Introduction of Hydrogen produced by Renewable Energy into the Peruvian Electricity Market

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Abstract– Hydrogen energy is considered as the fuel of the future and it is already being introduced in the energy markets of more developed regions; however, it remains uncertain its potential impact in developing countries such as Peru. On the other hand, the Peruvian energy sector has being growing during the last decade but electricity production has also been shifting from a renewable energy source, such hydropower toward a fossil fuel namely natural gas. The paper examines the potential for hydrogen production from solar and wind power and also the potential substitution of natural gas by hydrogen produced by renewable energy sources. A potential carbon emission reduction is also estimated as a preliminary approach.

Keywords – Hydrogen Production, Renewable Energy / Peruvian Market / Electricity Generation / Carbon Emissions

I. INTRODUCTION

Energy is the very lifeblood of today's society and economy. Our work, leisure, and our economic, social and physical welfare all depend on the sufficient, uninterrupted supply of energy. Yet we take it for granted – and energy demand continues to grow, year after year. Traditional fossil energy sources such as oil are ultimately limited and the growing gap between increasing demand and shrinking supply will, in the not too distant future, have to be met increasingly from alternative primary energy sources [1].

On the technology front, hydrogen, a clean energy carrier that can be produced from any primary energy source, and fuel cells which are very efficient energy conversion devices, are attracting the attention of public and private authorities. Hydrogen and fuel cells, by enabling the so-called hydrogen economy, hold great promise for meeting in a quite unique way, our concerns over security of supply and climate change [1].

Even though all of the above has already been acknowledged by development regions, such Europe, there is still uncertainty as to whether or not hydrogen energy may be also an alternative for developing countries.

II. ENERGY SECTOR OF PERU

The energy sector in Peru has evolved during the last few years due to a continuous economic growth from 2001 to 2015, increasing at an annual rate of above 7.5%. [4]

A. Production and Reserves

The energy production in Peru is based on natural gas, hydropower, crude oil, and coal. In 2016, total energy production accounted for around 955 PJ while total energy reserves were established at about 36914 PJ. Natural gas is the main primary energy resource used in the country and represents nearly 79% of total energy production. However, in terms of energy reserves it represents about 54% of the total [4], as shown in Table I.

TABLE I
ENERGY PRODUCTION AND RESERVES FOR 2016 (TJ)

Energy Source	Production	%	Reserves	%
Natural Gas	753341	78.9%	19933761	54.0%
Crude Oil	85545	9.0%	2518249	6.8%
Hydropower	108719	11.4%	5965666	16.2%
Coal	7343	0.8%	230960	0.6%
Uranium	0	0	8265149	22.4%
TOTAL	954948	100%	36913785	100%

ADDAPTED FROM [4].

B. Energy Consumption

Energy consumption in Peru includes mainly electricity, hydrocarbons. Also, some biomass consumption is noted. Diesel Oil, which includes 5% of biodiesel, is the main energy source utilized in the country and accounted for about 32% in 2016. Also, electricity represented nearly 23% of the total in that year. Besides, both natural gas and liquefied petroleum gas accounted for around 11% of the total in each case. It is important to note that there is also a consumption of wood and it is nearly as significant as other energy sources and that amounts to about 11%. Moreover, there is also a consumption of gasoline, blended with ethanol, and accounts for over 10% [4]. In addition to that, there is also consumption of dung and yareta as energy sources, particular in rural areas of the country, as shown in Table II.

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TABLE II
ENERGY CONSUMPTION BY SOURCES FOR 2016 (TJ)

Energy Source	TJ	%	Energy Source	TJ	%
Diesel Oil / Biodiesel	227523	31.8%	Non energy products	11229	1.6%
Electricity	163325	22.9%	Fuel Oil	9687	1.4%
Wood	74797	10.5%	Dung and yareta	7174	1.0%
LPG	79569	11.1%	Bagasse	8665	1.2%
Motor Gasoline	11699	1.6%	Gasoline / Alcohol	71982	10.1%
Distributed Gas	79632	11.1%	Charcoal	1608	0.2%
Kerossene Jet	43450	6.1%	Coke	2477	0.3%
Coal	23286	3.3%	Solar Energy	1391	0.2%
TOTAL	714510			100.0%	

ADDAPTED FROM [4].

Energy consumption includes mainly transportation, residential, commercial and public, as well as industry and mining sectors. Energy consumption for Transportation sector accounted for around 45% of total energy consumption in 2016. Also energy consumption for Residential, Commercial and Public sector accounted for around 26% in the same year. Besides, energy consumption for Industry and Mining sector represented also about 26% [4], as shown in Table III.

TABLE III
ENERGY CONSUMPTION BY SECTORS FOR 2016 (TJ)

Sector	TJ	%
Transportation	369121	45.2%
Residential, Commercial and Public	209149	25.6%
Industry and Mining	208952	25.6%
Agricultural, Agroindustry, and Fishing	16949	2.1%
Non Energy	13319	1.6%
TOTAL	817490	100.0%

ADDAPTED FROM [4].

The following figure shows the participation of different sources and sectors in the energy mix [4].

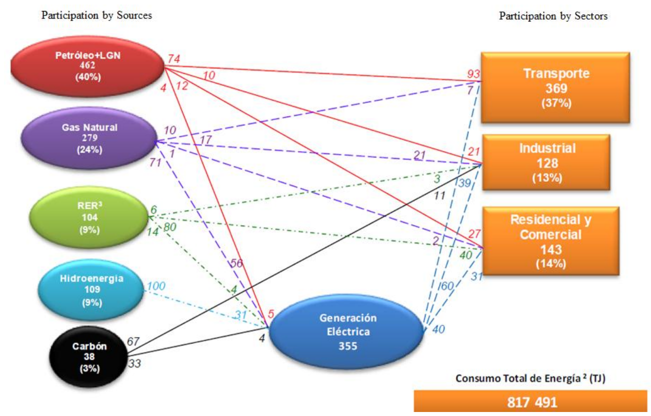

Fig. 1 Peru´s energy mix in P¨J for 2016. [4]

C. *Electricity Production*

Electricity production in Peru includes power plants that run on natural gas, hydropower, fuel oil, coal, diesel oil (with 5% biodiesel added), bagasse, wind, and solar energy. In 2006, around 56% of electricity was produced by natural gas power plants. Also, hydropower plants participation accounted for nearly 31% of the total. It is important to mention that almost 15 years ago, hydropower plants participation was over 90% of the total electricity production. Participation of renewable energies for electricity production is still at an incipient stage and accounted for less than 5% of the total. Moreover, it should be noted that overall energy efficiency associated with electricity production is around 53% due to increasing participation of thermal power plants in total production. Also, Transmission and distribution losses represent around 10.6% of total electricity produced by power plants [4], as shown in Table IV.

TABLE IV
ELECTRICITY PRODUCTION BY SOURCE IN TJ FOR 2016

Energy Source	TJ	%
Natural Gas	199607	56.3%
Hydropower	108719	30.7%
Fuel Oil	6994	2.0%
Coal	12524	3.5%
Diesel Oil / Biodiesel	11048	3.1%
Bagasse	9583	2.7%
Biogas, Wind and Solar	6068	1.7%
TOTAL	354543	100.0 %
Generation Losses	168514	47.5%
Electricity Production	186029	52.5%
Distribution Losses	19731	10.6%

ADDAPTED FROM [4].

Also, considering a coefficient of 0,56 tC/MW.h [9] for the electric power system in Peru, total carbon emissions would amount to about 29 million tons per year.

D. Peak-Time Electricity Dispatch

With regard to peak-time electricity dispatch, in March 2018, a total peak demand of 6389 MW was registered at 19:30 hrs. At that time, economic electricity dispatch was composed by hydropower (63%) and natural gas (63%) power plants. Also, at that time, renewable energy production contributed with over 4% for peak total demand [8], as shown in table V.

TABLE V
ELECTRICITY DISPATCH AT PEAK-TIME DEMAND IN TJ FOR MARCH 2018

Energy Source	%
Diesel Oil	0.00%
Fuel Oil	0.00%
Coal	0.00%
Natural Gas	33.36%
Hydropower	62.55%
Biogás	0.12%
Bagasse	0.22%
Solar	0.00%
Wind	3.75%
TOTAL	100.00%

ADDAPTED FROM [8].

III. HYDROGEN ENERGY

Hydrogen is not another fuel. It has physical and chemical properties very different from the other fuels. It is not a natural resource but it is encountered combined in other compounds such as hydrocarbons or water [2].

Actually hydrogen is an energy carrier which means that it has to be produced from energy resources, containing certain amount of energy once produced [2].

Hydrogen requires a final conversion element which may be a direct or an indirect one. A fuel cell is a direct energy conversion system, transforming chemical energy of hydrogen into electric energy. Internal combustion engines transform the chemical energy of hydrogen into mechanical energy, which may be used to drive a generator or for moving a transportation system [2].

A fuel cell shares common elements with both batteries and internal combustion engines. Thus, fuel cells are similar to batteries due to electrochemical principles that rule both of them, obtaining two devices in direct current (DC). On the other hand, fuel cells differ from batteries in the sense that they do not storage energy. Instead they transform the chemical energy of hydrogen into electricity in a continuous way, terminating electricity production once hydrogen supply is terminated. Such continuous electricity production characteristic is common to internal combustion engine, although they are subject to the Carnot limit and the fuel cell is not [2].

A. Hydrogen Production

There are various methods for hydrogen production and they can be both centralized and massive squemes as well as decentralized ones [2].

A designation of chemical conversion may be applied to both fossil fuels (coal and hydrocarbons) and renewable energy (biomass). The main processes include: reforming (with water vapor, partial oxidation, auto-thermal reforming), pyrolysis, and gasification [2].

In all of the above process, CO_2 is produced in higher or lower levels, and it is feasible its capture. This capture may become necessary if the process is intended to be applied to a fossil fuel in order to achieve an environmental cleaning associated with hydrogen. If the process is applied to biomass the capture of CO_2 would produce a negative emission of CO_2 although the economic cost may not be justified [2].

Within the above context, renewable energy appears as an attractive alternative for hydrogen production. Even though solar energy most common application is at high temperature, it is also possible to utilize solar photovoltaic modules for low temperature electrolysis production. Also hydrogen production based on wind energy utilizes low temperature electrolysis and it may be considered a feasible technology [2].

Similar to production processes, there are several procedures for hydrogen storage. Hydrogen stores a large quantity of energy per mass unit, but a very small one per volume unit. That is why there is an active field of research focusing on how to increase volumetric density of the procedure [2].

Once hydrogen is stored it is possible that the end user requires a distribution service which is a function of basically both the consumption and the needs [2].

It does not exist a fuel that is exempted from certain risks. In fact, the properties that turn a substance into a good fuel (high heating value) are the same properties that turn it into a potential dangerous substance. As a general rule, the better a fuel is the more the safety measures required to handle it. And hydrogen is not an exemption [2].

The following figure shows potential energy sources for hydrogen production [1].

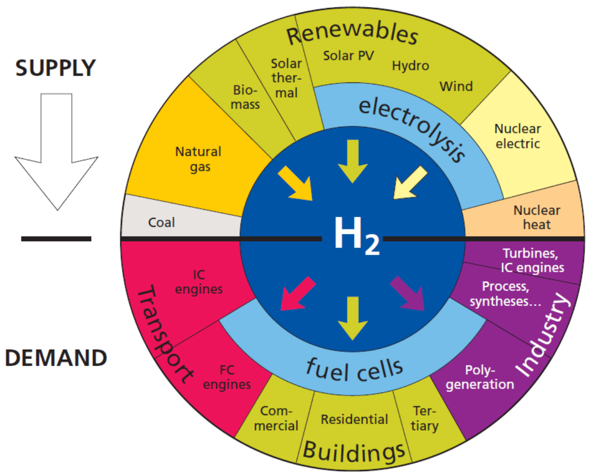

Fig. 2 Hydrogen: primary energy sources, energy converters and applications. [1]

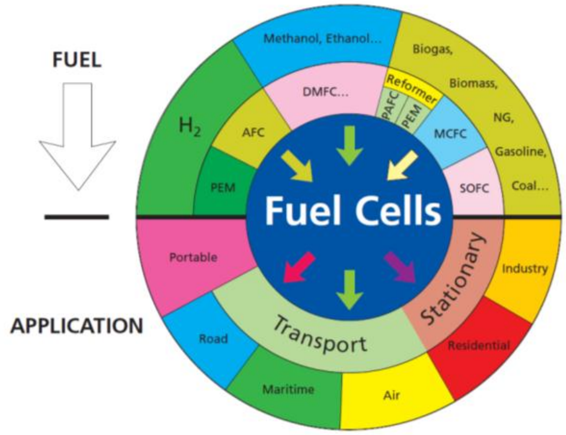

Fig. 3 Fuel cell technologies, possible fuels and applications. [1]

B. Fuel Cell Technology

There are several criteria for fuel cells classification. A technical one is according to the electrolyte that they use, including: Proton-exchange membrane fuel cell (PEMFC), Alkaline fuel cell (AFC), Phosphoric-acid fuel cell (PAFC), Molten carbonate fuel cell (MCFC), Solid oxide fuel cell (SOFC) [2].

Another criterion could be their working temperature range, including: Low temperature (operating at 80°C), including PEMFC and AFC; Intermediate temperature (operating at 200°C) including PAFC and High temperature (operating between 650 and 1100°C), including MCFC and SOFC [2].

As a general rule, application of fuel cells of high and medium temperature are more adequate for stationary usages en which the power required ranges from 1 to 100 MW and useful life is estimated at 5 years. On the other hand, fuel cells of low temperature are more adequate for transportation applications, in power range of 10 to 200 kW and with a vehicle's autonomy between 300 and 500 km. Fuel cells of intermediate temperature can be also used for stationary applications of lower power (up to 10 MW), and those of low temperature can be used in stationary applications of reduced power (up to 5 kW) [2].

The following figure shows different types of fuel cell technologies that may be utilized [1].

IV. POTENTIAL FOR HYDROGEN ENERGY IN PERU

A. Potential for Hydrogen Production from Solar Energy

Peru has a high potential for solar power utilization. Since 2012, five solar power plants have already been operating showing capacity factors over 30%. According to [5], solar irradiation levels reach almost 7 kW.h/day-m^2 in the southern part of the country, wherein four 20-MWp and one 16-MWp have been installed through a bidding process that was conducted early in 2010. Also, 185 MWp more of solar power capacity is expected to be installed in 2018.

B. Potential for Hydrogen Production from Wind Energy

With regard to wind power utilization, Peru has also a high potential. Since 2014, three wind power plants have already been operating showing capacity factors over 60%. According to [6], wind velocity levels reach almost 11 m/s at about 80 m height in the mid-southern part of the country, wherein one 32-MW and another 98-MW power plants have been installed through the same bidding process that was conducted early in 2010. Also, one 30-MW and another 80-MW power plant have been operating in the northern part of the country with wind speeds over 10 m/s, also at 80 m height. In addition to that, 162 MWp more of wind power capacity is expected to be installed in 2018.

C. Potential for Substitution of Natural Gas by Hydrogen

Hydrogen is being pursued as a sustainable energy carrier for fuel cell electric vehicles (FCEVs) and as a means of storing renewable energy at utility scale. Hydrogen can also be used as a fuel in stationary fuel cell systems for buildings, backup power, or distributed generation. Blending hydrogen into the existing natural gas pipeline network has been proposed as a means of increasing the output of renewable energy systems such as large wind farms. If implemented with relatively low concentrations, less than 5%–15% hydrogen by volume, this strategy of storing and delivering renewable energy to markets appears to be viable without significantly increasing risks associated with utilization of the gas blend in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network [3].

Adding hydrogen to natural gas can significantly reduce greenhouse gas emissions if the hydrogen is produced from low-carbon energy sources such as biomass, solar, wind, nuclear, or fossil resources with carbon capture and storage (CCS). Any social or environmental benefits associated with sustainable hydrogen pathways could arguably be attributed to natural gas with a hydrogen blend component in proportion to the hydrogen concentration [3].

For illustration purposes, the potential for substitution of natural gas by hydrogen will be estimated at a blending proportion of 10%. Thus, considering the total natural gas consumed for electricity production in 2016 as 199607 TJ, the potential for substitution using hydrogen would account for about 19961 TJ. Now, considering an estimated coefficient of 15 tC/TJ for natural gas, carbon emissions could be reduced in nearly 300000 tons per year.

However, in Peru, according to Law Decree 1002, it is expected that renewable energy production should achieve up to 5% of total electricity production [7]. Thus, considering total electricity production in 2016 as 186029 TJ, renewable energy could produce electricity up to 9301 TJ. Therefore, there is still room for further development of renewable energy projects for electricity production.

V. CONCLUSIONS

The Peruvian energy sector has being growing during the last decade but electricity production has also been shifting from a renewable energy source, such hydropower toward a fossil fuel namely natural gas. In 2016, natural gas contributed in 56% to electricity production while hydropower contributed only with 31%.

According to local regulations, established in 2008, it should be expected that renewable energies can contribute with up to 5% of total electricity production. At present, that target has not been achieved.

Peru has high potential for utilization of renewable energy for hydrogen production. Solar power plants are operating and capacity factors over 30% while wind power plants are operating at capacity factors of nearly 60%.

It is estimated that if hydrogen produced by renewable energy could be blended into natural gas pipelines a potential carbon emission reduction of 300000 tons per year could be accomplished.

REFERENCES

[1] European Commission, "Hydrogen energy and fuel cells, a vision of our future", Directorate-General for Research, 2003.

[2] J. Linares and B. Moratilla, "El Hidrógeno y la energía, análisis de situación y prospective de nuevas Fuentes tecnológicas energéticas". Asociación Nacional de Ingenieros del ICAI, 2007.

[3] National Renewable Energy Lab, "Blending Hydrogen into Natural Gas Pipeline Networks: A review of key issues". Technical Report NREL/TP-5600-51995, 2013.

[4] Ministerio de Energía y Minas – MINEM, "República del Perú, Balance Nacional de Energía 2016". Dirección General de Eficiencia Energética, 2018.

[5] Ministerio de Energía y Minas – MINEM, "Atlas Solar del Perú". 2003.

[6] Ministerio de Energía y Minas – MINEM, "Atlas Eólico del Perú", 2016.

[7] RER Decreto Legislativo 1002, "Promoción de la inversión para la generación de electricidad con el uso de energías renovables", 2008.

[8] SINAC-COES, "Estadística de Operación 2016".

[9] The World Bank – Carbon Finance Unit, "Poechos I Project", 2018.