Renewable and Sustainable Energy Reviews 51 (2015) 623–633

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Hydrogen: A sustainable fuel for future of the transport sector

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ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form
5 May 2015
Accepted 29 June 2015

Keywords:
Alternate fuel
Hydrogen
Hydrogen storage
Environment
Transport sector

ABSTRACT

Mobility (transport of people and goods) is a socio-economic reality and need for which is bound to grow in the coming years. Modes of transport should be safe, economic and reasonably environmental friendly. Hydrogen could be ideal as a synthetic energy carrier for transport sector as its gravimetric energy density is very high, abundantly available in combined form on the earth and its oxidation product (water) does not contribute to greenhouse gas emissions. However, its sustainable production from renewable resources economically, on-board storage to provide desirable driving range, usage in durable energy conversion devices and development of infrastructure for its delivery remain significant challenges. In this article, recent developments in the field of production, storage, transport and delivery of hydrogen along with environmental and safety aspects of its use as an energy carrier are presented. Almost any energy source can be used to produce hydrogen. Presently, non-renewable sources dominate hydrogen production processes but the need of the hour is to develop and promote the share of renewable sources for hydrogen production to make it completely sustainable. Hydrogen may be used as fuel for almost any application, where fossil fuels are used presently and would offer immediate benefits over the conventional fuels, if produced from renewable sources. For achieving a successful "hydrogen economy" in the near future, the technical and economic challenges associated with hydrogen must be addressed quickly. Finding feasible solutions to different challenges may take some time but technological breakthrough by way of on-going efforts do promise hydrogen as the ultimate solution for meeting our future energy needs for the transport sector.

Contents

Abbreviations: GHG, greenhouse gas; CNG, compressed natural gas; DME, dimethyl ether; Bcm, billion cubic metres; btoe, billion tonnes of oil equivalent; SMR, steam methane reforming; POX, Partial Oxidation; CPOX, Catalytic Partial Oxidation; PEC, photoelectrochemical; PV, photovoltaic; CG, coal gasification; BG, biomass gasification; FCNF's, functionalised carbon nanofibres; TW, terawatt

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http://dx.doi.org/10.1016/j.rser.2015.06.040
1364-0321/

1. Introduction

Energy production for growing needs and associated environmental challenges are twin issues of paramount interest that require our serious attention in the 21st century [1]. The global primary energy demand was estimated to be 13.371 billion tonnes of oil equivalent (btoe) in 2012 by International Energy Agency and is projected to reach 18.30 btoe in 2035 in current policies scenario, representing a growth rate of 1.37% [2]. To satisfy the world's growing appetite for energy and keep our planet healthy, at least 10 TW (terawatt) of carbon-free power generating capacity has to be created by 2050 [3]. The dramatic increase in the international prices of petroleum in the recent years, the finite nature of fossil fuels, growing concerns relating to adverse environmental impact associated with increasing use of fossil fuels on greenhouse gas emissions, and health and safety considerations are forcing the international community to search for new energy sources and develop alternative ways of powering the world's growing population of motor vehicles [4]. Energy related global CO_2 emissions were estimated to be 30.4 gigatonnes (Gt) in 2010 [5].

At present, a large portion (about 65%) of the world energy demand is met by the liquid and gaseous fossil fuels (i.e., petroleum and natural gas), because of their widespread availability and convenience of use, with petroleum oil being the largest primary fuel contributing a share of more than one third of the global primary energy mix and more than 92% of transport energy demand and balance being provided by natural gas (5%) and electricity 3% [6,7]. However, world's fossil fuel production is expected to peak soon, and thereafter begin to decline. While some energy experts estimate that about half the world's oil production is consumed by road vehicles, the International Energy Agency (IEA) estimates that about 77% of global transport oil demand in 2010 was on account of road transport and the respective shares of biofuel, gas and electricity in transport sector was estimated to be 39%, 3%, and 1% respectively in 2010 [6,8]. By 2050, the global energy demand is projected to double or triple and oil and gas supply is unlikely to meet the demand.

The constantly increasing number of automobiles raises environmental concerns, such as exhaust emissions and global warming, and account for some 18% of primary energy use and some 17% of global CO_2 emissions [9]. Local air pollution (particulate matter, ozone), climate change, congestion, land use, accidents, and noise are particular concerns in this respect. Local air pollution, especially from road transport, is quickly becoming a major issue for urban air quality, particularly in the world's growing megacities. The consumption of fossil fuels is responsible for the increase in the CO_2 in the atmosphere of approximately 3×10^{12} kg/year, a major contributor of global warming [10,11].

The major problem is the fact, that a large amount (approximately 98%) of the CO_2 on earth is dissolved in the water of the oceans (7.5×10^{14} kg C in the atmosphere, 4.1×10^{16} kg C in the oceans). About 2×10^{12} kg C per year dissolves in the water of the ocean. The solubility of carbon dioxide decreases with the increasing temperature of water by approximately 3%/K. If the average temperature of the oceans increases, the carbon dioxide solubility equilibrium between atmosphere and ocean shifts towards the atmosphere and leads to a reduction in the CO_2 flux into the ocean and therefore, to an additional increase of the greenhouse gas in the atmosphere [12].

To resolve the problems of increasing fuel requirement and containing emissions associated with road transport, there is an urgent need to find out solutions for use of energy in vehicles. The principal options are demand-side measures, development and use of more efficient vehicles and use of cleaner alternative fuels that are sustainable like bio-ethanol, bio-diesel, CNG and hydrogen [11]. Bio-diesel, a substitute to petroleum-diesel is derived from vegetable oils, animal fats, and used waste cooking oil including triglycerides. Significant efforts are being made globally for liquid biofuel production from vegetable oils and *Jatropha curcas* L (JCL), which has attracted a lot of attention of investors, policy makers and clean development mechanism project developers. The oil produced by this crop can be easily converted to liquid bio-fuel [13]. Additionally, the press cake can be used as a fertilizer and the organic waste products can be digested to produce biogas. But biofuels alone cannot solve the dual problem of meeting a growing fuel demand for transport sector and reducing emissions.

CNG is another alternative automotive fuel that is being used in many countries. Of all the alternatives, CNG achieves the greatest reduction of 20–25% in CO_2 emissions from vehicles excluding hydrogen and electricity [11]. To further reduce the emissions from CNG, hydrogen can be blended with CNG. The alternatives to petrol and diesel exhibit some kind of constraints and drawbacks. No other fuel is expected to be as easy and cheap to produce and handle as petrol and diesel. While petrol and diesel can be produced from crude oil with high conversion efficiencies, the production of any alternative fuel will generally involve higher conversion losses. Moreover, the gaseous fuels are relatively difficult to handle and require a new distribution and refuelling infrastructure. Energy carriers like hydrogen and electricity even require new elements of drive-train like fuel cells, motors and batteries.

Among the possible alternatives, hydrogen looks promising for transport applications on three counts: GHG emissions reduction, energy security and reduction of local air pollution. The breakthroughs in fuel cell technology in the late 1990s and use of hydrogen in the internal combustion engines without incurring major investments are the main reasons behind the growing interest in hydrogen especially for transport application. Hydrogen is emission-free at the point of final use and thus avoids the transport-induced emissions of both CO_2 and air pollutants. This is also where fuel cells can make the significant impact by way of their high conversion efficiencies compared to the internal combustion engine [7].

According to the report put forward by the European Commission in 2003 and the US Department of Energy in 2004 [4], in many countries hydrogen is considered as an important alternative energy vector and fuel cell as a key technology for meeting energy needs in the stationary power, transportation, industrial and residential sectors on sustainable basis. In the present review, applications of hydrogen, its production methods, properties as a