



ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

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

Review Article

Fuel cell and hydrogen technologies research, development and demonstration activities in Singapore – An update

Siew Hwa Chan ^{a,b,**}, Jan Pawel Stempien ^{b,*}, Ovi Lian Ding ^b,
Pei-Chen Su ^a, Hiang Kwee Ho ^b

^a School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

^b Energy Research Institute at NTU, Nanyang Technological University, 1 CleanTech Loop, #06-04, Singapore 637141, Singapore

ARTICLE INFO

Article history:

Received 18 March 2016

Received in revised form

7 May 2016

Accepted 18 May 2016

Available online xxx

Keywords:

Fuel Cell

Hydrogen

Singapore

Review

Research, development and demonstration

ABSTRACT

In this paper the authors review the activities of Singapore-based research institutions and business players in the field of fuel cells and associated hydrogen technologies undertaken till date. The scope of this paper spans almost 15 years of accomplishments and focuses on highlighting the acquired capabilities and achievements. The review shows slow, but consistently growing research activities, demonstration undertakings and business endeavours of local and overseas companies.

© 2016 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Contents

Introduction	00
Singapore's interest in energy and environmental sustainability	00
Singapore's interest in hydrogen technologies	00
Hydrogen demonstration activities	00
Hydrogen related research and development activities in Singapore	00

* Corresponding author.

** Corresponding author. Energy Research Institute at NTU, Nanyang Technological University, 1 CleanTech Loop, #06-04, Singapore 637141, Singapore.

E-mail addresses: mshchan@ntu.edu.sg (S.H. Chan), jpstempien@ntu.edu.sg (J.P. Stempien).

<http://dx.doi.org/10.1016/j.ijhydene.2016.05.192>

0360-3199/© 2016 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Singapore's collaborations with overseas research institutions	00
Private sector activity	00
Conclusion	00
Acknowledgements	00
References	00

Introduction

In 2013, Singapore was home to 5.4 million people living on slightly over than 716 km² [1]. The busy island city-state located 140 km north from the equator generated 302.25 billion current-US\$ (2013) GDP [2] making it one of the richest countries in terms of PPP-adjusted GDP per capita [3]. To this end, the country has consumed 26.1 Mtoe of primary energy and emitted 45.56 Mt of CO₂ from burning of fossil fuels [4]. The country has virtually no natural resources and depends on imports to satisfy the most basic of its needs, including water and energy supply. Singapore sees becoming economically and environmentally sustainable as a prerequisite for continuous social development. The efforts of the country are reflected in being named Asia's Greenest City by the Siemens-Economist Intelligence Unit in 2011 [5]. To highlight the significance of this achievement, it is remarked that the World Economic Forum's pilot Environmental Sustainability Index ranked Singapore as bottom 10 worst performing countries as recently as in the year 2000 [6]. The country is now the lowest emitter of greenhouse gases per GDP among its ASEAN peers and on par with the lowest polluting countries, like Switzerland, Japan or France. However, the energy consumption per capita and emissions per capita are high, placing Singapore as 27th in terms of emissions per capita [7] and close to OECD average in terms of energy use per capita.¹

Since 2009 Singapore has been publishing *The Sustainable Singapore Blueprint*. In the most recent edition (2015), the country looks at adopting eco-friendly buildings, sustainable transport, efficient energy and water use and improving air quality, among others. To achieve the ambitious goals of the blueprint, we believe that the use of hydrogen technologies along with solar, energy storage and other sustainable technologies is necessary. Fuel cells can be used as non-intermittent electricity and heat sources that are powered by solar- and wind-renewable hydrogen or the by-product hydrogen available from local chemical and petrochemical industries. In such scenario, hydrogen is a clean energy carrier allowing to potentially increase the energy conversion efficiency, resolve intermittency issue of renewable energy, and provide more environmentally friendly energy system [8]. Similar, country-focused studies, were reported for China [9], European Union [10], the USA [11], India [12], Japan [13] and Australia [14]. Hydrogen is recognized as one of possible future energy carriers. Research programs on fuel cells, electrolysis, reforming, storage and other facets of the hydrogen

technology are being conducted at numerous institutions around the world [15–21].

Singapore's interest in energy and environmental sustainability

The United Nations Framework Convention on Climate Change conference in 1997 cemented the need for sensible use of resources, especially energy related ones. It had focused on the greenhouse gas emissions related to increasing use of energy, resulting from economic growth. The problem concerns developed and developing countries alike. A need has been identified to improve the utilization of natural resources and reduce dependence of economic growth on these resources. Despite the energy use in Singapore per constant value GDP is increasing over the past 25 years at a rate of 0.253% per annum, the greenhouse gases emissions per constant value GDP dropped by a significant 13.6% per annum showing a significant devotion to making the country sustainable.² Some of the possible contributing factors to this trend are the switching to natural gas as a main fuel in electricity generation, imposing strict rules pertaining car ownership and social promotion of energy savings and energy efficiency. A number of government agencies were formed in order to institutionalise the government's approach and organisation to address the problem and made the promotion of sustainability less dependent on political and economic circumstance. These agencies included Ministry of the Environment and Water Resources, National Environment Agency, National Climate Change Secretariat, Energy Market Authority, Urban Redevelopment Authority, etc. In 2010, the National Climate Change Secretariat (NCCS) was formed to develop and implement Singapore's domestic and international policies and strategies to tackle climate change [22]. The core mission of NCCS is to lead the whole-of-nation effort to address the challenges and opportunities of climate change. The agency is responsible for:

- Facilitating efforts to mitigate carbon emissions in all sectors,
- Helping Singapore adapt to the effects of climate change,
- Harnessing economic and green growth opportunities arising from climate change,
- Encouraging public awareness and action on climate change.

Singapore is enthusiastically looking forward to adapting renewable energy, however, the availability of these sources

¹ Based on own calculations using data from the World Bank, OECD and International Energy Agency.

² Based on own calculations using data from the World Bank and International Energy Agency.

Download English Version:

<https://daneshyari.com/en/article/7709829>

Download Persian Version:

<https://daneshyari.com/article/7709829>

[Daneshyari.com](https://daneshyari.com)