ECONOMIC ASSESSMENT OF THE INDUSTRIAL SOLAR PRODUCTION OF LIME

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The use of concentrated solar energy in place of fossil fuels for driving the endothermic calcination reaction $CaCO_3 \rightarrow CaO + CO_2$ at above 1300 K has the potential of reducing CO_2 emissions by 20% in a state-of-the-art lime plant and up to 40% in a conventional cement plant. An economic assessment for an industrial solar calcination plant with 25 MW_{th} solar input indicates that the cost of solar produced lime ranges between 128-157 $/ton, about twice the current selling price of conventional lime. The solar production of high purity lime for special sectors in the chemical and pharmaceutical industry might be competitive with conventional fossil fuel based calcination processes at current fuel prices.

1 INTRODUCTION

Lime and cement industries together are responsible for 6% of global anthropogenic CO_2 emissions [1, 2]. Strategies proposed for mitigating these emissions include the use of concentrated solar energy as the source of process heat for the calcination step of the lime and cement production processes. The technical feasibility of the solar calcination process has been demonstrated for solar reactor prototypes at power levels of 10 kW [3, 4].

2 METHODOLOGY

The economic analysis requires a definition of the material and energy flows and an estimation of the costs of the solar calcination plant components, their operation, and maintenance. Our approach only considers capital and operational cost differences between solar and conventional lime plants, i.e. system components that are common to both applications are omitted from the cost calculations [5]. The reference case for this study is based on a 50 tpd conventional lime plant with 3 MW_{th} thermal power entering to an 80%-efficient single shaft kiln [5]. This plant size represents the lower limit for commercial lime production. Typically, large industrial lime plants produce up to 1500 tpd of lime in long rotary kilns with about 45% efficiency [2].

3 PLANT DESIGN AND COST ESTIMATES

Plant and cost specifications as well as economic data for the baseline case are listed in Table 1 [5]. Heliostat costs are assumed to decrease as a function of heliostat field size and mass production. Cost curves for solar towers are derived from data of existing solar test facilities or developed in previous engineering studies. While “beam down” (BD) systems are always equipped with a secondary concentrator (CPC), “tower top” (TT) systems only need it if the solar concentration ratio is not sufficient to reach the required kiln temperatures. Indirect costs include engineering, procurement, commissioning, and management (EPCM), which in general amount to 20% of the initial capital cost. On top of the total investment costs (including indirect costs), a contingency of 15%, typical for high risk projects, is added. The selling price for conventional lime may be multiplied with a “lime quality factor” (LQF) in order to study its effect on the economics of a solar lime plant.

Parameter	Unit	Typical value
Plant Specification		
Solar power input to kiln	MW_{th}	25
Peak insolation level	W/m^2	1000
Minimum insolation level	W/m^2	500
Solar concentration ratio	-	2000
Direct normal irradiance (DNI)	$kWh/m^2/a$	2300
Single heliostat area	m^2	120
Heliostat availability	-	0.98
Land use factor	-	0.35
Optical efficiency (incl. CPC)	-	TT: 0.61 BD: 0.52
Kiln efficiency	-	0.45
Cost Specification		
Land price	$\$/m^2$	2
O&M cost of heliostat field	$\$/m^2/a$	7
Fuel oil price (average)	$/t	176.5
Economic Data		
Lime selling price (in 2000)	$/t	60
Lime quality factor (LQF)	-	2
CO_2 tax	$/t	38
Plant lifetime	a	25
Discount rate (DR)	%	15

Table 1: Baseline input parameters [5].

4 RESULTS AND DISCUSSION

Figure 1 presents the sensitivity of the payback time (PBT) relative to variations of different baseline parameters for three TT solar plant sizes (1, 5, and 25 MW_{th}). Each baseline value is varied by 10% in such a way that PBT is decreasing. The most sensitive parameters are, in this order: the annual direct irradiance, the kiln efficiency, the heliostat cost, the optical efficiency, and the lime selling price.

Table 2 summarizes economic indicators such as the net present value (NPV), the internal rate of return (IRR), and the payback time (PBT). Starting with the baseline parameters from Table 1, two TT solar lime plants with 5 MW_{th} (case 1) and 25 MW_{th} (case 2) thermal input are compared. Only for the larger plant the NPV is slightly positive after the end of the investment period. Although for this case the effective IRR exceeds the 15% discount rate (DR) required by an investor, the PBT of more than 8 years makes the investment less attractive. However, PBT close to economically beneficial 5-6 years can be achieved for the 25 MW_{th} TT solar lime plants if all sensitive parameters listed in Figure 1 are simultaneously altered by 10% (case 3). In addition, reducing the heliostat costs to about 100 $/m^2$ (case 4) will have a large impact on the profitability since the heliostat field costs typically constitute about 60% of the additional costs for the solar lime plant [5]. Furthermore, improving the kiln efficiency from 45 to 50% compared to the baseline case would also yield favourable results for both 25 MW_{th} TT (case 5) and 25 MW_{th} BD (case 6) solar lime plants. These measures, together with a moderately higher selling price for solar produced high purity lime, help ensure the economic viability of the industrial solar production of lime.

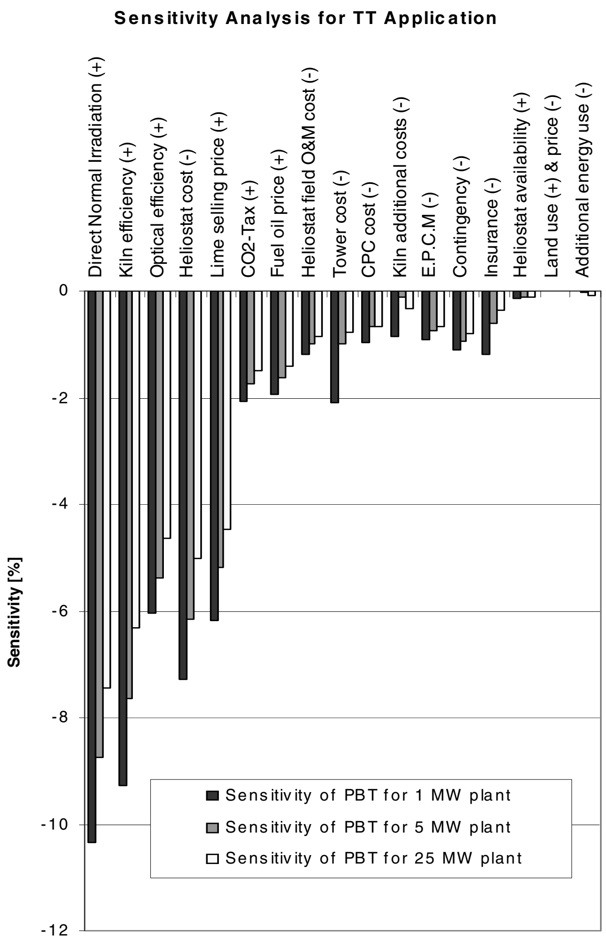

Fig. 1: Sensitivity analysis for a TT solar system. "(+)" / "(-)" denotes a 10% increase/decrease [5].

5 CONCLUSIONS

Our economic assessment indicates that the cost for solar-produced lime ranges from 128-157 $/t for a 25 MW_{th} plant. The solar production of lime has the potential of being economically viable provided some prerequisites are fulfilled. Firstly, the heliostat costs should not exceed 100 $/m^2$. In this respect, a significant effect from the economy of scale can be expected. Secondly, the kiln efficiency should attain 50%, resulting in a smaller heliostat field and, consequently, reducing the investment costs. Thirdly, it is conceivable that the extremely pure solar-produced lime will allow for a much higher selling price than the actual market price for lime (at about 60 $/t). Finally, solar-based lime production can reduce CO_2 emissions by 20% in a state-of-the-art lime plant and by 40% in a conventional cement plant. Governmental subsidies and regulations like the levy of a CO_2 tax may help introduce the solar lime technology into the market.

6 ACKNOWLEDGEMENT

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7 REFERENCES

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ECONOMICS of solar calcination plants		A: Baseline (Table 1)		B: Sensitivity (Figure 1)		C: Baseline (optimized)	
	Case	1	2	3	4	5	6
		5 MW_{th} TT	25 MW_{th} TT	25 MW_{th} TT	25 MW_{th} TT	25 MW_{th} TT	25 MW_{th} BD
Lime quality factor (LQF)	-	2	2	2.2	2.2	2.14	2.62
Selling price for solar lime	$/t	120	120	132	132	128.4	157.2
NPV after 25 years (DR = 15%)	$1000	-1377	399	7645	11762	8112	10402
IRR (for NPV = 0)	%	9.81	15.41	22.86	31.10	25.60	25.60
PBT	a	11.4	8.4	6.5	5.4	6.0	6.0

Table 2: Economic data for solar calcination plants: A) Using baseline parameters for 5 MW_{th} TT (case 1) and 25 MW_{th} TT (case 2) solar systems; B) Simultaneously altering sensitive parameters by 10% (case 3) and in addition reducing heliostat costs to 100 $/m^2$ (case 4); C) Optimizing baseline parameters by reducing heliostat costs to 100 $/m^2$ and increasing kiln efficiency to 50% for 25 MW_{th} TT (case 5) and 25 MW_{th} BD (case 6) configurations.