RJBS
Romanian Journal of Building Services
Revista Română de Instalații
Volume 1 / No. 3 / 2015 / www.rjbs.ro

Implications of the Progressive Transition to Hydrogen Economy

Mohamad Y. Mustafa – Narvik University College, 8505 Narvik, (Norway)
Email: myfm@hin.no

Abstract: Transport and consumption of fossil fuels have contributed to global warming, environmental pollution such as oil spills, fossil fuel scarcity issues, rising prices of products etc. Hydrogen consumption, on the other hand, would not, since hydrogen can be produced by electrolyzing water and the latter is abundant and ubiquitous. In this paper, the importance and challenges facing the transition to a hydrogen economy are discussed. Hydrogen can be used in a direct conversion device to produce electricity with efficiency higher than that of the combustion process, and it has the potential to reduce the harmful emissions as the only by-product of the reaction of hydrogen with pure oxygen is water. The conversion device, which avoids combustion and uses hydrogen to directly produce work is the fuel cell. Fuel cells are still too expensive for commercial applications. Thus, any efforts to achieve these goals would be a significant contribution to promoting hydrogen technology.

1. Introduction

Replacing today's fossil fuel economy with a hydrogen economy would alleviate much of today's environmental and political problems. Transport and consumption of fossil fuels have contributed to global warming, environmental pollution such as oil spills, fossil fuel scarcity issues, rising prices of products etc. Transition to Hydrogen as energy source instead of fossil fuel, is prone to moderate all those problems, since hydrogen can be produced from water, which is abundant and ubiquitous, through an electrolysis process, with much less harm to environment.

Moreover, Proton Exchange Membrane (PEM) fuel cells, a key component of the hydrogen economy, produce only water as its byproduct, and therefore, greenhouse gases and other air pollutants would cease to be produced.

The science of fuel cells is well established, because the principles of operation of fuel cells were discovered even before the invention of the diesel engine, but the technology of making and producing fuel cells, at a wide range, is still at its early stages, and are well-kept secrets by the producing companies, which are still very few.

However, there are still many other challenges in the transition to a hydrogen economy. Infrastructure for producing and distributing hydrogen needs to be established, economical means for storing hydrogen need to be developed and, if PEM fuel cells are to supplant the internal combustion (IC) engine, PEM fuel cells need to be as (if not more) durable, efficient, economical, and powerful as IC engines. Our current endeavor aims to meet this last challenge.

The first step in understanding fuel cells is to understand the principles and materials used in making fuel cells. The second step is to improve the design of the fuel cell to produce a marketable product. Cost-effective and rapid improvement of current fuel cell designs require the talents of a diverse group of scientists and engineers: chemists and physicists are needed to understand the fundamental chemical and mechanical processes and their interactions, engineers are needed to produce improved designs and models so as to implement these models to optimize fuel cell performances and finally experiments are required to validate these models and designs. This paper aims to discuss the importance and challenges facing the transition to a hydrogen economy.

2. Energy Options

Our primary source of energy is fossil fuel in the form of coal, oil and natural gas. Other sources of energy such as solar, wind and wave energies may make a significant contribution to our needs, but this contribution would be very limited and is not expected to exceed 10% of the total demand for energy as projected by figure 1:

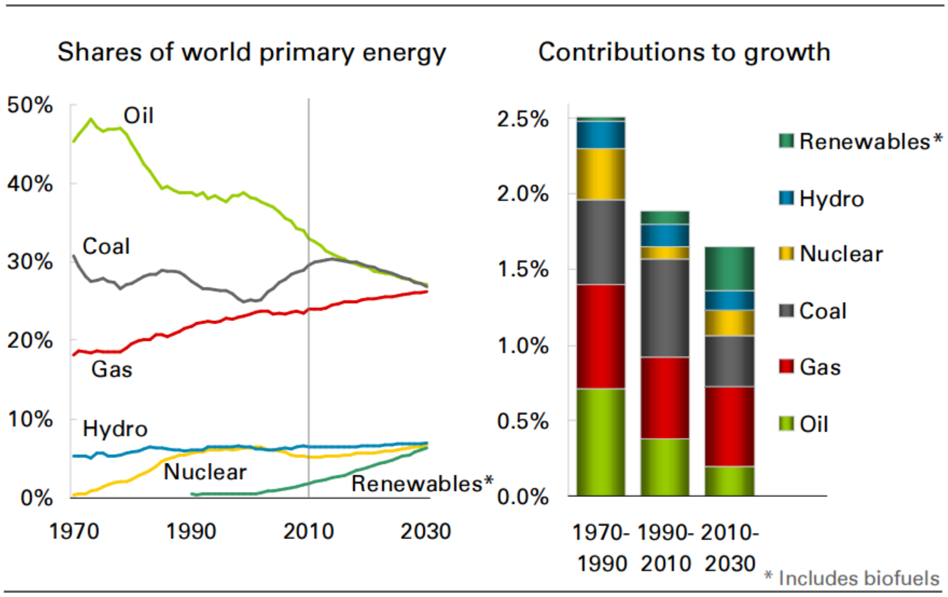

Figure 1 Energy Outlook 2030 [1]

Despite the fact that these predictions are not necessarily very accurate, and the trend of oil consumption could change due to social and political reasons, the fact remains that fossil fuels are running out at a considerable rate and views that they will finish in a specific number of years may differ, but there is no disagreement that they will be exhausted one day. In contrast, the demand for energy is growing due to the rapidly increasing population, rising standards of living and the emergence of new industrial economies [2].

Finiteness of fossil fuel resources is not the only problem. The use of fossil fuels has created other difficulties, mainly environmental pollution and global warming problems. Nevertheless, there have been some remedial efforts to reduce the impact of environmental pollution, such as the *Kyoto Protocol in 1997*, which compels industrial societies to gradually reduce the levels of production of harmful emissions, particularly carbon dioxide, in an effort to reduce the greenhouse effect causing the global warming dilemma and its predictable tragic consequences.

This, however, creates further problems, such as the increasingly stringent legislations directed to the control of harmful emissions. Yet, it fosters the efforts for exploring cleaner sources of energy.

In the light of these circumstances, it is very important to find a clean and reliable substitute for fossil fuels. Fuels produced from biological waste (bio-fuels) for instance, are becoming very popular; but considering the demand for energy in a typical power plant, such as a 500 MW power station, and considering the average efficiency of a power plant which is in the range of 40%, the necessary power supply for such a station is 1,250 MW, which means a consumption of nearly 32 kg/s of natural gas (the calorific value of natural gas is 10.83 kWh/kg) or nearly 62.5 kg/s of biofuels (taking the calorific value of sunflower oil; 5.56 kWh/kg, as an average value for biofuels) [3]. And considering an average yield of 1200 kg/acre of biofuel crops, it is obvious that enormous land area is needed to run a station of that moderate size.

Although plants grown for the production of biofuels may not be human food plants, increased plantation of biofuel plants occupies part of the agricultural land used for growing crops in addition to consuming water resources and affecting the wild life, not to mention the greenhouse gases that will be emitted in the process as a result of using fuels containing carbon. Furthermore, the biofuel solution would not be acceptable when the world is running out of food and, in terms of priority; agricultural land and water cannot be sacrificed for running cars when the majority of people are suffering the scarcity of food supplies.

The most abundant source of energy on planet earth is hydrogen; it is available in almost infinite quantities in water, which covers two thirds of the surface of earth, in hydrocarbons and it is part of every organic material, but it is not freely available as a substance due to its high reactivity with other materials. Hydrogen is distinguished by its high energy density and its clean reaction with oxygen in a combustion or oxidation process where the only by-product is water, which renews the cycle of hydrogen production.

Energy is required to extract hydrogen from hydrogen-rich materials such as the electrolysis of water or thermal cracking of hydrocarbons and, as such, the economy of hydrogen extraction has a direct impact on the energy efficiency of the system where it is used. However, the same argument applies to hydrocarbon fuels, and the comparison between the two should involve a well-to-wheels analysis.

Hydrogen is the smallest atom, and it is possible, using the appropriate type of catalyst, to divide it to an electron and a proton, which can be utilized in a fuel cell to generate electrical energy.

3. Fuel Cells and Heat Engines

The fuel cell, which is the subject matter of this research, is an electrochemical energy conversion device that converts the chemical energy of its inputs to electrical energy in a chemical reaction without the need to combustion, thus eliminating the high energy losses and harmful emissions which are usually combined with the combustion process.

The energy waste in the combustion process is an important factor that renders the efficiency of the process low; this is normally in the range of 28 - 45%; higher value in the case of heat recovery in a combined heat and power plant (CHP) or combined power and power plant (CPP).

The efficiency of a heat engine is limited by the rise in temperature which is limited by the Carnot efficiency. This implies that in order to achieve high values of efficiency, the heat engine has to be operated at very high temperatures; this has another disadvantage which is the production of Nitrogen oxides, which are likely to form at elevated temperatures.

Nevertheless, heat engines and particularly the internal combustion engine, are credited with being the workhorses of our modern-day civilization, however their main problems can be summarized as follows:

Whether they are operated on Hydrogen or hydrocarbon fuels, harmful exhaust emissions which pollute the environment will be produced. In the case of hydrocarbons, carbon monoxide, carbon dioxide and Nitrogen oxides will be produced together with water vapor. In the case of pure Hydrogen, Nitrogen Oxides will be produced at high temperatures together with water vapor. In both cases harmful emissions cannot be avoided.

They are limited by the Carnot efficiency and have to be operated at high temperatures; hence, a lot of the energy used in them is wasted. The pressure volume diagram below (Figure 2) shows the heat losses combined with the combustion cycle and Carnot efficiency.

The use of Hydrogen in a combustion process creates more problems that are technical. For instance, the blow-by gases containing water vapor will condense in the engine compartment and cause deterioration of the lubricating oil, which will reduce the life-time of the engine.

Heat engines are severely criticized for their nasty effect on the environment, added to this is the fact that they are dependent on the rapidly depleting resources of energy, which are not being utilized properly due to the poor efficiency of heat engines.

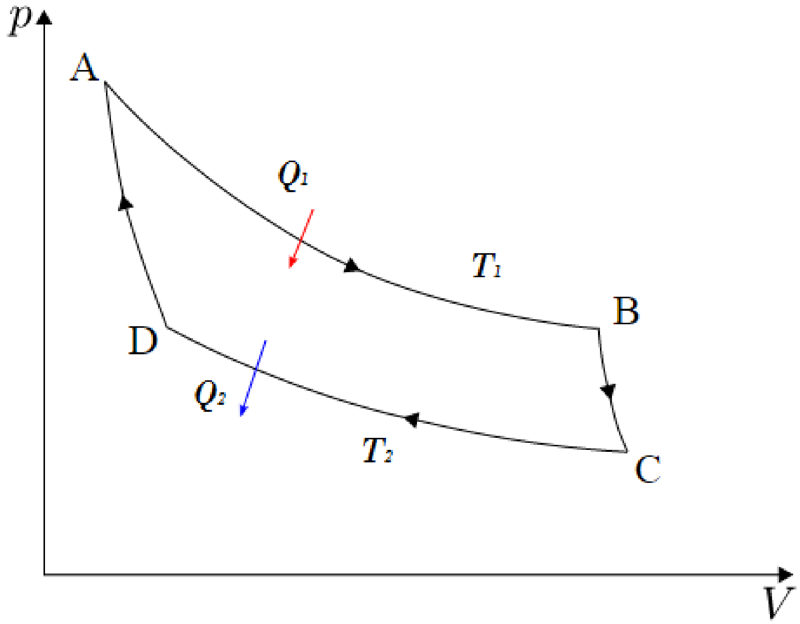

Figure 2 Pressure-Volume diagram of a combustion cycle and Carnot efficiency, T_1 and T_2 are isotherm lines, Q_1 and Q_2 refer to input heat and rejected heat respectively

The low temperature direct conversion process, in which hydrogen is chemically oxidized, is the best alternative to heat engines. In this process, the heat emitted to the surroundings, or in driving the reaction, is kept to a minimum. This method would meet the pressing need of humanity to find replacement methods of power generation and utilization, that can both reduce the amount of energy needed per unit time, i.e. power in terms of KWh, so as to conserve energy resources, and at the same time, protect the environment by reducing the amount of harmful emissions, and thermal loading i.e. greenhouse effects.

In fact, the fuel cell technology can overcome those difficulties; and pave the way for utilizing different sources of energy. However, the major challenge that scientists, particularly engineers, face with fuel cell technology is the cost of manufacturing, and this is the major issue that will be tackled in this research.

Fuel cells (FC) are emerging as power plants for the future, due to the desire to reduce impact of harmful emissions. There are many positive signs which support this orientation, the main development is the commercialization of Hydrogen fueled vehicles by major vehicle manufacturers around the world. This is also supported by the growing interest in establishing hydrogen-fueling stations to provide for the upcoming spread of hydrogen cars. In addition to automotive applications, fuel cells are being designed for aerospace, military applications, stationery power and small electronics appliances. Despite considerable research on FC technologies worldwide, progress towards commercial utilization of these technologies is slow. Several progresses have been made in new materials, and manufacturing techniques in the past decade, however FCs still demand significant technological advancements to achieve cost reduction and increased durability, to allow full exploitation of FC technology.

There are five major types of FCs based on the type of electrolyte used; polymer electrolyte membrane (PEM), solid oxide fuel cell (SOFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC) and molten carbonate fuel cell (MCFC). Operating temperature for each FC type is different and varies from low temperature of 80 ^oC for PEMFC to as high as 1000 ^oC for the SOFC. However, working principle of all FCs is similar, as they directly convert chemical energy in a fuel to electrical energy through an electrochemical reaction. In an FC device, ions are transferred through a membrane, while electrons are forced to flow around an external electric circuit. Due to its low temperature and easy start-up, PEMFC is the most preferred FC type for many applications.

4. Conclusion

Hydrogen has a major advantage over fossil and biological fuels. It can be used in a direct conversion device to produce electricity with efficiency higher than that of the combustion process, and it has the potential to reduce the harmful emissions as the only by product of the reaction of hydrogen with pure oxygen is water.

The conversion device, which avoids combustion and uses hydrogen to directly produce work is the fuel cell. Ever since its discovery in 1839 at the hands of the welsh barrister (Gentleman scientist) William Grove, fuel cells lay dormant until the early fifties when a clean, reliable and a highly efficient energy converter was needed for space missions that the fuel cells were brought to light again.

In today’s measures, fuel cells are still too expensive for commercial applications and many efforts are spent by the research community to bring their price down. Thus any efforts to achieve these goals would be a significant contribution to promoting hydrogen technology.

5. References

[1] BP Energy Outlook 2030 Washington, DC, 26 April 2011, http://www.eia.gov/conference/2011/pdf/presentations/Finley.pdf)

[2] Bhinder, F.S., et al., Parametric Study of the Combined Fuel Cell-Gas Turbine Power Plant. ASME Conference Proceedings, 2006. 2006(42398): p. 703-711.

[3] M. Y. Mustafa, "Design and manufacturing of a. (PEMFC) proton exchange membrane fuel cell," PhD. Thesis, Coventry University, May 2011. [Online]. Available: https://curve.coventry.ac.uk/open/file/272310c1-2614.../mustafacomb.pdf. [Accessed August 2015].