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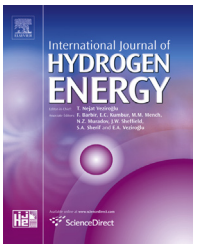

Towards sustainable energy. Generation of hydrogen fuel using nuclear energy

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ABSTRACT

The increasing demand for sustainable energy results in the development of new technologies of energy generation. The key objective of hydrogen economy is the introduction of hydrogen as main energy carrier, along with electricity, on a global scale. The key goal is the development of hydrogen-related technologies needed for hydrogen generation, hydrogen storage, hydrogen transportation and hydrogen distribution as well as hydrogen safety systems. It is commonly believed that hydrogen is environmentally clean since its combustion results in the formation of water. However, the technology currently employed for the generation of hydrogen from natural gas, does in fact lead to the emission of greenhouse gases and climate change. Therefore, the key issues in the introduction of hydrogen economy involve the development of environmentally clean hydrogen production technology as well as storage and transport. The clean options available for hydrogen generation using nuclear energy; such as advanced nuclear fission and, ultimately, nuclear fusion, are discussed. The latter, which is environmentally clean, is expected to be the primary approach in the production of hydrogen fuel at the global scale. The present work considers the effect of hydrogen on properties of TiO_2 and its solid solutions in the contexts of photocatalytic energy conversion and the effect of tritium on advanced tritium breeders.

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Notation

ADS	Accelerator-driven subcritical systems
ARC	Affordable, robust, compact
BA	Broader Approach
CNG	Conversion of natural gas
DEMO	Demonstration power reactor
FNS	Fusion neutronics source
HTGR	High temperature gas cooled reactor
IFERC	International Fusion Energy Research Centre
IPHE	International Partnership for Hydrogen Energy
ITER	International Thermonuclear Experimental Reactor
JAEA	Japan Atomic Energy Agency
LGE	Litre of gasoline equivalent
RAFM	Reduced activation ferritic/martensitic steel
REBCO	Rare earth barium copper oxide
TBR	Tritium breeding ratio

Introduction

The world's resources of easily accessible fossil fuels are rapidly shrinking. As a result, their cost undergoes rapid increases with spikes into extreme ranges. This behaviour has a negative impact on economies. Therefore, there is an increasingly urgent need to develop a fuel that can be obtained from a raw material that is commonly available. Such a fuel is hydrogen. As a consequence, it has been agreed that globally hydrogen will be the key energy carrier, along with electricity [1].

The established International Partnership for Hydrogen Energy, IPHE (2003) aims at coordination of the developments related to implementation of a hydrogen economy. The goal of the IPHE is the development of a range of hydrogen-related technologies, including hydrogen generation, storage, transportation, distribution and hydrogen safety. The ultimate aim of the hydrogen economy is to replace fossil fuels by hydrogen which is widely available and abundant. The related key issues to be addressed include safe storage as well as minimization of hydrogen escape to the troposphere that may lead to enhanced global warming via cloud formation.

The key question is: *how to generate hydrogen fuel in an environmentally clean manner?* The aim of the present work is to consider the approaches for sustainable energy generation in general and the use of nuclear energy for hydrogen generation in particular. The increasingly important need to develop environmentally clean energy is promoted by the UN program of Future Earth through a Sustainable Energy Network, SEN, which aims to establish the related education programs. The present work considers briefly its mission.

Before going into the concept of hydrogen energy, the present work outlines the Future Earth program and the key recommendations on sustainable practices in energy conversion.

Emission of greenhouse gases

Modern day society has an increasing need for energy production. At the same time the rising global emissions of greenhouse gases imposes a strong imperative to abandon the use of fossil fuels, such as coal, natural gas and gasoline. There is a growing awareness that the combustion of fossil fuels leads to climate change and the associated damage to the environment and health.

Despite the measures undertaken in many countries to reduce their emission of greenhouse gases, the content of CO_2 in the atmosphere is still rising [2–5] (Fig. 1).

As seen in Fig. 1, the concentration of greenhouse gases, mainly carbon dioxide, in the atmosphere is increasing globally at a dramatic pace due to burning fossil fuels for energy production. Despite international efforts to impose emission targets, the amount of CO_2 in the atmosphere recently surpassed the level of 400 ppm [6]. The emission data indicate that the current global approach aimed at reducing emissions, which is also very costly, is clearly not adequate to rectify the problem [7], and it will be interesting to see if the agreement reached by nearly 200 countries in Paris in December 2015 is a real starting point for emission reduction of greenhouse gasses. It is important to note at his point that in addition to CO_2, the greenhouse effect is also produced by a range of other gases, such as methane and nitrous oxides, which are monitored but their lower abundance means they have a smaller impact on enhancing greenhouse conditions. Climate change may also be related to escape of hydrogen gas to the troposphere where, after combining with oxygen, it may contribute to an increased level of clouds. While this effect is a minor contribution to climate change, the global hydrogen economy must promote technologies which minimize loses of hydrogen gas.

The most common source of emission of greenhouse gases at present is the use of fossil fuels (gasoline, natural gas and coal) in production of energy. It is expected that the introduction of a hydrogen-based economy will successfully lead to a reduction in the concentration of greenhouse gases. However, hydrogen must first be generated in a cost effective way. The availability of cheap hydrogen will lead to global independence from rapidly shrinking resources of fossil fuels, however, *what is the optimal way for hydrogen generation from economic and environmental perspectives?*

An awareness is growing that hydrogen generation using the conversion of natural gas (CNG) results in emission of greenhouse gases. The cost of hydrogen production using this well-established technology is relatively low.

According to the US Department of Energy [8,9], the cost of hydrogen generated using CNG technology is in the range US$ 0.5–0.6 LGE (per litre of gasoline equivalent). According to Bockris [10], however, the costs of air pollution and climate change associated with the generation of the equivalent amount of hydrogen using the CNG method is US$ 0.86/LGE. The latter costs, which are substantial, are born by the entire community [11].

The commonly assumed strategy to reduce the emission of greenhouse gases currently aims at the development of renewable energy and reducing overall energy demand. The importance of developing alternative approaches that would allow facilitate a reduction in emissions and reverse the damaging effects of climate changes are compelling. Therefore, there have been efforts to generate hydrogen using solar energy [12,13]. It seems that nuclear energy –

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