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Comparative cost evaluation of nuclear hydrogen production methods with the Hydrogen Economy Evaluation Program (HEEP)

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ABSTRACT

In this paper, a comparative cost assessment of some selected nuclear hydrogen production methods is performed with various options of hydrogen storage and transportation by employing Hydrogen Economy Evaluation Program (HEEP), as developed by International Atomic Energy Agency (IAEA). This HEEP software package is treated as one the most comprehensive ones with various nuclear hydrogen generation options. In the HEEP database, there are three different nuclear power plant options and three hydrogen production plant options included. The cost estimations for capital, fuel, decommissioning, O&M, and consumables are performed and evaluated in addition to the thermal energy and electricity cost details. These cost estimations include various hydrogen storage and transportation options. The hydrogen storage options considered are mainly compression, liquefaction and metal-hydride storage, which are available in the HEEP database. Furthermore, both pipeline and vehicle transportation costs are considered for cost calculations and evaluations.

Introduction

Global energy demand tends to increase with increasing population and welfare. In this regard, energy has been a critical element in shaping local and international policies of countries and their economies, environmental policies, sustainable issues, social dimensions, etc. [1]. Fossil fuel based energy systems are treated as non-sustainable due to their finite reserves and environmental effects. The shift from fossil fuels to nuclear and renewable resources is expected due to the increase in energy demand accompanied by growing concerns over environmental issues, such as global warming.

Hydrogen is expected by many energy experts and stakeholders to become the most important fuel for solving energy and environmental problems as we currently face. It is carbon-free and does not emit greenhouse gases and hence does not contribute to global warming. Hydrogen is treated as a promising candidate to be an excellent energy carrier that helps expand markets for renewable and nuclear energy resources,

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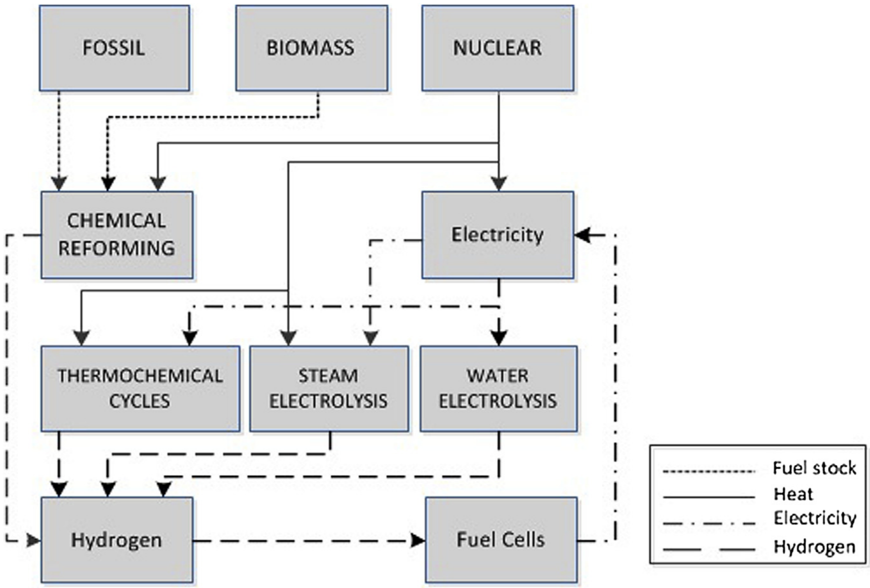

Fig. 1 – Hydrogen production methods from various energy sources (Adapted from Refs. [4,5]).

as well as contributing to sustainability and resolving environmental issues [2]. Hydrogen exists in abundance in nature in the form of water, but not alone which brings a need to produce it for use in a sustainable and environmentally-friendly manner. There are several methods of achieving this, including steam reforming of natural gas, coal gasification, water electrolysis and thermochemical water decomposition [3–5]. The main methods for production of hydrogen from various energy sources are summarized in Fig. 1.

Nuclear hydrogen production can be made by low-temperature electrolysis, high-temperature electrolysis, thermochemical, and hybrid processes. Low temperature electrolysis is simply splitting water into hydrogen and oxygen using electrical power which possesses a high amount of electricity consumption (~1.23 V/molH_2O). High-temperature electrolysis, which can also be called steam electrolysis, is a method to split steam into hydrogen and oxygen. Electrical energy requirement for splitting steam is lower than that of liquid water, and higher efficiencies can be obtained by using heat as a part of energy source. This method is not yet commercially available whereas a lab scale solid oxide electrolysis cell (SOEC) is demonstrated by Idaho National Laboratory (INL) [6].

Thermochemical processes are known as a series of some chemical reactions to split water into hydrogen and by-products using high and/or medium grade heat. Although these processes seem to be using only heat as the energy source, additional electrical power is required for additional or required electrolytic processes. The original Sulfur–Iodine (SI) process has been proposed by General Atomics (GA) and 75 L/h production is achieved through three key reactions. Japan Atomic Energy Agency (JAEA) continued the SI process with a plan to construct a 2 tons/day hydrogen with connection to a nuclear reactor. Hybrid Sulfur Cycle (HyS) is a two-step process, having a maximum working temperature of around 800°C. A modified HyS has been introduced in Japan, to decrease the maximum temperature range to (500–700 °C) [7]. The hybrid copper–chlorine (Cu–Cl) cycle is a medium temperature cycle having 3 to 5 steps with different configurations including both thermochemical and electrochemical steps. This process is led by Argonne National Laboratory (ANL), Atomic Energy of Canada Ltd (AECL), and Atomic Energy

Table 1 – Nuclear reactors and their specifications for hydrogen generation (Adapted from Ref. [6]).

Reactor type	Coolant	Reactor coolant temperature (°C)	Reactor size range (MWt)	Hydrogen production route
Light water reactors (PWR, AP, EPR)	Light water	280–325	2000–4080	Water electrolysis
Heavy-water reactors (CANDU, ACR)	Heavy water	310–319	2000–3200	Water electrolysis
Supercritical water reactor (S-LWR, CANDU, SCWR)	Light water	430–625	1600–2540	Water electrolysis, Thermochemical
Liquid metal fast reactors (SFR, LFR)	Sodium: lead: lead bismuth	500–800	45–3000	Water electrolysis, Thermochemical CH_4 reforming
Molten Salt Reactors (AHTR)	Salts	750–1000	900–2400	Water&steam electrolysis, Thermochemical CH_4 reforming
Gas-fast Reactors (GFR)	Helium	850	600–2400	Water&steam electrolysis, Thermochemical CH_4 Reforming
High-Temp. Reactors (HTGR, VHTR)	Helium	750–950	100–600	Water&steam electrolysis, Thermochemical CH_4 reforming

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