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Penetration of hydrogen-based energy system and its potential for causing global environmental change: Scoping risk analysis based on life cycle thinking

Ryunosuke Kikuchi *

Department of Basic Science and Environment (CERNAS), ESAC, Polytechnic Institute of Coimbra, Bencanta, 3040-316 Coimbra, Portugal

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Abstract

A hydrogen-based economy seems superficially to be environmentally friendly, and many people have worked toward its realization. Today hydrogen is mainly produced by decarbonizing fossil fuels (e.g. natural gas), and in the future decarbonization of both fossil fuels and biomass will play a leading role in the production of hydrogen. The main purpose of this paper is to suggest the identification of potential environmental risks in terms of "life cycle thinking" (which considers all aspects from production to utilization) with regard to the hydrogen-based economy to come.

Hydrogen production by decarbonization results in CO_2 emissions. The final destination of the recovered CO_2 is uncertain. Furthermore, there is a possibility that hydrogen molecules will escape to the atmosphere, posing risks that could occasion global environmental changes such as depletion of stratospheric ozone, temperature change in the stratosphere and change of the hydrides cycle through global vaporization. Based on the results of simulation, requirements regarding the following items are proposed to minimize potential risks: hydrogen source, production and storage loss.

Keywords: Alternative energy; Global change; Life cycle thinking; Hydrogen production; Potential risk

1. Introduction

In recognition of the reduction targets for greenhouse gas set by the Kyoto Protocol, studies have focused on hydrogen as a means of meeting the demand for clean energy. Investment in

* Tel.: +351 239 802287; fax: +351 239 802979.
E-mail address: kikuchi@mail.esac.pt.

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research has already led to significant developments in hydrogen-related technologies in countries such as member states of the European Union, the USA, Canada, and Japan (Corrêa, 2003). The fuel cell system, which promises to become the centerpiece of a hydrogen-based economy, is considered a major consumer of hydrogen (Hoffmann, 2002). As the fuel cell emits only water (vapor), it is a nonpolluting system. It is reported that many countries and economies will be able to easily adopt a hydrogen-based economy because hydrogen can be made by a variety of methods (Hoffmann, 2002). It would seem that this statement about the plurality of production methods is true. In the future, it will be possible to produce hydrogen by alternative (unconventional) methods such as water photolysis using a semiconductor (Khaselev and Turner, 1998) and ocean thermal energy conversion (Avery, 2002). Such methods are still at the R&D stage and are not yet ready for industrial application. Today hydrogen is mainly manufactured by decarbonizing fossil fuels (Harris et al., 2001).

A hydrogen-based economy seems to be environmentally advantageous, but there is doubt as to whether this new energy economy has no disadvantage at all. A few reports mention this point (e.g. Tromp et al., 2003). It is necessary to consider all processes from hydrogen production and consumption (e.g. supply to a fuel cell) through to transport and storage in order to evaluate whether a hydrogen-based economy is really environmentally friendly. There are various energy scenarios for the future: A1F1 family, A1B family, A1T family, B1 family, Dynamics as usual, Spirit of the coming age, Conventional worlds, Barbarisation, Great transition, FROG, GEOpolity, Jazz, Cybertopia, Trading places, Normative world, A passive mean world, Grasping at straws, Global sustainability, Local stewardship, Isolation, Provincial enterprise and so on (International Energy Agency, 2003). A quantitative approach to risk assessment may be dependent upon the preferred scenario (and/or type of production process). As yet, it is difficult to assess which scenario for the globalization of a hydrogen economy is reasonable. The main attention in this paper is therefore focused on a qualitative approach in order to avoid unjust data analysis that may be caused by the dependence upon a certain scenario. A detailed quantitative risk assessment will be left until a scenario has been selected and/or this new economy is realized. The purpose of this paper is therefore not to examine each process in detail and prove inherent environmental impact from the technical and scientific standpoints. Considering the current situation, the main purpose is to suggest the identification of potential risks in terms of promoting both "life cycle thinking" with regard to hydrogen and the establishment of a hydrogen-based economy with its environmental and health benefits.

2. Process of penetration by hydrogen economy

Although this paper aims to avoid discussion that is scenario-dependent as described above, a penetration forecast is presented below for reference.

Total world consumption of intentionally produced hydrogen was estimated at about 500 billion (10^9) Nm^3 in 1998 (Gregorie-Padro and Putsche, 1999). The largest volumes of hydrogen are consumed in ammonia production and methanol production. Today, most hydrogen is derived from hydrocarbon sources such as the steam reforming of natural gas (Harris et al., 2001). Rising energy prices and concern for the environment are prompting increased interest in hydrogen as a renewable energy resource. Ideally, solar (thermal) energy would be used to produce hydrogen directly from water; hydrogen would subsequently be oxidized for energy generation. Water generated as by-product would be recycled (Suresh et al., 2004). Increasing attention is being given to production of hydrogen for use in fuel cells that would provide energy to numerous applications, including transportation (Suresh et al., 2004). Automakers are most excited about