Available online at www.dergipark.gov.tr

INTERNATIONAL ADVANCED RESEARCHES
and
ENGINEERING JOURNAL

Journal homepage: www.dergipark.gov.tr/iarej

International Open Access

Volume: 01
Issue: 01

December, 2017

Investigation of hydrogen production cost by geothermal energy

Ceyhun YILMAZ[a]*, Mehmet KANOGLU[b]

[a]Department of Mechanical Engineering, Afyon Kocatepe University, 03200 Afyonkarahisar, Turkey
[b]Department of Mechanical Engineering, University of Gaziantep, 27310 Gaziantep, Turkey

ARTICLE INFO

Review Article
Article history:
Received 10 November 2017
Accepted 20 November 2017

Keywords:
Geothermal energy,
Hydrogen production,
Hydrogen Economy,
Water electrolysis.

ABSTRACT

Geothermal energy has a significant potential on hydrogen economy where it can contribute sustainable production of hydrogen by renewable energy sources. In this paper, using geothermal electricity in hydrogen production by electrolysis is investigated. The cost of producing one kg of hydrogen by electrolysis as functions of temperature and mass flow rate of geothermal fluid for steam and binary cycles is studied. The analysis is based on an economic model of geothermal power production. The results show that the cost of hydrogen is inversely proportional to both the geothermal resource temperature and mass flow rate.

1. Introduction

Geothermal energy is the thermal energy within the earth's interior. Geothermal energy is used to generate electricity and for direct uses such as space heating and cooling, industrial processes, and greenhouse heating. High-temperature geothermal resources above 150°C are generally used for power generation. Moderate- (between 90°C and 150°C) and low-temperature (below 90°C) geothermal resources are best suited for direct uses such as space and process heating, cooling, aquaculture, and fish farming [1]. With the increasing scarcity of fossil fuels and increasing concerns over the environmental problems they cause, the use of renewable energy resources will likely increase and diversify. Geothermal energy appears to be a potential solution where it is available to some of the current energy and environmental problems, and a key resource for making society more sustainable [2].

Geothermal energy provides an affordable, clean method of generating electricity and providing thermal energy. Geothermal power plants tap certain high-temperature resources to generate electricity with minimal or no air emissions. The common types of geothermal power plants are dry steam, single- and double-flash, binary, and flash/binary cycles.

Hydrogen is considered by many to be a potential replacement for fossil fuels [3]. The total cost of producing hydrogen depends on production, liquefaction, storage and distribution costs [4]. Today approximately 9 billion kilograms of hydrogen are produced annually. More than 95% of the merchant hydrogen is used for industrial applications in the chemical, metals, electronics, and space industries. There are several methods used to produce hydrogen. These methods include: natural gas reforming, electrolysis, liquid reforming, nuclear high-temperature electrolysis, high-temperature thermo-chemical water-splitting, photo-biological, and photo-electrochemical. Steam methane reforming accounts for 80% of the hydrogen produced. Electrolysis is the process of making a non-spontaneous process occurs by applying an external power supply to the application. A number of existing and planned demonstration projects are using or will use electrolysis, even though it is one of the more energy intensive processes for producing hydrogen. However, it provides a pathway for producing hydrogen from carbon free renewable energy [5].

* Corresponding author:
E-mail address: ceyhunyilmaz@aku.edu.tr

Hydrogen provides the connecting point between renewable electricity production and transportation, stationary and portable energy needs. When the electricity from solar photovoltaics, wind, geothermal, ocean and hydro technologies is used to produce and store hydrogen, the renewable source becomes more valuable and can meet a variety of needs. In transportation applications, hydrogen provides a way to convert renewable resources to fuel for vehicles. Renewably produced hydrogen for transportation fuel is one of the most popular hydrogen economy goals, as it can be domestically produced and emissions free [6].

Honnery and Moriarty [7] investigated wind power at the global scale in an attempt to assess the potential for future hydrogen production. Hydrogen generation is done via low-pressure electrolysis and transmission via high-pressure gas pipelines. Naterer et al. [8] examined the potential of electrolysis and thermochemical hydrogen production to serve both decentralized needs with production during off-peak hours, and centralized base-load production from a nuclear station, respectively.

Despite the existence of numerous investigations on the use of renewable energy sources for hydrogen production, reports on using geothermal energy sources for hydrogen liquefaction are limited. Jonsson et al. [9] investigated the feasibility of using geothermal energy for hydrogen production and estimated that using geothermal energy could avoid 16% of the work consumption for electrolysis and 2% for liquefaction. Sigurvinssona et al. [10] investigated the use of geothermal heat in high-temperature electrolysis (HTE) process. This HTE process includes heat exchangers and an electrolyser based on solid oxide fuel cell (SOFC) technology working in inverse, producing oxygen and hydrogen instead of consuming them. Using features related to the heat exchangers and the electrolyser, a set of physical parameters will be calculated by using a techno-economic optimization methodology.

Mansilla et al. [11] studied a techno-economic optimization of the upper heat exchanger network in the high temperature electrolysis process for producing hydrogen. Heat obtained by coupling the process either to a high-temperature reactor or to a geothermal source. Ingason et al. [12] investigated the most economical ways of producing hydrogen solely via electrolysis from water, using electricity from hydro and geothermal power. The mixed integer programming model presented here facilitates the search for optimal choices from the 23 potential power plants, 11 of which are based on geothermal sources, and 12 are hydropower stations. Kanoglu et al. [13] investigated the use of geothermal energy for hydrogen liquefaction. In a study, the potential of geothermal resources of the western United States for producing electricity is investigated. This electricity would be used for the production of hydrogen [14].

In this paper, the use of geothermal power for hydrogen production is investigated economically. The electricity produced from a geothermal power plant is used in a water electrolysis process. The cost of producing one kg of hydrogen at various geothermal resource temperatures and mass flow rates are studied considering steam and binary geothermal power cycles.

2. Cost of Hydrogen Production

To compare the hydrogen costs for the hydrogen technologies, a model created by Steinberg and Cheng of Brookhaven National Laboratory in 1989 was used. The model was revised to determine the current and future costs of hydrogen as production technologies improve and become more viable. The model can be broken down into three main parameters that are included in the cost analysis of the hydrogen production: (1) capital costs of the plant, (2) annual operating costs, and (3) return on investment (profit margin). Figure 1 summarizes the resulting hydrogen production costs associated with each of the plants modeled [15]. Steam reformation is currently the cheapest method of hydrogen production and electrolysis powered by the PV powered electrolysis is the costliest. However, the economic analysis of different H_2 production technologies seems to be incomplete without the consideration of environmental cost associated with these processes [16].

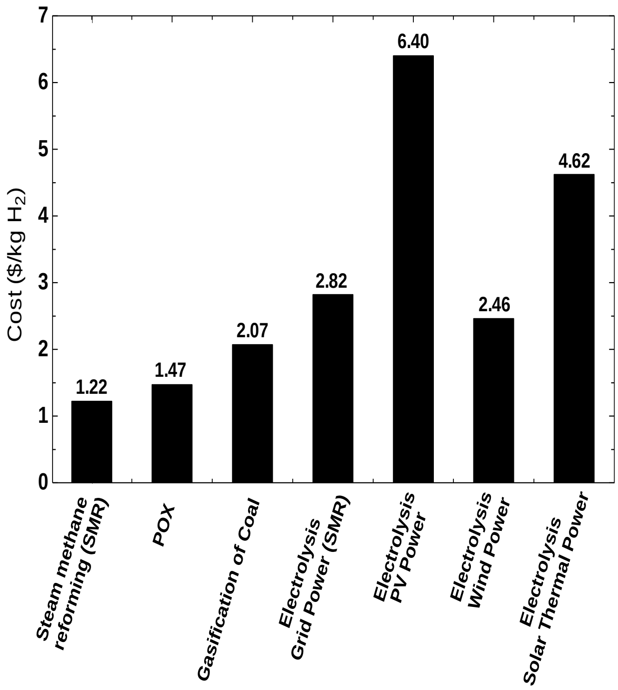

Figure 1. Hydrogen production cost for modeled technologies for 11,870,000 GJ/year production capacity [15]

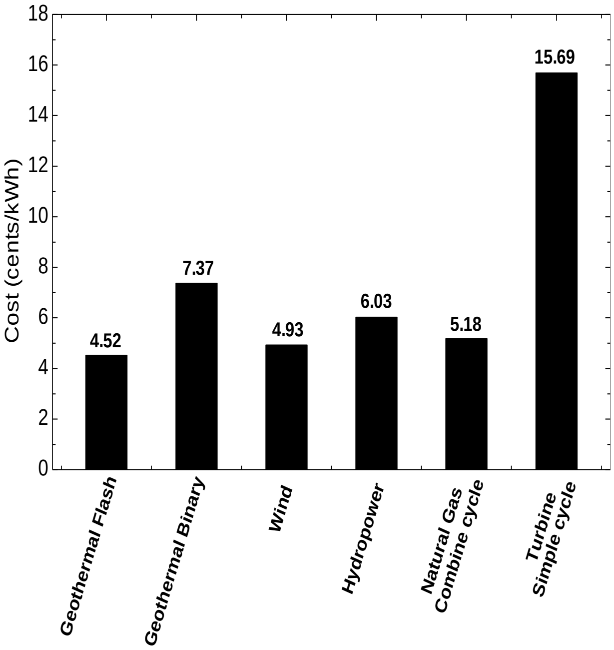

Figure 2. Cost of electricity production for various technologies [17]

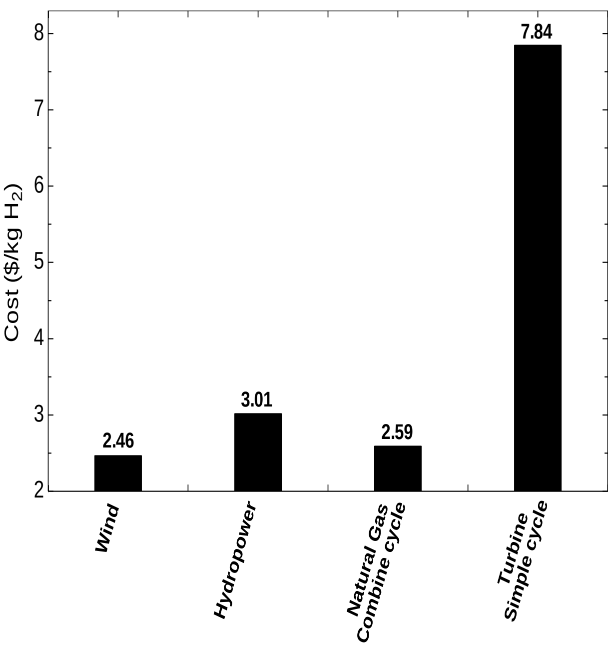

Figure 3. Comparative cost of hydrogen production for various technologies [17]

New geothermal plants are generating electricity from \$0.045/kWh to \$0.074/kWh. Once capital costs for the plant are recovered, the price of power can decrease to below \$0.05/kWh. The price of geothermal energy is within the range of water electricity choices available today when the costs over the lifetime of a plant are considered. Figure 2 presents cost of electricity production for various technologies [17].

In hydrogen production, the most widely used commercial technology is alkaline water electrolysis. The mean electricity energy consumption in the electrolysis of water is about 50 kWh/kg hydrogen.

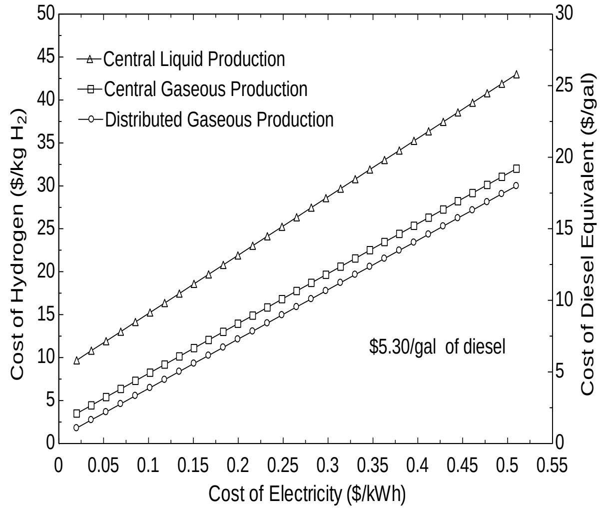

Figure 4. The effect of electricity cost on hydrogen cost [19]

The cost of the electric energy makes large-scale electrolytic production of hydrogen uneconomical compared with the steam-methane reforming method. Work is underway to improve the AWE technology with an advanced alkaline electrolyser that would increase cell efficiency somewhat and reduce the electricity requirement to about 43 kWh/kg [18].

Comparative cost of hydrogen production for various technologies is given in Figure 3. Here, hydrogen is produced by electrolysis method. Wind, hydropower and combined cycle involve much lower costs compared to simple Rankine cycle [17].

When comparing costs of various power producing methods, renewable and non-renewable, it should be noted that renewable technologies provide other system and environmental benefits that are not generally reflected in market prices.

Electricity rates proved to be a major contributor to the overall hydrogen cost. Based on reasonable efficiencies, an electricity cost of slightly less than \$0.10/kWh would be needed to produce and deliver central gaseous hydrogen that is cost-competitive (Figure 4). Cost of hydrogen increases linearly with increasing cost of electricity [19].

3. Cost of Hydrogen Production by Geothermal Energy

Many research and development projects throughout the world are devoted to sustainable hydrogen production processes. Low temperature electrolysis, when consuming electricity produced without greenhouse gas emissions, is a sustainable process, though having limited efficiency. To be sustainable, a hydrogen production process must be carried out without consumption of any raw materials other than water and be driven by forms of energy produced without greenhouse gas emissions.

Low-temperature electrolysis carried out using sustainably produced electricity satisfies these criteria and is currently used to produce hydrogen. However, today, due to high capital costs, it is more expensive in economic terms than the process of producing hydrogen by steam reforming of natural gas; and alternative processes will not be implemented unless they result in lower production costs [20].

When hydrogen is produced by electrolysis, the necessary electricity input can be obtained from a geothermal power plant. The cost of producing electricity from a geothermal power plant depends on many factors. The more significant factors are cycle type (single- or double-flash, binary, flash/binary etc.), resource temperature, mass flow rate of geothermal water, and well cost. These parameters in combination determine, to a large extent, the economic value of a geothermal resource. The other parameters include well spacing, well replacement rate, steam content (quality), non-condensable gas content, plant site, power cycle, plant efficiency, and load factor [21].

In the present study, the cost of producing hydrogen by geothermal power is investigated. The economic model for the cost of geothermal power is based on the study by Bloomster and Knutsen [21]. In this model, two power cycles are considered: binary cycle and steam cycle. The binary cycle uses isobutane as the working fluid, The steam cycle model is based on a double-flash steam plant. The electricity requirement for the electrolysis is taken to be 50 kWh/kg hydrogen.

Figure 5 shows the cost of hydrogen as a function of temperature of geothermal fluid at various flow rates. The cost of hydrogen decreases with increasing temperature. This is expected since the thermal efficiency of a geothermal power plant increases with resource temperature. At lower temperatures small changes in temperature have a larger impact on hydrogen costs, while at the higher temperatures the impact is smaller. The cost is inversely proportional to the flow rate since higher flow rates correspond to larger plant installments. It is well known that as the plant size gets larger the cost of power decreases.

In the economic model of geothermal power cycles, the binary cycle appears more economic than the steam cycle below about 225°C (see Figure 5). Power plants using the steam cycle, however, are closely competitive, running about 10% higher in total power costs at 200°C and 20% higher at 160°C. The breakeven temperature and comparative advantage of either cycle could vary over a wide range depending on the relative costs of the energy supply and power plant, the non-condensable gas content, scaling rates, and other factors.

Figure 6 shows the cost of hydrogen as a function of mass flow rate of geothermal fluid at various temperatures. The cost of hydrogen decreases with increasing flow rate. This is expected since the larger flow rates correspond to larger plant installments and as the plant size gets larger the cost of power decreases. Hydrogen costs are much more sensitive to flow rate at lower temperatures than at higher temperatures because the thermodynamic efficiency declines rapidly with temperature. Well flow rate and temperature are two of the most important resource parameters in the cost relationship. The importance of the well flow rate to power cost is that, for a constant temperature, the power production potential from a well is proportional to flow rate. Therefore, the number of wells and the cost of the energy supply to the power plant are directly related to flow rate.

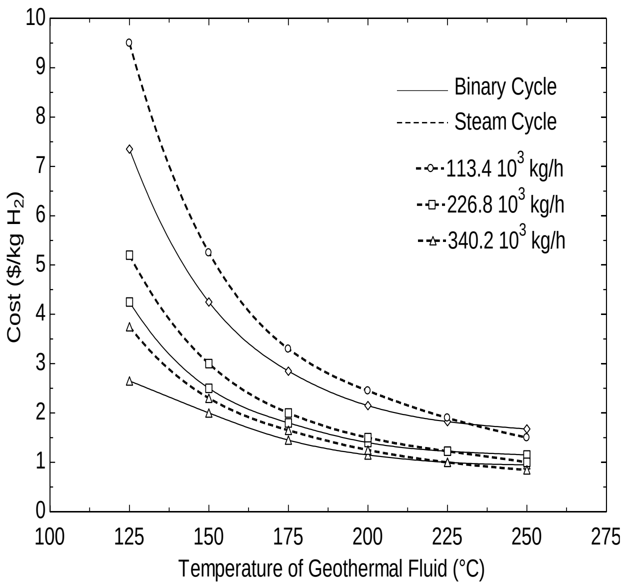

Figure 5. Comparative effect of temperature of geothermal fluid on cost of hydrogen production [21]

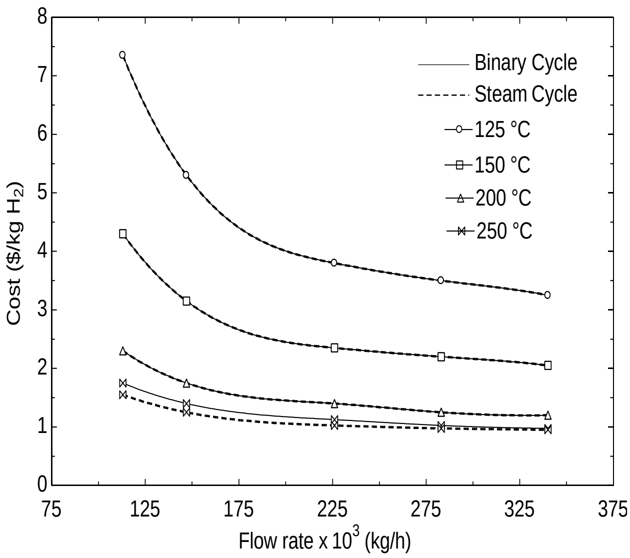

Figure 6. Effect of flow rate on the cost of hydrogen production [21]

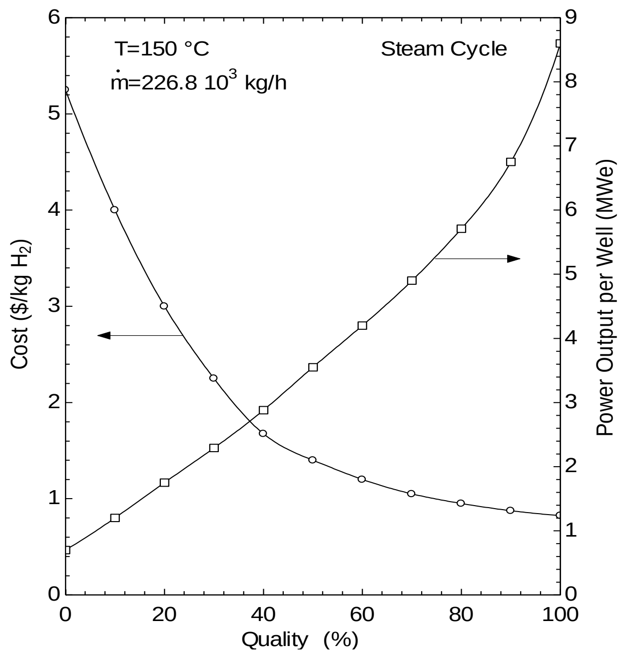

Figure 7. Effect of steam content (quality) on power output and cost of hydrogen production [21]

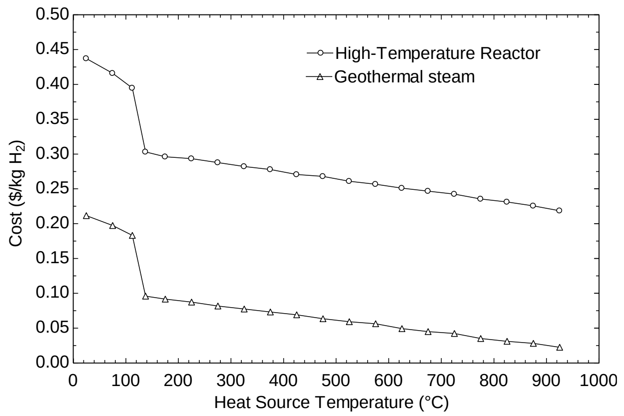

Figure 8. Cost of vaporizing and heating water to the required temperature for the electrolyser [20]

The steam content at the wellhead has a significant effect, like well head temperature, on hydrogen production and power cost (Figure 7). The steam content is expressed as the mass percent of saturated steam in the geothermal fluid at the wellhead. Note that most existing geothermal resources are liquid dominated. The enthalpy of the brine increases rapidly with the steam content. If the temperature and flow rate remain constant, the cost of hydrogen production decreases rapidly with steam content contrary to the power output per well. Steam content and fluid temperature are both related through the common factor, enthalpy.

High temperature electrolysis is an alternative to the conventional electrolysis process. Some of the energy required to split the water is provided as heat instead of electricity, thus reducing the overall energy required and improving process efficiency. Because the conversion efficiency of heat to electricity is low compared to using the heat directly, the energy efficiency can be improved by providing the energy to the system in the form of heat rather than electricity. Thermal energy from a geothermal source is very inexpensive compared to thermal energy from a high temperature cooled reactor (HTR) (Figure 8).

4. Conclusions

Geothermal energy has a significant potential on hydrogen economy where it can contribute sustainable production of hydrogen. In using geothermal energy, the production of hydrogen can be viewed as a carbon free process. The geothermal plant generates the electricity for the electrolysis plant. Once the hydrogen is produced, storage and distribution methods need to be considered. Hydrogen is sometimes liquefied for storage. Geothermal power may be used for hydrogen liquefaction process. Geothermal heat may also be used for precooling hydrogen in an absorption refrigeration system before hydrogen is liquefied. These examples show that geothermal energy can be used in various ways in a sustainable hydrogen economy.

References

1. Barbier E. Nature and technology of geothermal energy: a review. Renewable and Sustainable Energy Reviews-An International Journal 1997;1(2):1-69.
2. Ozgener L, Hepbasli A, Dincer I. Parametric study of the effect of dead state on energy and exergy efficiencies of geothermal district heating systems. Heat Transfer Engineering 2007;28(4):357-364.
3. Scott DS. Smelling Land: The Hydrogen Defense Against Climate Catastrophe. Canadian Hydrogen Association, 2007, www.h2.ca.
4. Syed MT, Sherif SA, Veziroglu TN, Sheffield JW. An economic analysis of three hydrogen liquefaction systems. Int. J. Hydrogen Energy 1998;23(7):565-576.
5. Hand TW. Hydrogen production using geothermal energy, Theses and dissertations. Utah State Univ. 2008.
6. http://www.hpath.org
7. Honnery D. Moriarty P. Estimating global hydrogen production from wind. International Journal of Hydrogen Energy, In Press, 2008.
8. Naterer GF, Fowler M, Cotton J, Gabriel K. Synergistic roles of off-peak electrolysis and thermochemical production of hydrogen from nuclear energy in Canada. International Journal of Hydrogen Energy 2008;33(23):6849-6857.
9. Jonsson VK, Gunnarsson RL, Arnason B, Sigfusson TI. The feasibility of using geothermal energy in hydrogen production. Geothermics 1992;21:673-681.
10. Sigurvinsson J, Mansilla C, Lovera P, Werkoff F. Can high temperature steam electrolysis function with geothermal heat? International Journal of Hydrogen Energy 2007;32(9):1174-1182.

11. Mansilla C, Sigurvinsson J, Bontemps A, Maréchal A, Werkoff F. Heat management for hydrogen production by high temperature steam electrolysis. Energy 2007;32(4):423-430.
12. Ingason HT, Ingolfsson HP, Jensson P. Optimizing site selection for hydrogen production in Iceland. International Journal of Hydrogen Energy 2008;33(14):3632-3643.
13. Kanoglu M, Dincer I, Rosen MA. Geothermal energy use in hydrogen liquefaction. International Journal of Hydrogen Energy 2007; 32(17):4250-4257.
14. Farhar B, Dunlevy P. Feds identify opportunites for potential geothermal development on public Lands. U.S. Department of the Interior, Apr. 2003. http://www.doi.gov/news/030414b.htm.
15. Sherif S, Veriziglo T, Barbir F.: Hydrogen Energy Systems. Wiley Encyclopedia of Electrical and Electronics Engineering, vol. 9, J. G. Webster (Editor), New York: John Wiley & Sons,1999, pp. 370-402.
16. Mirabal ST. An economic analysis of hydrogen production technologies using renewable energy resources. Master Thesis, University of Florida: 2003.
17. Badr M, Benjamin M. Comparative cost of California Central Station Electricity generation technologies, California Energy Commission, June 2003
18. Kruger P.: Alternative energy resources:the quest for sustainable energy, John Wiley&Sons, Hoboken, NJ, 2006.
19. Yuzugullu E, Genung K, Hoesly R. Analysis of geothermally produced hydrogen on the big island of hawaii: a roadmap for the way forward, Hawaii Natural Energy Institute (HNEI),2008.
20. Sigurvinsson J, Mansilla C, Arnason B, Bontemps A, Maréchal A, Sigfusson TI, Werkoff F. Heat transfer problems for the production of hydrogen from geothermal energy. Energy Conversion and Management 2006;47(20):3543-3551.
21. Bloomster CH, Knutsen CA. The economics of geothermal electricity generation from hydrothermal resources, Battelle Pacific Northwest Laboratories (BNWL), Richland, Washington,1989.