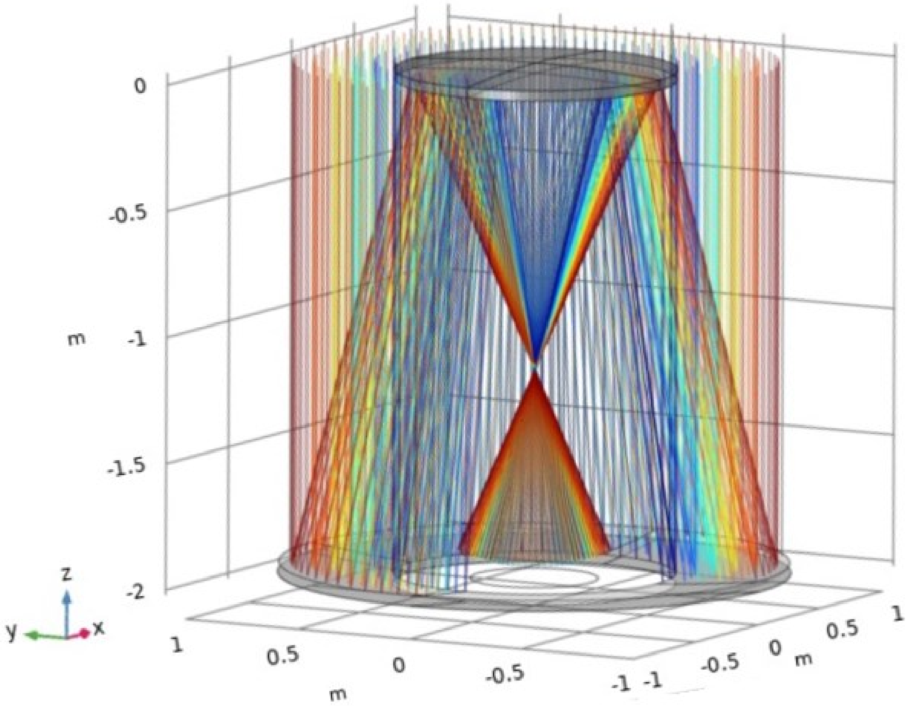

Figure 8. Schematic representation of the path of the sun's rays in the equipment for experiment with Fresnel Lens.

This sun's rays' path should be "seen" within the equipment described in Figure 9 below.

Figure 9. Equipment set up for Fresnel Lens experiments.

In the control table, the ore inside a tray (0,5 × 0,5 × 0,05 m L×W×H) will be hit by sun light only. In the experiment, the ore in the same tray, will be hit by CSE from four square meters of heliostats focusing sun light at the secondary mirror.

The focal point of the concave mirror is just below the Fresnel lens so that the circumference of CSE is just within the width and length of the Fresnel lens. The resulting effect can be seeing in Figure 10 below.

Figure 10. Four focus point Fresnel lens used to focus CSE onto ore being transported by conveyor belt.

By distributing the total CSE in four focal points that are within the conveyor belt width, a better thermal conductivity and distribution of the CSE can be achieved, thereby improving the efficiency. The interaction between CSE and ore is unknown. So, this will influence the final solution set up. It is expected that iron ore, which is dark gray, will absorb CSE better than white gypsum. But by what factor shall these initial experiments elucidate?

4. Discussion and Conclusions

The laws of thermodynamics apply, so whenever planning on dry-reducing moisture in minerals, one must consider the level of moisture, the dryness target, the air humidity, the color of the ore, the wind and the local solar irradiation and availability. The interaction between ore and CSE is another critical factor. A dark ore, like iron, should absorb CSE more efficiently than a white, like gypsum. Grain and pile sizes and format will also influence the overall efficiency. Ultimately, economically speaking, CSE harvesting is the determining factor in terms of financial viability.

The potential benefits for mining applications are basically of two types, 1) in logistics (elimination/reduction of dead weight), and 2) in processing (elimination/reduction of energy losses due to water evaporation). But there is no one solution that fits all, for each mining and processing operation, a specific solution must be developed. We are at early stages of determining for iron ore the parameters of our solution.

The adoption of CSE as the energy to dry-reduce moisture in minerals is the way ahead. It will contribute for a more sustainable mining sector by reducing GHG emissions and pollution. For mining companies, mine and ports are logical locations where drying can be considered. For processing plants, the solution must fit within the available site space.

In the processing phase, either intermediate (concentrates) or final (steel pellets, alumina, etc.) drying by CSE is even better since volumes are much smaller, requiring less CSE. All mining and processing companies knows its own logistics and energy costs. The cost of heliostats is dropping and at present is around US$106.00/m^2 [3]. Our solutions require minimal operational modifications to mining or processing companies. By changing from fossil fuel to CSE (renewable energy), companies will be supporting the move towards more sustainable mining.

There are no minimal ore daily volumes for the solution since the economics is dictated by several factors. Basically, initial ore/concentrate moisture level, moisture reduction target (%), site solar irradiation and availability are the key factors. The interaction between ore and CSE influences the process efficiency and impacts on the CAPEX.

What makes our solution unique is the ability to focus and inject CSE in each and all ore layers during pile forming, regardless of its size, using double tracking heliostats. As a way to harvest more CSE a Fresnel lens for conveyor belts just prior courtyard dumping is a promising solution since conveyor belts are typically very long and thus good for CSE harvesting. Both solution work on the principle that the CSE is focused and injected in "close" proximity to the ore layers as the pile is forming on the courtyards, not requiring thermal conductivity in "long" distances. Our solutions can be used in any pile format.

We would like to acknowledge Vale for supporting our PoC project.

5. References

1. Z. Y. Li, et al. Dewatering and Drying in Mineral Processing Industry: Potential for Innovation, *Drying Technology*, 2010, 28: 834–842.
2. Ultrafine coal dewatering: Relationship between hydrophilic lipophilic balance (HLB) of surfactants and coal rank. Behzad Vaziri, Hassas Fırat, Karakaş Mehmet, International *Journal of Mineral Processing*, Vol. 133, 10 December 2014, Pages 97-104 https://www.sciencedirect.com/science/article/abs/pii/S0301751614001616.
3. IVT, Reduction of Moisture of the Ore, *Instituto Vale de Tecnologia*, http://www.itv.org/en/inovation/reduction-of-moisture-of-the-ore/.
4. Reuters Events, CSP tower installation costs drop on heliostat innovations, pre-assembly, https://analysis.newenergyupdate.com/csp-today/csp-tower-installation-costs-drop-heliostat-innovations-pre-assembly.
5. Fernando Berlinck Dutra Vaz, Secagem de minérios e seus concentrados em pátios, em fornos solar e sobre esteiras transportadoras e processos calcinação, sinterização e metalúrgico utilizando energia solar concentrada, *Brazilian Patent* BR 20 2020 000528 1, filed Jan. 9, 2020, pending.