The prospect and challenges of renewable hydrogen production in Iraq

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Abstract The energy demand in Iraq has increased in the past decade as a result of growth in population and industrialization. Although, most of the energy demand is being met using energy derived from fossil fuels, which are fast depleting and have the problem of emission of greenhouse gases when combusted. Recently, there have been an increasing awareness in the quest for alternative source of cleaner and sustainable energy production. One of such alternatives is hydrogen energy, which has been tagged as the energy of the future with zero-emission when combusted with oxygen. Moreover, hydrogen has wide applications in electrochemical cells for electricity production or as fuel in internal combustion engines for powering vehicles. The present study gives an overview of the prospect and challenges of renewable hydrogen production in Iraq. Moreover, the availability of the different feedstocks for the production of renewable hydrogen as well as the state-of-the-art in Iraqi context were examined. The prospect and challenges in the production of renewable hydrogen in Iraq were also presented.

Keywords Biomass; Renewable hydrogen; Iraq; Natural gas; Reforming;

1. Introduction

Iraq is well known as one of the leading oil producers in the world with proven large reserves. Most of the energy demands in Iraq are met primarily from energy derived from fossil fuel due to high dependence on crude oil [1]. Several efforts via policy formation have been made by the government to increase energy supply through natural gas and renewable energy. Iraq has high potential of solar, wind and biomass energy resources[2]. The government target is to increase the share of energy from renewable sources to 10% by 2020 [3]. Presently, electricity generation in Iraq is mainly from oil, gas and hydropower [4]. Besides, the electricity demand is augmented with import from Iran and Turkey [4]. Due to the vast solar energy resources, the government can develop part of the energy mix around solar energy [5]. In addition, the great potential of offshore wind power around the Arabian Gulf could also be a huge contribution to the energy mix [6]. Most importantly, the huge biomass resources can be harnessed for production of other sources of renewable energy such hydrogen.

The consideration of including hydrogen energy in Iraq energy mix has several advantages. Hydrogen energy is the cleanest and most efficient source of energy [7-8]. The use of hydrogen fuel cells for energy production is more efficient and cleaner compare to the conventional fossil-based engines and power plants [9-10]. Hydrogen energy find wide applications to power vehicles and other
domestic energy demands [11]. The utilization of hydrogen energy has zero emission thereby reducing the emission of greenhouse gases, which is a major challenge in the utilization of energy from fossil sources [12]. In line with the several advantages of utilizing hydrogen energy as part of the energy mix, the present study investigates the prospects and challenges of renewable hydrogen production in Iraq. The study begins with an overview of renewable energy potential in Iraq. This was followed by an overview of the sources and potential state-of-the-art production of renewable hydrogen in Iraq. A glimpse of the potential of Hydrogen production from Natural gas in Iraq was also reviewed. Finally, the potential of hydrogen production from biomass in Iraq was also considered.

2. Overview of renewable energy potential in Iraq

Iraq has abundant renewable sources such as wind, solar, biomass and geothermal. Although, these renewable energy sources have been utilized to its full potential. However, studies have shown that renewable energy in 2015 accounted for about 0.8% of the total energy consumption in Iraq [13]. The use of renewable energy potential in Iraq are discussed in the next section.

2.1 Solar energy

Several yearly reports by Iraqi meteorologist organization (IMO) revealed that there is a lot of solar resources in Iraq [1]. However, the solar radiation varies depending on the geographical location. Study have shown that the central Iraq receives more sunshine that the northern part [14]. Also, the southern part has been reported to also receive one of the greatest amounts of solar radiation in the world. The map showing the photovoltaic power potential in Iraq, Iraq global horizontal irradiation, and the Iraq direct normal irradiation are depicted in Figures 1-2. The photovoltaic power potential map shown in Figure 1 is employed to evaluate the amount of electricity in KWh that can be generated from 1 KWP free-standing crystalline silicon (c-Si) modules, optimally inclined towards the Equator. In general, the solar resources map describes a glimpse of the estimation of the available solar energy for electricity generation and other energy applications. It usually denotes the mean daily/yearly summation of electricity production from a 1 KW-peak grid-connected solar PV power plant a particular period. The global horizontal irradiation map shows the estimation of the total amount of shortwave radiation received from above by a surface horizontal to the ground. The global horizontal irradiation data is essential for photovoltaic installations. The direct normal irradiation map shown in Figure 2(b) helps in the estimation of the quantity of solar radiation received per unit area by surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.

Figure 1. Photovoltaic power potential in Iraq (The World Bank, Solar resources data: Solargis, 2017)
2.2 Wind energy

Wind is one of the most significant sources of renewable energy. Studies have shown that wind energy is the most suitable, effective and a non-expensive sources of electricity generation. Based on the available research on the wind energy potential in Iraq, wind velocities in Iraq has been reported to be in the range of 5-10 m/s [15]. However, the values of the wind velocities vary depending on the region. Basically, Iraq is divided into three regions based on their wind velocities. The first region which is made of 48% of Iraq account for 2-3 m/s of the wind velocities. The second region is made of 35% of Iraq and accounts for 3.1-4.9 m/s of the wind velocities. While the last region which accounted for 8% of the Iraq accounts for 5 m/s of the wind velocities. A study by Mahdy and co-researchers revealed that wind speed is higher in Iraq at night compared to noon hours. Moreover, the wind speed often attained more than 10 m/s once in a day [2]. Due to fluctuation in the wind speed, there might be difficulties in the electricity generation by wind energy without a back-up battery.

2.3 Biomass energy

Biomass is an important source of energy, which is the fourth most abundant natural resource [16], it could be in the form of solid, liquid and gas. The solid biomass consists of organic, non-fossil-based materials. The liquid biomass includes the bio-based liquid obtained from the conversion of solid biomass. The gaseous biomass also known as biogas mainly consist of methane and carbon dioxide, which are often products of anaerobic digestion of biomass. On a broad note, the different forms of biomass resources, which include agricultural crops and residues, sewage, municipal solid waste, industrial residues, animal residues, and forest crops and residues are depicted in figure 3 [17]. Due to the arid nature of Iraq, the biomass energy source is majorly derived from municipal solid wastes, agricultural residues and industrial wastes. Studies have shown that there is a huge availability of biomass energy resources in Iraq [18]. However, due to the huge reserve of crude oil and natural gas, the biomass potential as sustainable source of energy production has been left untapped. Several researchers have investigated the potential of using biomass from dates and sugarcane as feed stocks for bio-ethanol production [19].
3. Sources and potential state-of-the-art production of renewable hydrogen in Iraq

Basically, hydrogen can either be produced from fossil-based sources or from renewable sources as shown in figure 4. The production of hydrogen from the fossil-based source include hydrocarbon reforming and hydrocarbon pyrolysis[20-21]. While the production of hydrogen from the renewable sources include thermochemical and biochemical conversion of biomass and water splitting [22]. Iraq has huge potential for hydrogen production from different naturally abundant sources such as natural gas and biomass.

3.1 Potential of Hydrogen production from Natural gas in Iraq

One of the important feedstocks for the production of hydrogen is natural gas which mainly consist of 98% methane. In Iraq, there have been increase in the production of crude oil which often co-produced with associated gas. However, the associated gases are under-utilized and continuously flared. Based on world energy report, there is a large proven natural gas reserves in Iraq (Figure 5). As at 2016, the natural gas production in Iraq was estimated to be 900 ktoe and proven research of 3158 bcm. Rather than
consuming the large amount of the natural gas produced for electricity generation, hydrogen production could also be included into the energy mix using natural gas as feed stock.

![Graph showing natural gas production and flaring in Iraq](https://www.iea.org/publications/iraqenergyoutlook/)

**Figure 5.** Natural gas production and flaring in Iraq

Typically, hydrogen can be produced from natural gas using therm-ocatalytic means such as steam methane reforming, dry (CO₂) methane reforming, partial oxidative methane reforming, and photocatalytic reforming [20,24-25].

The steam methane reforming is well established technology used for the production of hydrogen. Over 45% of global hydrogen is produced by steam methane reforming. The steam methane reforming entails the utilization of steam at reaction temperature of 700-1000°C for the reforming of methane in the presence of a catalyst (mostly Ni-based catalysts). Beside hydrogen, other gases such as carbon monoxide and carbon dioxide are co-produced. The combination of the H₂ and CO often referred to as synthetic gas are important chemical intermediates for the production of liquid hydrocarbons and oxygenates via Fischer-Tropsch synthesis. A typical steam methane reforming reaction involve the main reforming Equation and the water gas shift reaction. One major challenges of the steam methane reforming are catalyst deactivation by sintering and carbon depositions. Research focus have been on the development of highly stable and active Ni-based catalysts for steam methane reforming.

The dry methane reforming entails the utilization of CO₂ for the reforming of methane in the presence of a catalyst at temperature range of 600-1000 °C. One major advantage of the dry methane reforming is the production of energy and the consumption of CH₄ and CO₂, the two principal components of greenhouse gases for hydrogen and syngas production. However, the dry methane reforming as a highly endothermic process which is also prone to catalyst deactivation by coke deposition. The dry methane reforming mainly consists of the reverse water gas shift reaction, the Boudouard reaction and the methane decomposition reaction.

Hydrogen and syngas production by the partial oxidative reforming is an exothermic reaction between methane and oxygen in the presence of a catalyst. Beside hydrogen that is produced in this process, syngas with H₂/CO ratio of 2 is also produced. One major advantage of the partial oxidative methane reforming over the other forms of reforming is the low energy requirement for the reaction. In addition, small amount of CO₂ is produced as co-products compared to other reforming processes.

The autothermal methane reforming is a relatively new reforming process that combined both the steam methane reforming and the partial oxidative methane reforming. The reaction usually occurs at temperature range of 1000-1500°C and pressure of 1-80 bar in the presence of a catalyst. The
thermodynamic advantage of the two processes are harnessed thereby bringing the overall enthalpy of the reforming process to zero.

3.2 Photocatalytic reforming
The abundant solar resources in Iraq can be harnessed for hydrogen production by reforming processes. Usually, a semiconductor such as TiO$_2$ are usually employed to absorbed photons with energy equal to or greater than the semiconductor band gap. Unlike the conventional reforming process, the photocatalytic reforming occurs at room temperature and atmospheric pressure.

3.3 Potential of Hydrogen production from Biomass in Iraq
Since there is a vast availability of biomass in Iraq, hydrogen production from biomass can be added to the energy mix. This can be achieved using the thermochemical routes for hydrogen production which include gasification and pyrolysis. In addition, the biological process can be employed to convert the municipal liquid waste to hydrogen and other syngas as shown in Figure 7.

3.4 Biomass gasification and pyrolysis
Biomass can be effectively converted to hydrogen using gasification and pyrolysis. Hydrogen production by biomass gasification involves the thermochemical conversion of biomass at high temperature (> 700°C) without combustion. Usually, the amount of oxygen or steam utilized in the process is usually controlled. Besides hydrogen, syngas is often produced during biomass gasification. Unlike gasification, biomass pyrolysis involves the conversion biomass at high temperature in the absence of oxygen. Usually, pyrolysis occurs in the first two minutes of gasification. During pyrolysis hydrogen alongside syngas, bio oil and chars are produced.

Figure 6. Biochemical and thermochemical route for biomass conversion [23]

The biological process for biomass conversion entails the breaking down of biomass molecules using microorganisms such as bacteria or enzymes. The rate of hydrogen production using the biological means is slower compared to the thermochemical route. Typically, hydrogen production by biological process can be categorized into direct biophotolysis, indirect biophotolysis, photo fermentation, and dark fermentation. The direct biophotolysis involve the process of utilizing solar energy resources for the conversion of biomass to hydrogen. In the process, the main feedstock is water. In the indirect biophotolysis, the H$_2$ and O$_2$ evolution in the direct biophotolysis are separated into two stages. The photo fermentation process utilizes photosynthetic bacteria for the production of hydrogen. While in dark fermentation, hydrogen is produced by anaerobic bacterial grown in the dark on carbon rich substrates.
4. Conclusion
In this study an overview of the prospect and challenges of renewable hydrogen production in Iraq has been investigated based on existing literature. The study revealed that there are vast renewable resources in Iraq mostly from solar, wind, biomass. These renewable energy resources have not been fully harnessed to increase the share of renewable energy in the country energy mix. Despite the great opportunity available for the development of renewable hydrogen from natural gas and biomass sources in Iraq, there are still several challenges that have hinder its development. One of such challenges is the lack of will and necessary government policy to back up the development of renewable hydrogen from the different sources as highlighted in this study. In the light of this, it is therefore proposed that necessary policy should be put in place by the government to accelerate the development of the renewable hydrogen production in Iraq. The production network starting from the feed stock sourcing to the hydrogen production must be guided by workable policies to achieve a realistic production process.

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