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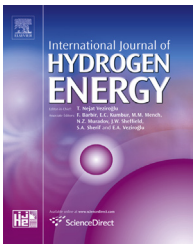

Sustainable practices: Solar hydrogen fuel and education program on sustainable energy systems

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ABSTRACT

Owing to the increasingly apparent climate change, it becomes imperative to use renewable energy in the production of fuel that is environmentally friendly. At the same time, there is a need to introduce the related education programs to develop the skills of the technical staff working at the front line of rapidly developing renewable energy technologies.

Hydrogen is expected to be the fuel in the near future. At present hydrogen fuel is mainly produced using steam reforming of methane (SRM). However, hydrogen generation using the SRM results in emission of greenhouse gases and climate change. Therefore, there is a common consensus that the SRM technology will soon be challenged by the technologies of solar hydrogen generation using photoelectrochemical cells (PEC). However, the PEC technology will be the ultimate winner only if the effects related to climate change and pollution are fully monetised. While such radical development is difficult for implementation due to economic reasons, the increasingly urgent need to reduce climate change dictates the need to increase competitiveness of the PEC method. This imposes the need to increase the efficiency of the solar energy conversion and reduce the costs of the related raw materials and devices.

The development of renewable energy-related technologies, such as those related to solar hydrogen, imposes the need to introduce education programs in order to train technical and research staff working at the front line of rapidly developing sustainable energy systems. The present work considers such programs addressing a range of energy-related topics, such as hydrogen energy, electrochemical energy, photoelectrochemical energy and alternative renewable energy as well as industrial ecology and energy policy. It is concluded that implementation of these programs is urgently needed in order to protect the environment through sustainable development.

Acronyms and abbreviations: ECE, energy conversion efficiency; IPHE, International Partnership for Hydrogen Energy; LGE, litre of gasoline equivalent; PEC, photoelectrochemical cell; PV, photovoltaics; SES, sustainable energy systems; SRM, steam reforming of methane.

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1. Introduction

The increasing demand for energy has resulted in the rapid shrinkage in the supply of fossil fuels. The resulting increase of gasoline price is substantial and is expected to continue to rise towards the level that is prohibitive to the development of the economy.

The emission of greenhouse gases has a detrimental effect on climate change, which is already apparent. The resulting negative impact on the economy is substantial and cannot be ignored. Therefore, there is an increasingly urgent need to develop an alternative fuel that is environmentally friendly.

The world is heading towards the hydrogen economy with the hope that hydrogen will be a sustainable fuel for the future [1]. This perception is related to the expectation that hydrogen combustion results in the formation of harmless water instead of toxic and greenhouse gases. While it is correct that hydrogen fuel will result in a substantial reduction of air pollution in urban areas, it is important to take into account the emission-related costs associated with the upstream stages of hydrogen generation, such as extraction of primary materials and device manufacture. In general, a complete assessment of the environmental consequences of different technologies must include not only the use stage but also the upstream stages. In other words, while hydrogen is an environmentally clean fuel during its use (combustion), there is also a need to perform an analysis on greenhouse gas emission during the stages of its generation.

The use of gasoline results in carbon emission during its combustion. On the other hand, however, hydrogen utilisation leads to the emission of greenhouse gases, if it is generated by, for example, the steam reforming of methane, SRM. While the latter process usually takes place in industrial areas, its detrimental effect on climate is substantial and cannot be ignored. According to the data reported by Brinkman et al. [2], the greenhouse gas emission for a spark ignition vehicle running on gasoline is approximately 550 g of CO_2 per mile and, at the same time, the emission for a vehicle running on hydrogen obtained by SRM is approximately 250 g of CO_2 per mile. While this data indicates that the hydrogen-powered vehicle is environmentally cleaner than that powered by gasoline, the detrimental contribution to climate in both cases is substantial if hydrogen fuel is produced from natural gas. Therefore, the introduction of hydrogen as a fuel will not resolve the problems related to the environmental consequences of carbon emission if hydrogen is generated using the SRM technology or an alternative technology resulting in carbon emission.

Awareness is growing that hydrogen can be considered as an environmentally friendly fuel only when it does not lead to the emission of greenhouse gases during the stage of its generation. This is possible only when hydrogen is generated using renewable energy [3]. Therefore, it is imperative to develop a technology of hydrogen generation using a renewable energy, such as solar energy. Awareness is also growing that the technology of hydrogen production using renewable energy may be commercialised only when its cost is competitive with hydrogen generated using the SRM method. At present, the latter is the least expensive. Therefore, the utilisation of hydrogen fuel that is environmentally friendly also during the stage of its generation requires that the effects related to climate change are fully monetised [2].

The present work compares the market prices for hydrogen fuels that are produced in different ways, including the SRM, water electrolysis using grid electricity and photovoltaic (PV) electricity, as well as the price of solar hydrogen generated by photoelectrochemical water splitting. The latter method does not result in pollution of the environment. This work also considers the most likely trends in the development of these prices in the future in order to predict the most feasible technology of hydrogen production. The main effort is focused on the methods based on the use of renewable energy, including the photoelectrochemical water splitting (PEC) and water electrolysis using PV electricity. It is argued that the key issue in commercialisation of solar hydrogen technologies is the energy conversion efficiency (ECE) (to be maximized) and the costs of materials used for harnessing solar energy (to be minimized). Therefore, the efforts in reducing the cost of hydrogen through an increase of ECE, must take into account the costs of raw materials and the related devices.

The imperative to protect the environment from detrimental effects of climate change resulted in the release of a key document of the United Nations on the Commitment to the Sustainable Practices of Higher Education Institutions on the occasion of the UN Conference on Sustainable Development in Rio de Janeiro 2012 [4]. This document, which strongly supports the development of environmentally clean energy, indicates the need to undertake research programs on new sustainable technologies. The UN document also indicates the need to develop the skills necessary to enter a sustainable development workforce. The logical intension of the UN document is that the development of renewable energy-related technologies must be accompanied by appropriate modification of the education system, which is needed to educate the technical staff able to work at the front line of environmentally friendly technologies. The new educational system should help the students and the technology managers to assess competing technologies in regards to both economic and environmental aspects.

2. Gasoline

Before the 1960's, the price of gasoline (in the US) was around $0.1 per litre. The first signal of the lack of balance between supply and demand, and the resulting effect on the market price of gasoline, has been observed in the early 1970's. The resulting price increase, which is shown in Fig. 1 [5], indicates that the market of gasoline already exhibits some symptoms of panic.

At present, awareness is growing that due to the continuing shrinkage of resources the price of gasoline is expected to rise to the level that could have a preventive impact on the development of the economy. As a consequence, hydrogen has been proposed to be the fuel for the future.

In his State of the Union Address in 2003, President George Bush has announced US policy to depart from fossil fuels and develop an alternative fuel; hydrogen. This policy, which has