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Strategy for a sustainable development in the UAE through hydrogen energy

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ABSTRACT

Recently, it has been reported that United Arab Emirates is considered one of the highest energy consumers per capita in the world. Consequently, environmental pollution and carbon emission has been a major challenge facing the country over the past several years due to unprecedented high economic growth rate and abnormal population increase. Utilization of hydrogen energy to fulfill UAE's energy needs would be one of the key measures that the country could undertake to achieve a sustainable development and without any major environmental consequences. Hydrogen energy, which is an energy carrier, is consider by many scientists and researchers a major player in fulfilling the global energy demand due to its attractive features such as being environmentally clean, storable, transportable and inexhaustible. It can be used as a fuel in the proton exchange membrane (PEM) fuel cell, which is an electrochemical device that generates electric power and it can be utilized in various applications. Production of hydrogen energy can be carried out either through utilizing conventional resources or by renewable resources. Conventional resources such as crude oil and natural gas can produce hydrogen by steam-reformation while hydrogen can be produced from coal through gasification. On the other hand, hydrogen production through renewable resources can be achieved through biomass gasification, solar-hydrogen, wind-hydrogen and hydropower electrolysis process. Other renewable resources such as geothermal, wave, tidal and ocean thermal energy conversion (OTEC) can also contribute into hydrogen production but at a marginal level. In this report, a roadmap to achieve a sustainable development in the UAE through utilization of hydrogen energy is presented. The report highlights the potentials of energy resources that the country possesses with respect to both conventional and non-conventional energy and determines major resources that could significantly contribute to production of hydrogen energy. Moreover, the study will present three proposals where PEM fuel cells are introduced in the country's electricity, transportation and commercial sectors to fulfill its energy demand and achieve the desired sustainability as well as environmental and economical benefits associated with such schemes compared with business as usual.

1. Introduction

Since its independence in 1971, United Arab Emirates (UAE) took huge steps toward achieving a solid and sustainable economic growth as well as urban development. Subsequently, the population of the country has risen tremendously because of high urbanization and increase in the number of expatriates that are residing and working in various sectors throughout the country. Currently, the UAE with a total area of 84,000 km^2 has one of the most diversified economies of all the major oil-producing Arabian Gulf states. The economic diversification was carried out through implementation of several major projects in various sectors, including refinery and petrochemicals, tourism, banking, real estate, aviation and airports, re-export commerce, and telecommunications making the UAE to be the second largest economy in the Middle East. For instance, Dubai, which is one of the key emirates in the country has become a central hub for regional trade and finance, accounting for about 70% of the emirates' non-oil trade in 1998 [1]. Furthermore, free trade zones are established in all major emirates in order to provide a significant contribution to the gross domestic product (GDP).

According to Energy Information Administration (EIA), UAE's maximum crude oil production capacity is estimated to be around 2.5 million barrels per day (bbl/d). In addition, the country's natural gas production is estimated to be approximately 4 billion cubic feet per day (bcf/d). Generally, UAE plays an essential role in the world energy market because it possesses roughly 100 billion barrels of proven oil reserves, which is nearly 10% of the world's crude oil

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supply. Moreover, UAE possesses about 215 trillion cubic feet of natural gas, which is regarded the world's fifth-largest natural gas reserves after Russia, Iran, Qatar and Saudi Arabia [2].

With high economic and population growth rates and a fairly low energy cost, the country's energy consumption has risen tremendously in the past decades, making it one of the highest energy consumers per capita in the world. Consequently, environmental pollution and carbon emission has reached a record high. For instance, UAE's emission per capita was at least twice of the developed countries such as the United States and EU countries with an annual average emission of 10.5 tonnes carbon equivalent (TCE) per capita in the past 23 years period. Surprisingly, the world's annual average emission was at a marginal rate of 1.1 TCE per capita during the same period [3].

Many scientists, energy economists, and energy policy makers believe that hydrogen energy, which possesses significant attractive characteristics such as being environmentally clean, storable, transportable and inexhaustible, could play a key role in UAE's future sustainable development by meeting the country's future energy demand and without any environmental sacrifices. Hydrogen can be produced from either conventional energy resources (oil, natural gas and coal) or non-conventional energy resources such as nuclear, biomass, solar, wind energy, hydro energy and other renewable resources.

Hydrogen can be used in both liquid and gaseous forms. This energy carrier can be used to fuel a revolutionary device named proton exchange membrane fuel cell (PEM), used in major applications throughout the world. PEM fuel cell presented in Fig. 1 is a device that utilizes hydrogen as a fuel and oxygen to generate electricity through an electrochemical process and producing heat and water during the operation. A single fuel cell has no significant meaning due to its low power output. Therefore, several fuel cells are arranged in a stack to provide the desired electrical power. Presently, PEM fuel cells have demonstrated to gain worldwide attention due to their attractive characteristics such as being environmentally clean, low operating temperatures and achieve a quick response. Generally, this type of energy converter is used in transportation; stationary power for residential and commercial proposes and recently fuel cells are considered for aerospace applications [4].

Theoretically, a PEM fuel cell operates at any temperature ranging from 0 °C to 100 °C, although in practice this range is from 10 °C to 80 °C. The fuel cell's performance, which is described in terms of cell voltage and power density, is usually better at an elevated temperature due to a higher reversible voltage and a lower ohmic resistance, but activation and concentration overpotentials are somewhat higher [5]. Fuel cell's performance can be greatly improved if pure oxygen is utilized instead of a dry air, where oxygen accounts only 21% by volume. In other words, oxygen's partial pressure is about 5 times higher than oxygen in air, so that it causes a significant reduction in the overall electrochemical potential. Therefore, the performance curves of a fuel cell operating on air as an oxidant are different from the one operating on oxygen [6].

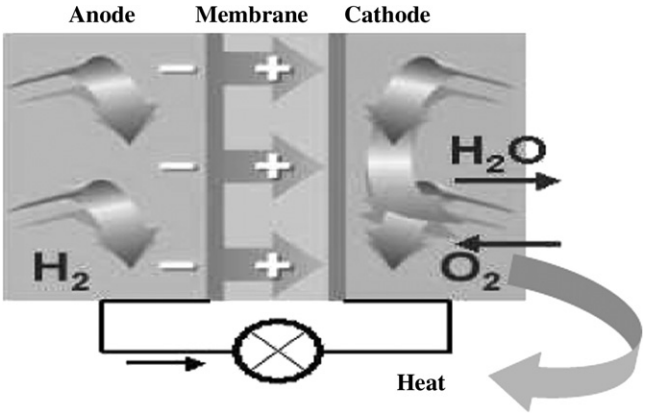

Fig. 1. Schematic diagram of a PEM fuel cell.

The objective of this report is to present a roadmap to achieve a sustainable development in the UAE through hydrogen energy. The report will highlight the potential of UAE's energy sources that possesses in terms of conventional and non-conventional energy resources and through which hydrogen could be produced and to determine major resources that could significantly contribute to production of hydrogen energy. Moreover, economical and environmental assessment of introducing hydrogen fueled PEM fuel cell in country's three major sectors namely commercial, power generation and transportation sectors are to be carried out as well.

2. Hydrogen energy production methods

2.1. Conventional energy

2.1.1. Coal

Hydrogen can be produced from coal through coal gasification where coal is converted into a gaseous mixture of hydrogen, carbon monoxide, carbon dioxide, and other compounds by applying heat under pressure in the presence of steam and a controlled amount of oxygen. The coal is chemically broken apart by the gasifier's heat, steam, and oxygen, setting into motion chemical reactions that produce a synthesis gas, or "syngas"—a mixture of primarily hydrogen, carbon monoxide, and carbon dioxide. Coal gasification can also be used to produce electricity by routing the syngas to a turbine to generate electricity. Coal gasification technology is most appropriate for large-scale, centralized hydrogen production. This is due to the nature of handling large amounts of coal and the carbon capture and sequestration technologies that must accompany the process. Unfortunately, this technology of hydrogen production method cannot be applied for the UAE due to lack of such fossil fuel in the country, which conversely has huge resources of oil and natural gas [7].

2.1.2. Crude oil

The United Arab Emirates, UAE is considered one of the world's foremost oil and gas-producing countries with approximately 10% of the world's proven oil reserves [2]. The United Arab Emirates since its independence in 1971 has been playing an important role in the organization of the petroleum exporting countries, OPEC, which is an international Organization of 11 developing countries that are heavily reliant on oil revenues as their main source of income. The country's current share of oil export is approximately 2.5 million barrels per day. However, recently it was proved that there is major limitation to OPEC's oil production resulting in its anticipated failure to meet world's abnormal growth in energy demand [8]. In addition, pricing of crude oil by linking it to the US $ has generated a sever loss to the UAE's economy [9].

It was estimated that hydrogen production capacity of world refineries is 1.15×10^{10} ft^3/day. Moreover, if hydrogen was burned as it was produced, the rate of energy release for the world's refineries would be 46 GW(t). In general, hydrogen is added to heavy crude oils to produce gasoline, diesel, jet, and other fuels.

For the high-quality crude oils, the energy value of the products (jet fuel, gasoline, etc.) exiting the refinery is −95% of that of the crude oil entering the refinery. Some of these crude oils would operate, with some difficulty, in a car engine without refining. In contrast, for low-grade, heavy, more-plentiful, and cheaper crude oils, the energy value of the products exiting the refinery is −80% of