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Hydrogen for a sustainable global economy

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ABSTRACT

The topic of this special issue of the Journal of Cleaner Production is "Sustainable Hydrogen from Biomass." It is of interest to practitioners in the energy sector, governmental policy makers, researchers, educators, as well as to the general public. The purpose of this special issue is to increase public awareness and to stimulate exchange of information among actors expected to play important roles in making hydrogen available for the sustainable energy system of the future.

Hydrogen as a biofuel, that is, hydrogen produced from biomass in a sustainable way is recognised as an important component of the fuel market for the future low or non-carbon based energy systems. In this special issue, the main focus is on hydrogen produced from vegetable biomass by fermentation. The development of a two-stage bioprocess for the cost-effective and environmentally friendly production of pure hydrogen from multiple biomass feedstocks is elucidated by a collection of papers presenting preliminary results of Integrated Research Project HYVOLUTION supported by the 6th Framework Programme of the European Union. The attention is turned to:

- the over-all concept and characteristics of the two-stage hydrogen fermentation process,
- key technological issues of fermentative hydrogen production,
- the availability of vegetable feedstocks including agricultural byproducts that suitable for fermentative processing,
- prospects of societal integration and sustainability of the fermentative hydrogen production technology.

Other papers included in this special issue are devoted to:

- simultaneous production of hydrogen and methane by fermentation of lactose-containing feedstocks derived from byproducts of milk processing,
- hydrogen gas generation from organic material by electrohydrogenesis, that is, a bioelectrochemical process performed in reactors known as a microbial electrolysis cells,
- the ideas for Europe-wide effort on education of hydrogen users and training of skilled staff needed for facilitating the transition to the future hydrogen economy.

1. Introduction

Todays energy systems based mainly on fossil fuels cannot be regarded as sustainable. In view of the expected increase of global energy demand, there is a growing concern about energy supply security, increasing prices of energy carriers, local air pollution and global climate change. The center of the problem is oil with its share of more than one third in the global consumption of primary energy and more than 95% of the energy consumption in the transport sector. Other factors of concern are the multifaceted negative environmental impact of coal mining combined with the huge contribution of coal usage to the global carbon dioxide emissions, as well as the danger of dwindling reserves of natural gas.

Economic and political implications of possible fossil-fuel shortages, environmental damage and climate change are stimulating the search for alternative sources for energy and new cleaner energy technologies which are the topics of constant interest to the Journal of Cleaner Production (Dovì et al., 2009; D'Alessandro et al., 2010; Mizsey and Racz, 2010). The principal energy options in the transport sector are ' green' electric energy for electric vehicles,

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biofuels and (bio)-hydrogen. Combination of hydrogen with fuel cells confers energy saving because of the inherent high conversion efficiency. Biohydrogen production from renewable sources offers additional benefits as it is completely emission-free and can be produced from a great variety of primary energy sources thus adding to security of supply.

2. Background of this special issue

Recent progress in fuel cell technology makes it possible to envisage a major role of hydrogen in the future energy system and in particular in the transport sector (van den Hoed, 2007; Zapata and Nieuwenhuis, 2010). Experts from research, industry and policy making, as well as a number of powerful companies and public-private partnerships are promoting the concept of the so-called hydrogen economy. National or international activities aimed at implementing its necessary components, that is, hydrogen production, storage, distribution and use for energy are under way in different parts of the world (Taanman et al., 2008; Sartorius, 2008; Leaver and Gillingham, 2010). There are numerous examples of locally achieved substantial progress in this direction (Karlström, 2005; Maack and Skulason, 2006).

History proves that energy technologies and systems develop slowly. It will take several decades for the development and installation of the hydrogen infrastructure and for widespread use of hydrogen as a fuel to become a reality. Apart from addressing technical problems, it requires the build-up of manufacturing capability and the development of a large-scale hydrogen industry. Significant structural changes in the world economy may occur through reduced trade in fossil fuels and increased trade in feedstocks for hydrogen production, as well as changes in the employment markets. To make it happen, favourable policy support and incentives are needed, and the stimulation of public awareness together with consumer acceptance of hydrogen are required. International cooperation is essential to adopt regulations, codes and standards – especially with regard to safety – for the production, distribution, storage and use of hydrogen. Moreover, large-scale effort in training of skilled personnel and education of hydrogen users will be needed.

Hydrogen should not be seen as the ultimate solution to global energy problems in general and not as the single optimal fuel for the transport sector in particular. Bearing in mind the need for improving energy security and mitigating the effects of climate change and atmospheric pollution, all the options are subject to constraints of some kind. However, hydrogen has the potential to become a significant part of the future global energy mix and especially to contribute to decarbonisation of transport since it can be generated from many primary energy sources.

3. Research areas and themes represented in this special issue

This special issue is designed to present various aspects of the implementation of hydrogen technologies. The special focus is upon the special case of hydrogen as a biofuel. Still many find it hard to believe that micro-organisms produce hydrogen from biomass! The reward of this approach, which started in the 5th EU Framework Programme project “Biohydrogen”, will be enormous since it allows the greatest reduction in CO_2 emission. The research is continued in the 6th EU Framework Programme project “Non-thermal production of pure hydrogen from biomass – HYVOLUTION” and technologies developed as a result of the research in this Integrated Project will be commercialised post-2015. This will be in time to facilitate the transition to mass hydrogen markets, even more so since the European Commission has set an objective of 20% substitution by biofuels in the road transport sector in 2020.

However, before biological hydrogen production can be implemented, several hurdles need to be taken. Some are associated with biotechnology, others are shared with other hydrogen technologies. The starting point is the choice of vegetable raw material and ways to convert it into a fermentable feedstock which contains monosaccharides or sucrose. Feedstock conversion to hydrogen gas is done in two stages, thermophilic fermentation followed by photofermentation, for which dedicated bioreactor designs are needed. The obtained gas contains a significant percentage of carbon dioxide which is subsequently separated in the gas upgrading stage. All the process stages must be properly integrated to form an efficient production process and conditions for its sustainability need to be studied. This special issue includes 11 papers dealing with the abovementioned themes, originated from HYVOLUTION research. In order to present their common background and the way they complement each other, these papers are commented in a separate article (Claassen et al., 2010).

Clearly, the range of themes being investigated in project HYVOLUTION covers just a part of the field of research on biological hydrogen production. For example, apart from feedstocks of vegetable origin, lactose-containing feedstocks derived from byproducts of milk processing are also suitable for hydrogen fermentation. Results of experimental research on lactose as a source of hydrogen and methane are presented in a contribution to this issue (Banks et al., 2010).

Furthermore, hydrogen fermentation is not the only bioprocess suited for H_2 production from renewable sources. Electrohydrogenesis is a bioelectrochemical process for hydrogen gas generation from organic material in reactors known as a microbial electrolysis cells (MECs). In another contribution to this issue (Wrana et al., 2010), fundamental concepts of MEC technology and mechanisms for electron transfer between microbe and electrode are discussed, the challenges these electrochemical systems face are presented, and finally current MEC systems are reviewed.

As a complement to the research themes mentioned, a question of the utmost importance to the transition to hydrogen economy, that is, the demand for education of hydrogen users and training of skilled staff is discussed in this special issue. Europe-wide effort into awareness raising and into education and training at different levels is envisaged (Reijalt, 2010).

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References

Banks, C., Zotova, E., Heaven, S., 2010. Biphasic production of hydrogen and methane from waste lactose in cyclic-batch reactors. Journal of Cleaner Production 18 (Suppl. 1), S95–S104.

Claassen, P.A.M., de Vrije, T., Koukios, E., van Niel, E., Eroglu, I., Modigell, M., Friedl, A., Wukovits, W., Ahrer, W., 2010. Non-thermal production of pure hydrogen from biomass: HYVOLUTION. Journal of Cleaner Production 18 (Suppl. 1), S4–S8.

D'Alessandro, S., Luzzati, T., Morroni, M., 2010. Energy transition towards economic and environmental sustainability: feasible paths and policy implications. Journal of Cleaner Production 18 (4), 291–298.

Dovì, V.G., Friedler, F., Huisingh, D., Klemeš, J.J., 2009. Cleaner energy for sustainable future. Journal of Cleaner Production 17 (10), 889–895.

Karlström, M., 2005. Local environmental benefits of fuel cell buses – a case study. Journal of Cleaner Production 13 (7), 679–685.

Leaver, J., Gillingham, K., 2010. Economic impact of the integration of alternative vehicle technologies into the New Zealand vehicle flet. Journal of Cleaner Production 18 (9), 908–916.

Maack, M.H., Skulason, J.B., 2006. Implementing the hydrogen economy. Journal of Cleaner Production 14 (1), 52–64.

Mizsey, P., Racz, L., 2010. Cleaner production alternatives: Biomass utilisation options. Journal of Cleaner Production 18 (8), 767–770.

Reijalt, M., 2010. Hydrogen and Fuel Cell Education in Europe: from when? and where? To here! And now! Journal of Cleaner Production 18 (Supp. 1), S112–S117.

Sartorius, C., 2008. Promotion of stationary fuel cells on the basis of subjectively perceived barriers and drivers. Journal of Cleaner Production 16 (1 Suppl. 1), 171–180.

Taanman, M., de Groot, A., Kemp, R., Verspagen, B., 2008. Diffusion paths for micro cogeneration using hydrogen in the Netherlands. Journal of Cleaner Production 16 (1 Suppl. 1), 124–132.

van den Hoed, R., 2007. Sources of radical technological innovation: the emergence of fuel cell technology in the automotive industry. Journal of Cleaner Production 15 (11–12), 1014–1021.

Wrana, N., Sparling, R., Cicek, N., Levin, D.B., 2010. Hydrogen gas production in a microbial electrolysis cell by electrohydrogenesis. Journal of Cleaner Production 18 (Suppl. 1), S105–S111.

Zapata, C., Nieuwenhuis, P., 2010. Exploring innovation in the automotive industry: new technologies for cleaner cars. Journal of Cleaner Production 18 (1), 14–20.