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Review Article

Current research trends and perspectives on materials-based hydrogen storage solutions: A critical review

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ARTICLE INFO

Article history:
Received 24 June 2016
Received in revised form
29 November 2016
Accepted 30 November 2016
Available online xxx

Keywords:
Materials-based hydrogen storage
Reaction enthalpies
Nanoconfinement
Ionic liquids
Conversion of ortho-para hydrogen

ABSTRACT

Effective hydrogen storage solutions have been pursued for decades, and materials-based hydrogen storage is a research frontier of much current interest. Yet, no researched materials to date have come close to the DOE 2020 targets for hydrogen storage at ambient conditions, although some good results have been reported at cryogenic temperature. This paper critically reviews the current research trends and perspectives on materials-based hydrogen storage including both materials-based physical storage and materials-based chemical storage. In the case of physical storage, the efforts on exploring new porous materials with extra larger surface/pore volume, inducing hydrogen spillover effect, and tailoring reaction enthalpies are discussed. Meanwhile, for chemical storage, approaches to improve the kinetics and/or thermodynamics such as the development of composite hydride systems, nanoconfinement of hydride materials as well as the usage of ionic liquids as hydrogen storage materials or useful additives are discussed. Furthermore, the applied techniques on solid-state materials towards system integration such as shaping and electrospinning processes are introduced. Finally, the concept of storing hydrogen in para form for long-term hydrogen storage is discussed, and a converter packed with catalysts to process the normal hydrogen to para-hydrogen is highlighted.

Contents

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http://dx.doi.org/10.1016/j.ijhydene.2016.11.195
0360-3199/

Hydrogen as a fuel for the future

Today's world and particularly developing countries, rely heavily on fossil fuels. Most of the time, the fossil fuels are consumed for heat and electricity. The growing world population and increasing standard of life-style have led to a rapidly increasing demand of energy since 1950 and are projected to peak in 2035 (Fig. 1) [1]. Moreover, the non-renewable nature of fossil fuels such as coal, oil and natural gas at the humankind timescale has prompted governments in many countries to think about energy security. Fossil fuels will one day be inevitably used up, although this may not occur in the next two generations due to the relatively large reserves of natural gas and coal still available. However, with the current consumption rate the proven reserves of natural gas and coal should last for approximately 70 and 200 years, respectively, and oil is expected to deplete even earlier [2]. By that time, an alternative fuel is needed for the future energy demand when those fossil fuels become unavailable, more importantly for the transport sector, which is consuming almost 60% of the world energy [3]. Among potential candidates such as solar, wind, nuclear, tidal, hydro, biofuels and geothermal energy, hydrogen appears to be the best choice due to the highest energy density per unit mass (120 MJ/kg), no environmental implications and its abundance in the universe [4–6].

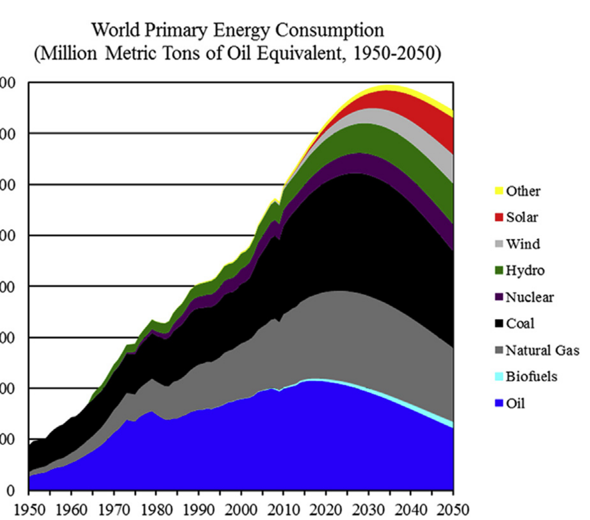

Fig. 1 – World primary energy consumption. Re-produced from Ref. [1] with permission.

The proposed 'Hydrogen Economy' is driven by electricity, and hydrogen presents a means to store electricity via chemical bonds of hydrogen. Typically, 6 kg of hydrogen is able to allow a light-duty vehicle to run for 500 km [7]. Ideally, the amount of hydrogen should be carried as a small volume and light weight. For practicality, the 2020 targets set by the US DOE are: gravimetric capacity of 5.5 wt.% and volumetric capacity of 40 $g \cdot L^{-1}$ at an operating temperature of −40 to 60 °C under a maximum delivery pressure of 12 bar [8]. These values were described for a complete system including tank, materials, valves, regulators, piping, mounting brackets, insulation, added cooling capacity and other balance-of-plant components [8]. To date, the extensive utilization of hydrogen as a fuel is being hindered by lack of effective hydrogen storage solutions. At standard temperature and pressure with a low density of 0.089 $g \cdot L^{-1}$, 6 kg of hydrogen gas will occupy a

Please cite this article in press as: Ren J, et al., Current research trends and perspectives on materials-based hydrogen storage solutions: A critical review, International Journal of Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.11.195