International Conference on Applied Energy 2019
Aug12-15, 2019, Västerås, Sweden
Paper ID: 0676

HYDROGEN FROM THERMAL SOLAR ENERGY IN ALGERIA

Chawki Ameur Menad*[1], Rabah Gomri[1], R. Menacer[2]

[1] University Frères Mentouri Constantine, Faculty of Sciences and Technology, Department of Génie Climatique, Constatine, Algeria

[2]Centre de Recherche Scientifique et Technique en Analyses Physico-chimiques (CRAPC), BP384, Bou-Ismail, RP 42004, Tipaza, Algeria.

ABSTRACT

Exploiting solar energy in Algeria became the main debate in energy sector especially after the oil crisis in the last three years. In fact, Algeria holds one of the best solar potential in the world, with the most efficient regions being located in the south of the country. Recently many researches have been exploiting solar energy for electricity production. However, producing hydrogen from solar energy is considered the future plan for improving the energy sector in Algeria. The main goal of this paper is the evaluation of hydrogen production potential from steam methane reforming through thermal solar energy systems in Algeria. The proposed model is based on a parabolic trough solar collector system and consists of two different parts, thermal solar energy in one hand, and hydrogen production from steam methane reforming in the other hand. The Algerian hydrogen potential production has been calculated in all regions (48 cities) of the country. The obtained results show that seasonal and the annual, hydrogen production potential could be the best solution to cover the energy needs.

Keywords: Thermal solar, Hydrogen production, Steam methane reforming, Parabolic trough solar collector.

1. INTRODUCTION

Recently one of the most important scientific debates in the world is global warming and greenhouse effect. Due to this debate, many researchers have proposed to exploit thermal solar as an energetic alternative solution. Exploiting this energy for an environmental purpose has given power to scientists to start developing new technologies and pathways. Solar energy could be transformed to several types of energy such as mechanical, electrical, chemical….etc. Hydrogen production through thermo-chemical cycles is an important technology to transform the solar energy because hydrogen has a good high calorific value and having storage possibilities **[1].** Many research projects have been developed using solar (thermal and photovoltaic) energy to produce hydrogen. One of these projects, a techno economic assessment of 100 MW based on the Dish Stirling technology using hydrogen as working fluid for centralized electricity production located in three typical Algerian cities: Algiers, In Salah and tamanrasset, has been studied by Mohamed Abbas et al **[2].** The study revealed that the city of Tamanrasset gave the lowest energetic cost of 11.5c$/kWh. Mohamed Douaka et al **[3]**, calculated the hydrogen production potential using wind energy in Algeria. The city of Adrar was the most productive zone with a cost of 1,214$/KgH$_2$. N. Chennouf et al, developed an experimental study about solar and hydrogen production system using alkaline water electrolysis in Ouargla (Algeria), the group conclude that the hydrogen produced is linked to geographic position **[4].** Another research has been done by D. Ghribi et al, proposed a mathematical model of hydrogen production system, using an electrolyser to maximize hydrogen production. This study showed the hydrogen production was 0.14 kg/m^2/day. However this value increased to 0.19 kg/m^2/day for a suitable period **[5].** Other studies focused on hydrogen production by hybrid systems in

Algeria**.** Mouloud Baik, et al **[6]** developed a solar/diesel hybrid system in the city of Djanet located in the south of the country to integrate 89.78% of the existing electrical grid initially generated from diesel energy. H. Derbal-Mokrane et al, used thermal/photovoltaic hybrid system and concluded that the hydrogen production rate depends on geographic position, climatic conditions and sun radiation **[7].**

Many research projects about the thermochemical cycles for hydrogen production have developed. Malika Ouagued et al **[8]** about hydrogen production using the parabolic trough solar collector adopting the Cu-Cl cycle in Algeria. The study showed that the hydrogen production potential was around 0.30 kg/m^2/day.

[20] Patrice Charvin et al, studied the solar thermochemical cycles hydrogen production from water splitting by the following cycles ZnO/Zn, Fe3O4/FeO, and Fe2O3/Fe3O4 cycle. The group showed that the hydrogen production was respectively 1255,754 MJ/KgH$_2$. 1498,239 MJ/KgH$_2$, 2798,894 MJ/KgH$_2$. Another study has been carried out by Stephane Abanadeset al **[9]** about the thermochemical hydrogen production from a two-step solar-driven water-splitting cycle based on cerium oxides CeO2, the study showed that the Productivity of hydrogen from was 662MJ/KgH$_2$ Andi Mehmeti et al **[10]** have studied several thermochemical hydrogen production methods: from conventional to emerging technologies, the study confirmed that the CH4 cycle was the best thermochemical. Combination of steam methane reforming cycle, with thermal solar technology is one of the best solutions for hydrogen production, due to its low energetic costs (165MJ/KgH$_2$), comparing to the other cycles. Exploiting the thermal solar energy, through a parabolic trough solar collector for hydrogen production from steam methane reforming in Algeria, is the main goal of this paper.

2. HYDROGEN PRODUCTIVITY FROM THERMO-CHEMICAL CYCLES THROUGH SOLAR ENERGY

Selecting the suitable thermo-chemical cycle for hydrogen production using thermal solar potential is an efficient pathway to cover the energy needs in one side and to protect the environment in the other side. Indeed this technology is available and the cost of is getting better due to the high productivity of hydrogen. The Tab2: shows the hydrogen productivity from different thermo-chemical cycles, including CH4 cycle.

Tab 1 **H**ydrogen productivity from thermo-chemical cycles through solar energy

Hydrogen cycle production.	Productivity of hydrogen MJ/kgH2
1/ ZnO/Zn [11]	1255.75 MJ /KgH2 [11]
2/ Fe3O4/FeO [11]	1498.239 MJ/KgH2 [11]
3/ Fe2O3/Fe3O4 [11]	2798.894MJ/KgH2 [11]
4/CH4 (700°C-1000°C) [12]	165 MJ /KgH2. [12]
5/CeO2 [13]	662MJ/KgH2. [13]
6/ H2SO4 [14]	295.500MJ/KgH2 [14]
7/ Cu –Cl [15]	195.7MJ/KgH2 [16]

3. THERMAL SOLAR ENERGY TECHNOLOGIES FOR HYDROGEN PRODUCTION

Combination between thermochemical cycles and solar thermal technology has given researchers the opportunity to develop other design and technics for hydrogen production. The following table shows the most important thermal solar technologies and efficiencies for hydrogen production.

Tab 2 thermal solar technologies and efficiencies for hydrogen production

Thermal solar technology for hydrogen production	Efficiency %	Temperature °C
Parabolic Trough collector [17]	42.21%	> 826.85
Parabolic Dish [18]	70–80%	450
Power Tower [19]	86.55%	515ºC
Linear Fresnel [20]	50%	200 °C

4. HYDROGEN PRODUCTION POTENTIAL

Steam methane reforming from renewable energy, is one of the best solutions for hydrogen production due to the hydrogen productivity, which is the lowest (**165MJ/KgH2) [12]** comparing to the other hydrogen cycles production. This interesting technology is suitable for Algeria especially in the south of the country due to its solar thermal solar potential, availability of natural gas. The south of Algeria has many natural gas production stations with the total production of 110million Ton/year in 2013, which is equivalent to 1,6million ton of Hydrogen production **[21].** The world hydrogen production comes from different resources, the steam methane reforming from natural gas has taken the major part by 48%as shown in figure 2 [22]. The steam methane reforming cycle divided into two different steps:

Steam methane reforming

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

Water gas shift

$$CO + H_2O \longrightarrow CO_2 + H_2$$

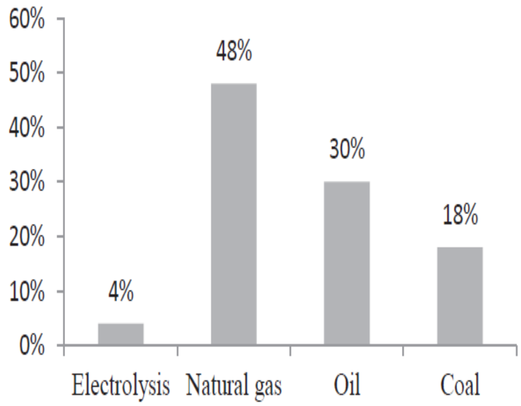

Fig 1 Resources of produced Hydrogen in the worldwide [22].

5. DESCRIPTION OF THE PROPOSED MODEL

Producing hydrogen from thermal solar energy in Algeria is the main purpose of the studied case. Figure 2 shows two different parts: the thermal solar part, and hydrogen production cycle part.

- In the solar field, the thermal fluid which is circulating in the parabolic concentrator is helium which is used to the necessary temperature (700°C -1000°C) to generate hydrogen from steam methane reforming.
- Helium is used in parabolic thermal trough solar collector because it's ability to increase a temperature up to 1000°C.
- The proposed model mentions that there is one pathway for producing hydrogen through steam methane reforming.

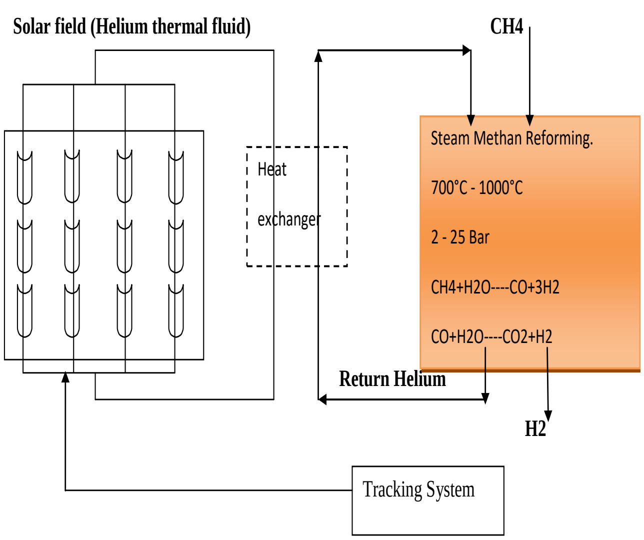

Fig 2 Thermal Solar energy for hydrogen production

Figure 3 shows solar parabolic trough collector (rectangular tube).

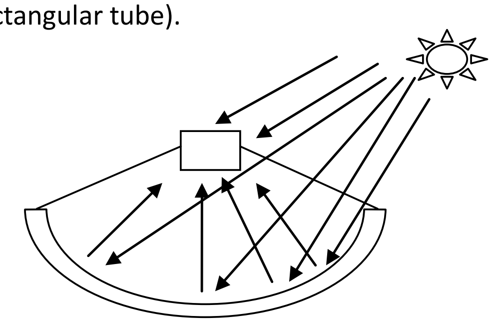

Fig 3 Solar parabolic trough collector (rectangular tube)

The thermal energy absorbed by the rectangular channel is calculated by:

$$Q = h.S.(Thot - Tcold) \quad (1)$$

Where; h, S, Thot, Tcold are respectively: the heat transfer by convection, surface of the selected channel, outlet temperature from the channel, inlet temperature to the channel.

$$Q = h.(H.W).(Thot - Tcold) \quad (2)$$

H.W=S the surface of the channel (m^2).

$$h = \left(\frac{\left(\frac{f}{8}\right)(Re-1000)\mathrm{Pr}}{\left(1+1{,}27.\left(\frac{f}{8}\right)^{\frac{1}{2}}.\left(Pr^{\frac{2}{3}}-1\right)\right)} \right).\frac{\mathrm{L}}{\mathrm{K}} \quad (3)$$

Pr, Re, f: are respectively Prandtl number, Reynolds number, friction factor.

The fraction coefficient is calculated by:

$$e^{\left(\frac{1}{\sqrt{f}}+0{,}8\right)} - Re\sqrt{f} = 0 \quad (4)$$

So, the outlet temperature is given by:

$$\mathrm{Thot} = Tcold + \left(\frac{Q}{\left(\frac{\left(\frac{f}{8}\right)(Re-1000)\mathrm{Pr}}{\left(1+1{,}27.\left(\frac{f}{8}\right)^{\frac{1}{2}}.\left(Pr^{\frac{2}{3}}-1\right)\right)} \right)\left(\frac{\mathrm{L}}{\mathrm{K}}\right).(\mathrm{H.W})} \right) \quad (5)$$

K : Incident Angle Modifier

5.1 Direct Normal Solar Irradiance

It is important to calculate Incident Angle modifier for getting the direct normal solar irradiance.

Incident angle modifier, K

$$\mathrm{k} = \cos(\mathrm{I_a}).0{,}0003178(\mathrm{I_a}) - 0{,}00003985(\mathrm{I_a})^2 \quad (6)$$

I_a : solar beam incident angle, in degrees.

However, the direct normal solar irradiance in the proposed model is calculated by:

$$I_{ba} = I_{bn}\cos(K).\cos(\propto).\cos(A) \quad (7)$$

Where:

$$I_{bn} = I_0 \ .\tau b \quad (8)$$

I_{ba}: The Direct normal solar irradiance

I_{bn}: The beam radiation.

τb the atmosphere transmittance of beam radiation.

I_0 : The extraterrestrial solar irradiance, outside the earth's atmosphere, W/m2.

a: solar altitude angle, (deg)

A: solar azimuth angle, (deg)

5.2 Heat Gain by Parabolic Trough Collectors

$$Q = m.\rho.Cp.(\Delta T) \quad (9)$$

$$\rho = 954 - 0{,}919T + 4{,}25.10^{-4}.T^2 - 1{,}67.10^{-6}.T^3 \quad (10)$$

$$Cp = 1575 + 1{,}708.T \quad (11)$$

m, ρ, Cp, T : Rate flow, density, heat specific, and temperature.

6. RESULTS AND DISCUSSIONS

This paper illustrates the prospects of using the thermal solar energy in Algeria for producing hydrogen from steam methane reforming due to the hydrogen productivity from CH4 cycle, which is around 165MJ/KgH2, and the availability of natural gas in all regions of the country.

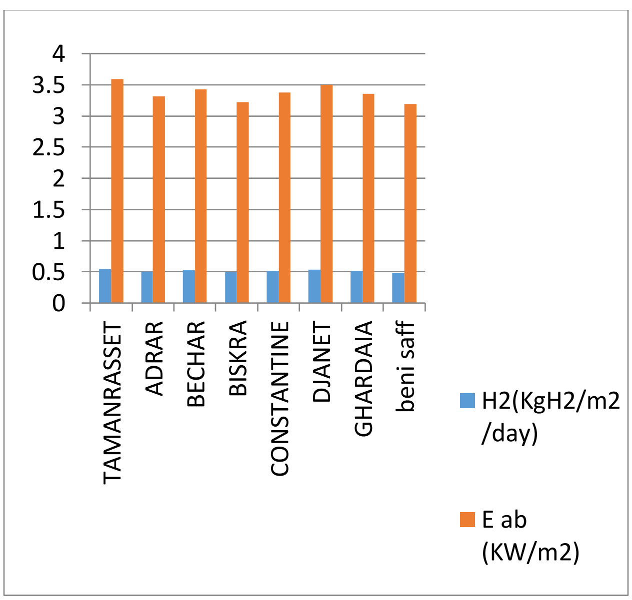

Fig 4 Hydrogen produced from steam reforming through parabolic trough collector

Figure 5 presents the prospect of the hydrogen production potential from the thermal solar energy capacity/m2/day (Po/ m2/day).

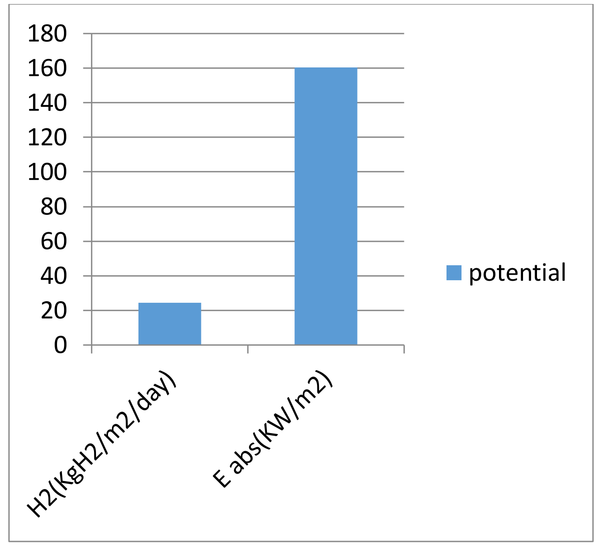

Fig 5 Prospects of the Hydrogen production potential from the thermal solar energy capacity/m2/Day (Po/ m2/Day)

Figure 6 presents the hydrogen produced for different Algerian cities.

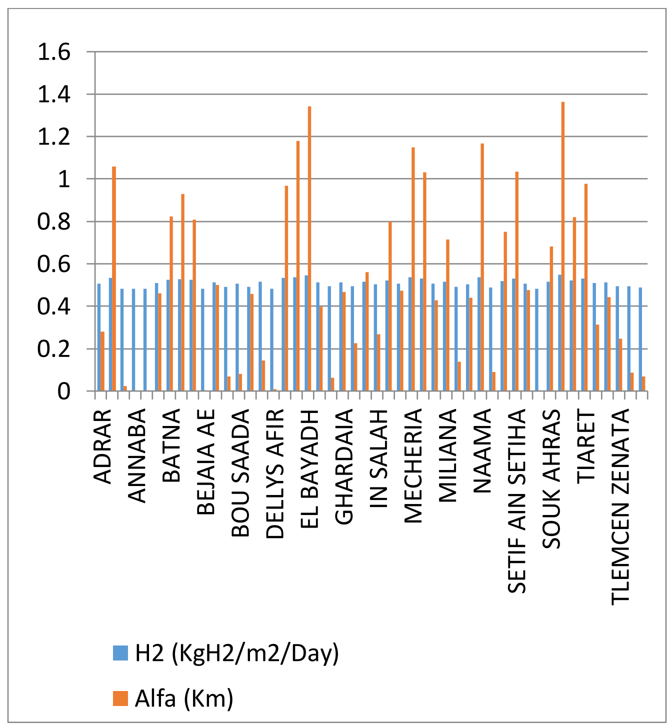

Fig 6 Hydrogen production

From figure 4, 5 and 6 we can conclude that:

- The best area in Algeria for production of hydrogen from solar thermal energy through solar concentrators is Tamenrrast city. Moreover, the most of efficient cities are located in the south of Algeria where the global irradiation is too high.
- Exploiting solar thermal potential in Algeria is an efficient pathway to cover the necessary needs of energy in the country.
- Winter in Algeria permits concentrators to provide a good solar thermal potential which improves the quality of hydrogen production especially in the south of the country, based on the studied model.
- Producing hydrogen from solar thermal energy gives around 1.6million Ton/year from steam methane reforming in Algeria.
- Steam methane reforming is the best solution for hydrogen production from solar energy due to hydrogen productivity comparing to the other hydrogen production cycles.
- The lowest amount for hydrogen production from solar thermal energy through concentrators is in the city of Beni saff in a horizontal position plan.
- From the obtained results, there is no big difference of hydrogen production between different cities in Algeria from steam methane reforming by using of solar parabolic trough collectors.
- Hydrogen from thermal solar energy is one of the best solutions to improve the GDP of Algerian government during the oil crisis, and instability of energy demand in the international market.

CONCLUSION

The solar energy is one of the most interesting renewable energy resources in Algeria for producing a considerable amount of hydrogen through thermochemical cycles (CH4) , in order to improve the quality of life in one side and protecting the environment in the other hand. However, getting the hydrogen from thermal solar energy is based on disponibility of fossil energy (natural gas), so reducing the emission of CO2 will be considerable, whilst transforming the energy strategy from fuel energy to renewable energy. The studied case explains that the solar thermal energy is interesting in summer and in the south of the country. In fact, combination between the steam methane reforming technology and the global thermal solar energy trough parabolic trough solar collector will provide a considerable amount of hydrogen in whole regions of the country. The benefits of using of helium as a fluid in parabolic trough solar collector. is to keep the pressure in the steam reforming cycle between 2bar and 25 bar for safety reasons.

ACKNOWLEDGEMENT

The principal author acknowledges his parents for all their support. The principal author would like to acknowledge Mr M. Jenckenson for all his efforts and help for preparing this paper.

REFERENCE

[1] https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html?fbclid=IwAR3ze-6tNrVZCCDFfFIvbt3uUB4g_9p_tiAvh9ILfieM3BXmx6Tt0YS-u9U

[2] Mohamed Abbas , Bousaad Boumeddane, Noureddine Said, Ahmed Chikouche, Dish Stirling technology: A 100 MW solar power plant using hydrogen for Algeria, i n t e r n a t i o n a l j ournal o f hydrogen energy 3 6 (2 0 1 1) 4 3 0 5 e4 3 1 4, doi: 10.1016/j.ijhydene.2010.12.114.

[3] Mohamed Douaka, Noureddine Settoub, Estimation of hydrogen production using wind energy in Algeria, Energy Procedia 74 (2015) 981 – 990, doi: 10.1016/j.egypro.2015.07.829

[4] Chennouf N, Settou N, Negrou B, Bouziane K, Dokkar B. Experimental study of solar hydrogen production performance by water electrolysis in the south of Algeria. Energy Proc 2012;18:1280e8.

[5] Ghribi D, Khelifa A, Diaf S, Belhamel M. Study of hydrogen production system by using PV solar energy and PEM electrolyser in Algeria. Int J Hydrogen Energy 2013;38(20):8480e90.

[6] Mouloud Baik, M. Hammoudi, Y. Salhi, S.K. Kirati, Hydrogen production by hybrid system and its conversion by fuel cell in Algeria; Djanet, i n t e rna t i onal journal o f hydrogen energy 4 3 (2 0 1 8) 3 4 6 6e3 4 7 4, https://doi.org/10.1016/j.ijhydene.2017.11.074

[7] Derbal-Mokrane H, Benzaoui A, M'Raoui A, Belhamel M. Feasibility study for hydrogen production using hybrid solar power in Algeria. Int J Hydrogen Energy 2011;36(6):4198e207

[8] Malika Ouagued, Abdallah Khellaf, Larbi Loukarfi, Performance analyses of Cu-Cl hydrogen production integrated solar parabolic trough collector system under Algerian climate, i n t e r n a t i o n a l journal o f hydrogen energy 4 3 (2 0 1 8) 3 4 5 1 e3 4 6 5, https://doi.org/10.1016/j.ijhydene.2017.11.040

[9] Stephane Abanades *, Gilles Flamant, Thermochemical hydrogen production from a two-step solar-driven water-splitting cycle based on cerium

oxides, Solar Energy 80 (2006) 1611–1623, doi:10.1016/j.solener.2005.12.005
[10] Andi Mehmeti, Athanasios Angelis-Dimakis, George Arampatzis, Stephen J. McPhail and Sergio Ulgiati, Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies, www.mdpi.com/journal/environments, doi:10.3390/environments5020000
[11] Patrice Charvin, Abanades Ste´phane, Lemort Florent, Flamant Gilles, Analysis of solar chemical processes for hydrogen production from water splitting thermochemical cycles, Energy Conversion and Management 49 (2008) 1547–1556, doi:10.1016/j.enconman.2007.12.011
[12] Andi Mehmeti, Athanasios Angelis-Dimakis, George Arampatzis, Stephen J. McPhail and Sergio Ulgiati, Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies, www.mdpi.com/journal/environments, doi:10.3390/environments5020000
[13] Stephane Abanades *, Gilles Flamant, Thermochemical hydrogen production from a two-step solar-driven water-splitting cycle based on cerium oxides, Solar Energy 80 (2006) 1611–1623, doi:10.1016/j.solener.2005.12.005
[14] XINGL YAN, RYUTARO HINO, Nuclear Hydrogen Production Handbook, page 533.
[15] Naterer GF, Gabriel K, Wang ZL, Daggupati VN, Gravelsins R. Thermochemicalhydrogen production with a copperechlorine cycle. I: oxygen release from copper oxychloride decomposition. Int J Hydrogen Energy 2008;33:5439e50.
[16] Derbal-Mokrane H, Benzaoui A, M'Raoui A, Belhamel M. Feasibility study for hydrogen production using hybrid solar power in Algeria. Int J Hydrogen Energy 2011;36(6):4198e207.
[17] EvangelosBellosChristosTzivanidisKimon A.Antonopoulos, A detailed working fluid investigation for solar parabolic trough collectors, Applied Thermal Engineering Volume 114, 5 March 2017, Pages 374-386, https://doi.org/10.1016/j.applthermaleng.2016.11.201
[18]] N.DKaushikaK.SReddy, Performance of a low cost solar paraboloidal dish steam generating system, Energy Conversion and Management Volume 41, Issue 7, May 2000, Pages 713-726, https://doi.org/10.1016/S0196-8904(99)00133-8
[19] Luo, Y, Du, X and Wen, D (2015) Novel design of central dual-receiver for solar power tower. Applied Thermal Engineering, 91. pp. 1071-1081. ISSN 1359-4311 https://doi.org/10.1016/j.applthermaleng.2015.08.074
[20] H.ZhaiY.J.DaiJ.Y.WuR.Z.WangL.Y.Zhang, Experimental investigation and analysis on a concentrating solar collector using linearFresnel lens, Energy Conversion and Management Volume 51, Issue 1, January 2010, Pages 48- https://doi.org/10.1016/j.enconman.2009.08.018
[21] Thomas Preggera, Daniela Graf, Wolfram Krewitt, Christian Sattler, Martin Roeb,Stephan Mo¨ller, Prospects of solar thermal hydrogen production processes, i n t e r n a t i onal j o u r n a l o f hydrogen energy 3 4 (2 0 0 9) 4 2 5 6 – 4 2 6 7, doi:10.1016/j.ijhydene.2009.03.025
[22] Tania Carbonell Moralesa, Victor Roca Olivab, Leyat Fernández Velázquezc, Hydrogen from Renewable Energy in Cuba, Energy Procedia 57 (2014) 867 – 876, doi: 10.1016/j.egypro.2014.10.296