Design and operation of renewable energy sources based hydrogen supply system: Technology integration and optimization

Wangyun Won a,1, Hweeung Kwon b,1, Jee-Hoon Han c, Jiyong Kim d,*

a Department of Chemical and Biological Engineering, University of Wisconsin-Madison, 1415 Engineering Drive, Madison, WI, 53706-1607, USA
b Department of Chemical and Biomolecular Engineering, Yonsei University, 50 Yonsei ro, Seodaemun-ku, Seoul, 120-749, Republic of Korea
c School of Chemical Engineering, Chonbuk National University, 567, Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do, 561-756, Republic of Korea
d Department of Energy and Chemical Engineering, Incheon National University, 119, Academy-ro, Yeonsu-gu, Incheon, 406-772, Republic of Korea

ARTICLE INFO
Article history:
Received 23 February 2016
Received in revised form 10 November 2016
Accepted 17 November 2016

Keywords:
Renewable energy
Hydrogen
Technology integration
Optimization
Korea

ABSTRACT
The benefits of hydrogen as a clean and efficient fuel can be realized fully only when hydrogen is produced from renewable energy sources (RES). In this study, a new methodology is proposed to identify the optimal configuration and operation of an RES-based hydrogen supply system. The key is a superstructure-based optimization model using mixed-integer linear programming (MILP), which can integrate multiple resources and various technologies, such as electricity generation (e.g., wind turbine, photovoltaic panel, and dish-stirling power systems) and hydrogen production technologies (e.g., water splitting using alkaline electrolyzer and biomass gasifier), to minimize the total annual cost. The performance of the proposed methodology was validated through an application study on Jeju Island, Korea. In the case study, process economics and main cost drivers were analyzed. In addition, the effect of integration of technologies along with different resources on the economics was discussed.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

The depletion of fossil fuels and effects to the environment from consuming them have stimulated global interests in a sustainable energy system. The current carbon-based energy system should be switched to a new energy system that can balance energy supply demand, protect the environment, and ensure energy security and economic viability. Among various alternatives, hydrogen-based systems are one of the most promising solutions to succeed the current system.

The main advantage of hydrogen as an energy carrier is the diversity in production of primary resources. Hydrogen can be produced from not only nonrenewable energy sources, such as oil, natural gas, and coal, but also renewable energy sources (RES), including wind, biomass, and solar energy. This diversity in production source contributes significantly to balancing energy supply and demand and ensuring energy security.

Employing RES for hydrogen production is central for better transition to a sustainable hydrogen economy because hydrogen is a low- or zero-emission energy from the end user's perspective [1]. For instance, the use of hydrogen in fuel cell vehicles (FCV) offers a number of advantages over using conventional transportation fuels; e.g., better fuel economy and lower greenhouse gas and air pollutant emissions [2,3]. To successfully implement the RES-based hydrogen production system, it is essential to analyze the features of the system components (e.g., RES potentials and conversion technologies) and their interactions and to design new future hydrogen systems with suitable technologies [4]. In particular, the economic viability of the RES-based hydrogen production system depends strongly on identifying the optimal configuration of the integrated system. Thus, one of the challenging questions for design of RES-based hydrogen production systems is which energy sources and what configuration should be selected with what capacity for regionally different potentials for RES and hydrogen demands?

Many studies have explored the design and integration of RES-based hydrogen production systems. Several authors have assessed the availability and potentiality of RES for hydrogen production using the approaches based on geographical information system (GIS) [5–9]. Also, researchers have developed approaches and models for the development of hydrogen production and supply systems, which range from the supply chain and infrastructure design [10–12] to a focus on the components of the
The technologies considered in this study are classiﬁed into three main groups: electricity generation, hydrogen production, and hydrogen supply. Each is described in detail below.

2. RES-based hydrogen supply system

The RES-based centralized hydrogen supply system is composed of various conversion technologies along with corresponding mass (e.g., water and biomass) and energy (e.g., electricity) ﬂows. To provide a holistic view for the possible system conﬁgurations, a superstructure, which is a network-based representation, is considered (Fig. 1).

In the RES-based hydrogen supply system, ﬁve primary resources are considered: wind, solar light, solar heat, biomass, and sea water. These resources are used to produce necessary energy (i.e., electricity) and material (i.e., water) or directly converted to hydrogen. To estimate the potentials of the RESs, meteorological data, such as wind speed, solar radiation, and availability of biomass, is used. Note that the biomass in this study indicates a lignocellulosic feedstock including crop residues and woody wastes, to avoid the conﬂict between energy and food production [27].

The technologies considered in this study are classiﬁed into three main groups: electricity generation, hydrogen production, and hydrogen supply. Each is described in detail below.

2.1. Electricity generation

For the PV system, the ﬂat plate type, which consists of a PV array and direct current (DC)-to-alternating current (AC) inverter, is considered [28]. For the solar power system, which uses concentrated solar thermal energy for electricity generation, the central tower and the dish-stirling power systems are considered. The central tower system consists of a heliostat ﬁeld (focusing solar thermal energy onto a receiver at the top of the tower), central tower, receiver, and steam generation plant [29]. The dish-stirling system consists of a parabolic dish, receiver, and stirling engine. The collector focuses solar energy on the receiver, which transfers heat to the engine to work for driving an electric generator [30]. The bio power system, which is very similar to a coal-ﬁred power plant, consists of various preprocessing processes (e.g., handling, size reduction, and drying), a combustor, a steam turbine, and an electricity generator [31]. Finally, ﬁve types of wind turbines are considered according to the power rate by blade diameter and tower height.

2.2. Hydrogen production

The electricity, generated by the wind turbine, PV, bio power, and solar power technologies, is used for the production of hydrogen via electrolysis technology. In this study, one type of technology, i.e., an alkaline electrolyzer, which is the most extensively used type in modern industry due to its various advantages (e.g., energy-efﬁcient and scalable enough for mass production), is considered [32–34].

Thermochemical water splitting using solar thermal energy is also an attractive technology for large-scale production of hydrogen. Its simple processing principle leads to high energy conversion efﬁciency [4,35,36]. Among various types of thermochemical water splitting technologies, the Counter Rotating Ring Receiver Reactor Recuperator (CR5), which is an innovative solar thermochemical heat engine with high efﬁciency in solar-to-chemical conversion, is selected [36,37]. The CR5 can be built up with ﬂexible capacity according to production strategy [38]. Whereas the CR5 is initially developed for carbon dioxide splitting to carbon monoxide production, it is also very efﬁcient for water splitting [39].

Regarding the biomass gasiﬁcation for hydrogen production, two types of technologies are considered: an oxygen-blown direct ﬁred entrained ﬂow (hereafter referred to as direct gasiﬁer) and indirectly heated air blown, atmospheric ﬂuidized bed (henceforth referred to as indirect gasiﬁer) [40]. The required oxygen in a direct gasiﬁer can be supplied from either water electrolysis or thermochemical water splitting technologies. Both biomass gasiﬁcation technologies include not only a gasiﬁer but also various processes that follow, such as gas clean-up, reformation, water gas shift reaction, and pressure swing adsorption [33,41,42].

2.3. Hydrogen supply

After production, the hydrogen is brought to appropriate pressure and transported to a storing facility that has a series of tanks to be stored as compressed hydrogen (CH2). Finally, the CH2 is delivered from the storage facility to the customer, to satisfy hydrogen demand.

3. Technology modeling

3.1. Electricity generation technology

3.1.1. Wind turbine

The energy output generated by a wind turbine is dependent mostly on the mean wind speed at the location. To represent the behavior of the wind (i.e., the frequencies of the wind speed)
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات