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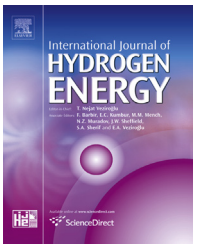

# Thermodynamic and thermoeconomic analyses of a geothermal energy based integrated system for hydrogen production

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ABSTRACT

In this paper, energy and exergy analyses of a geothermal power based multi-generation energy production system which generates electricity, hydrogen, domestic hot water, heating and cooling are presented. The energy generated from geothermal resources can be used to drive an Organic Rankine Cycle (ORC) and a Quadruple Effect Absorption Cooling System (QEACS), and further used to produce hydrogen using by a Proton Exchange Membrane (PEM) electrolyzer. A part of produced electricity from the ORC can be used as the work input for the PEM electrolyzer, and waste heat of geothermal resource in the electrolyzer process can be used to preheat the inlet electrolyzer water. Multigeneration system analysis is conducted by using the Engineering Equation Solver (EES) software using methods based on energy, exergy and thermoeconomic analyses. Also energy and exergy efficiencies of four sub-systems which are a geothermal power plant, an ORC, an absorption cooling system and a PEM electrolyzer are calculated. In addition, a parametric study is given in order to find out how different operating conditions affect the whole-system performance and its sub-systems efficiencies. As a result, it is observed that overall energy and exergy efficiencies of whole system are 47.04% and 32.15%, respectively. Parametric study shows that while geothermal water temperature rises from 130 °C to 200 °C, electrical power generation of system increases from about 4 MW to 8.5 MW and hydrogen production rises from about 0.030 $kgs^{-1}$ to nearly 0.075 $kgs^{-1}$. For the same increase of geothermal water temperature, hydrogen production cost decreases from about 4.8 \$/kg $H_2$ to 1.1 \$/kg $H_2$.



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## Introduction

Renewable energy use is increasing every day because of the disadvantages of non-renewable fossil energy sources on the environment. In spite of the increment in renewable energy use, fossil energy sources are still a major source for energy production with about 80% of total energy production [1]. Being the reason of recent climate changes, $CO_2$ emissions are caused mainly from burning of fossil fuels. Beside $CO_2$ production causing global warming, burning fossil fuels produce some other harmful gases such as $SO_x$ and $NO_x$. In order to decrease the dependence to fossil fuels, researchers are trying to find new alternative energy sources especially renewable ones. As it can be seen from Fig. 1 non-renewable energy sources supplying the most of primary energy need and electricity production are the main cause of $CO_2$ emissions. Natural gas, cleaner option for energy production relative to coal and petroleum, can be used in transition period but still it is not enough to decrease the global warming effect and it is compulsory to increase the usage of renewable energy sources. Geothermal energy is one of these alternatives that are capable to decrease the dependence to fossil sources.

Multi-generation is a type of system producing electricity, heating, cooling, hot water, fresh water, hydrogen, and etc. from the same source. The electricity produced from the multi-generation system is based on one or more prime movers, such as a gas turbine, a Rankine Cycle or an ORC. The ORC is a possible process that should be integrated into a multi-generation system because this cycle is suitable for recovering energy from low-grade heat sources. Geothermal power plant can be used to produce electricity by an ORC, hydrogen by using a PEM electrolyzer, cooling and heating by means of a single effect absorption cooling process. Among hydrogen production options, geothermal energy plays a key role because of its ability to yield both electricity and geothermal heat. In spite of hydrogen is a very clear energy carrier itself, it is very important to focus on the source of hydrogen. If hydrogen is produced via water electrolysis by using fossil fuels as an energy source for electrolysis, it is not a clear option like electricity from renewable energy sources for environment. For hydrogen generation with the electrolysis from geothermal energy source may be an efficient selection in hydrogen production alternatives in the future. Geothermal energy use is common and various thermodynamic systems like single flash, double flash, binary, and combined flash/binary designs are being used. There are many studies in the literature about the usage of geothermal sources and hydrogen production by using geothermal power.

Kanoglu et al. [2] have investigated four system designs based on geothermal power for hydrogen generation using by

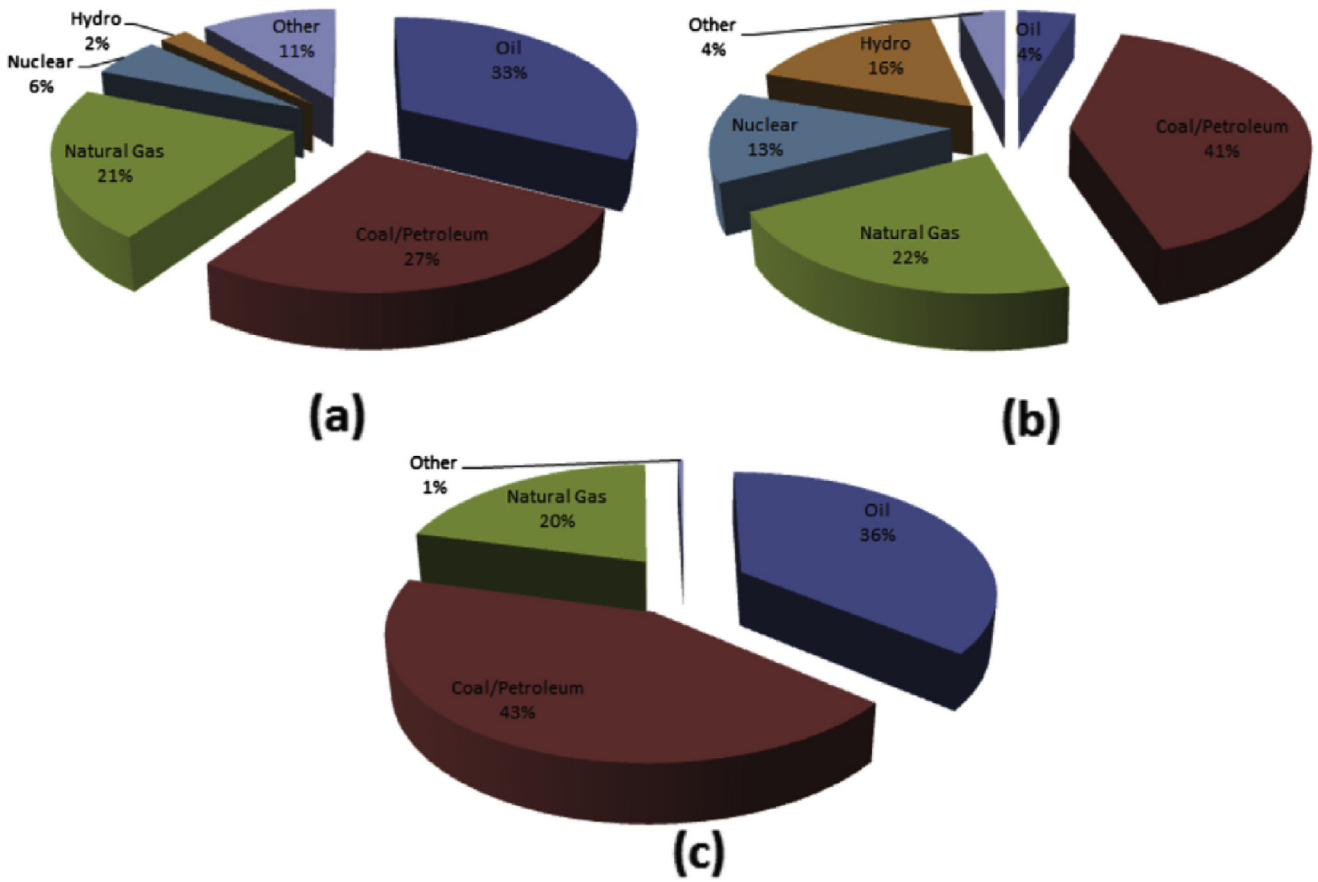


**Fig. 1 – (a) World's Total Primary Energy Supply (TPES), (b) Total electricity generation of the World by energy source, and (c) Total $CO_2$ emissions produced by energy source in 2010 (Other includes geothermal, solar, wind, heat, biofuels and waste etc [2].**

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