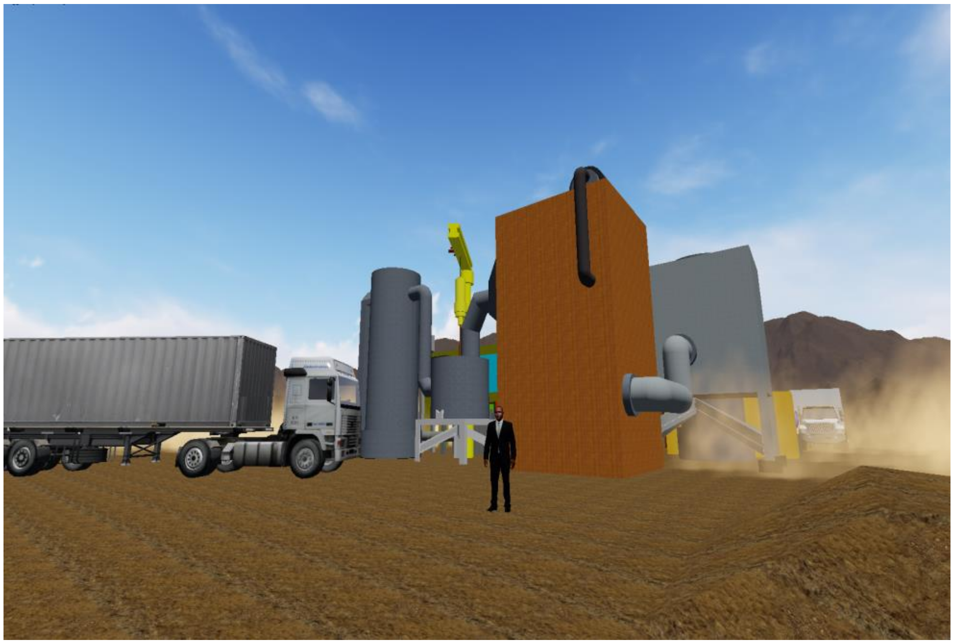
PTech: MSW for gasification to H2 and other gases.



DR. JOSÉ RAMOS SARAVIA

César Díaz Leigh, from UTEC (University of Engineering and Technology)
Sebastián Amaru Escalante Ccoyllo, from UTEC (University of Engineering and Technology)
EmIlio Roger Grandy Gonzáles, from UNI (National University of Engineering)
Juan Antonio Lorenzo Loo Kung Baffigo, from UTEC (University of Engineering and Technology)
Cynthia Mori Córdova, from UNI (National University of Engineering)
Fabian Mauricio Rivera Verde, from UTEC (University of Engineering and Technology)
Wilmar Huaccachi Herrera, from UNI (National University of Engineering)

Executive Summary

On Perú, treatment and elimination of municipal solid waste (MSW) is responsibility of local authority and Health Minister. At national level, on 2012 it has generated 4.68 millions of ton of MSW. In Lima, most of this waste is disposed in authorized landfills. However the rest of this waste does not have a good treatment and is incinerated. On one side, energy is a solution and at the same time a problem for a sustainable development, because of being necessary for everything, its current use constitutes the main source of contamination of the environment. Plasma gasification is one of the technologies which is being develop on the last years in order to give a potential use of this problem (MSW). On the other hand, hydrogen is a suitable fuel for refineries which uses it in their desulphurization processes. A combine facility of electrolysis and gasification by MSW could attend the hydrogen demand in a refinery. On the next pages, an evaluation of the technical and economical feasibility of the implementation in Peruvian refineries is made in order to produce hydrogen and other gases to be commercially sold [1].

Commented [1]: http://www.ods.org.pe/material-de-consulta/24-informe-anual-de-residuos-solidos-municipales-y-no-municipales-en-el-peru-gestion-2012/file

The present report is developed as an alternative of the problematic MSW bad treated in Lima. The report is compound by a methodology of 3 parts: Research-phase: where the team collects all the information available of the necessity on the refinery. On the design-phase: the team collects information about the technologies available on the market and how could this technology help us on the facility. Finally, on the post-design-phase, an evaluation of the environmental analysis, economics and legally are make to suggest a possible optimization and analyze if this implementation is feasible or not.

Table of Contents

1. 1. Introduction

Electricity supplying to peruvian energy market is based on hydroelectric (54,6 %), natural gas (40,5 %) , and renewable - solar and wind (less than 5%) - power plants [2]. It means that there is an opportunity for renewable energy - such as municipal solid waste (MSW) or biomass - to participate in the peruvian energy matrix. MSW can be converted to fuel (hydrogen, methane, etc.) and/or electricity.

On the one side, in Lima city (Peru), MSW production is 9 ton/day, and it will increase to 16 ton/day for year 2034 [3]. On the other side, some companies are hydrogen-intensive consumer, such as “La Pampilla” refinery, where hydrogen is fundamental to desulphurization processes. This refinery is located 1,5 km from the beach at the coast of Callao (Lima) refinery, which is located 1,5 km from the beach at the coast of Callao.

We will design a facility supplying hydrogen to “La Pampilla” refinery. The facility will integrate the following main processes: (i) water desalination from sea-water, to feed the (ii) electrolysis, to produce oxygen and hydrogen, (iii) plasma gasification to produce syngas using oxygen (from electrolyzer), and (iv) syngas cleaning, finally, a (v) methanation process to produce methane and other gases such as carbon dioxide and methane. All processes will use electricity from the public grid.

By-products (methane and carbon dioxide) of the facility will be commercialized locally.

2. 2. Project Design/Methodology

A three phase approach has been implemented to design the facility developed in this report:

(1) *Research phase:* Data collection. Information regarding the MSW availability, refinery’ hydrogen demand, equipment investment cost and technical specifications, and safety codes and standards were collected.

(2) *Design Phase:* Sizing equipment. Using technical/economic information, we select commercial equipment (plasma gasifier, electrolyzer, water desalinator) and evaluate different alternatives matching refinery’ hydrogen demand and MSW availability.

(3) *Post-Design Phase:* Environmental assessment and safety operation. In addition, educational material will be prepared.

3. 3. Conceptual Design

3.1. 3.1 General plant design

Our project proposes the addition of a facility plant that uses MSW plasma gasification technology coupled with water electrolysis in order to satisfy the oxygen necessary for gasification processes. This plant/process consists of an electrolyzer, which will provide oxygen for gasification process and hydrogen for the refinery and methanation processes. The plasma gasification reactor will produce the raw syngas. This raw syngas will pass through purification systems in order to bring high quality syngas. At the same time, supplied by the oxygen of the electrolysis process and the raw products of the gasification, methane reactor will produce other gases. Then, all hydrogen produced will be supplied to pipelines in the refinery to use it directly on their desulphurization processes. Other products such as methane and carbon dioxide will be storage and sold them locally.

3.2. 3.2 Seawater desalination

Seawater will be used as input of the oxygen and hydrogen production system. In order to preserve the electrolyzer in ideal conditions and to increase its efficiency a desalination system will pre-treat the water.

3.3. 3.3 Production of Hydrogen and Oxygen

Water electrolysis is used in order to separate hydrogen from water through electric current producing hydrogen and oxygen. Some of the most used technologies are proton exchange membrane electrolyzer (PEM), alkaline electrolyzer, electrolyzer based on solid oxides and reversible fuel cells.

Hydrogenics Inc. has been selected as the provider of the electrolyzer technology. According to an investigation made by ECS (Electrochemical Society) in 2010, the PEM technology is more advantageous than alkaline due his high efficiency. Thus, “HyLIZER 3000” of 15MW will be used. This equips counts with a 3000Nm3/h flow. Also, it can help to reduce the energy use of the compressor to storage the hydrogen due machine the exit press (until 35 bar). Besides the purity level obtained of the hydrogen is 99.998% [4]

This equipment will provide 50% of the oxygen required by the plasma gasification reactor while the remaining 50% will come from air separation unit.

The air separation unit extracts the necessary oxygen from air using pressure swing adsorption (PSA). This technology was chosen due to its high reliability, extensive use in other industries and low costs.

The hydrogen produced in this system will be utilized by the refinery covering the 50% of its demand. The other 50% will be send in a methanation reactor in order to produce methane

3.4. 3.4 Municipal Solid Waste treatment

MSW will be shredded and dehumidified in order to reduce the plasma torches energy consumption. A belt dryer will be employed due to its simple configuration; perforated belts through which hot steam passes. The hot steam will be produced in a heat exchanger where cold water receives heat from the hot syngas exiting the reactor, thus, no energy consumption will take place in the dehumidifier. Although these types of dryers have a lower moisture discharge capacity, they allow them to operate at low temperatures, thus avoiding unwanted emissions and risk of fire, reducing their cost.

3.5. 3.5 Plasma Gasification Reactor

Plasma gasification technology is established on the energy market more than 30 years [5]. Plasma gasification reactor will be employed to convert MSW to syngas (synthesis gas), which in turn will be used as desulfurization agent in hydrodesulfurization (HDS) and hydrotreatment (HDT) processes at La Pampilla refinery.

Commented [2]: http://www.globalsyngas.org/technology/plasma-gasification/

Commented [3]: http://www.globalsyngas.org/technology/plasma-gasification/

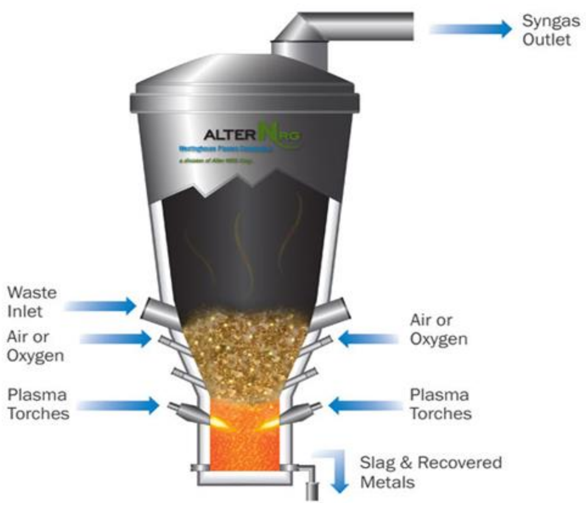


Figure 1. Plasma Gasificator by Westinghouse corp.

A Plasma Gasification Vitrification Reactor (PGVRN) from Westinghouse Plasma Corp was selected. PGVRN's technical specifications are shown in Table 1.

The hydrogen extracted from the syngas will cover 50% of the refinery demand, while the remaining part will be provided by the hydrogen produced in the electrolysis system.

3.6. 3.6 Purification Systems

3.6.1. 3.6.1 Syngas purification System

A Syngas purification system is a system that is used to obtain a clean syngas. Syngas typically requires some level of cleanup in order to meet specific requirements for downstream processes. This includes removal of particulate matter, sulfur compounds, chlorine compounds, unreacted hydrocarbons, and heavy metals. These contaminants can plug up reactors, cause corrosion, poison downstream catalysts, or prevent the plant from complying with environmental permits

3.6.2. 3.6.2 Hydrogen Purification System

A hydrogen purification system is a system that is commonly used to obtain a degree of purity of our final product that is hydrogen. But to be able to choose a purification system it must be observed what its use will be, because of this there are these types of systems. First we have of Pressure Swing Adsorption (PSA). With this technology, they can be achieved very high purity hydrogen. Currently it is the most widespread process in any type of refinery for the purification of hydrogen in a steam reforming process due to the high purity with which it is obtained. PSA is a very complex cyclic process that uses fixed beds of solid adsorbent to remove impurities from the gas. These impurities are retained in the adsorbent. There is also the membrane separation system based on selective permeability and separation by cryogenic systems. These systems are not widely used because the hydrogen comes out with a lower percentage of impurity than the PSA method and also are not widely used due to their high investment costs and, above all, their operation.

Our system removes oxygen from hydrogen via a catalyst to get high purity H_2 after adsorption of drying through the dusty filter. Through one step of purification, the purity can reach to 98-99.999% and dew point can be lower than - 70°C; Through a second purification step, O_2 can be lowered down to less than 0.1 ppm and dew point can be lowered to -90°C [6].

Figure 2. Hydrogen purification system

Their properties are listed below:

H2 capacity	10-5000 Nm3/h
H2 purity%	>98-99.999%
Dew point	<-60°C
Work pressure	0.2-4.0 MPa

Table 1. Hydrogen purification system: Technical characteristics

3.7. 3.7 Methanation reactor

Methanation refers to produce methane by a hydrogenation of carbon monoxide or dioxide. Synthetic methane can be produced by 2 different types of methane reactors: biological and catalytic. In this case, catalytic reactor has been chosen by his importance in the industry and is commonly used in power-to-methane processes. The results efficiency is limited by Sabatier reaction with a maximum efficiency of 80%.

In research papers catalytic reactors can be found as a complex set of different equips that makes this process. Specifically, Outotec GmbH gives an estimated flow and cost of the complete set [7]. Specific technical characteristics are not available for this equip. Nevertheless, some data such as production and an approximately cost by their final product has been rescued. The flows and cost has been used in our calculations for the necessary input and therefore for the output.

The hydrogen required by this process will be provided by the electrolyzer while the monoxide and dioxide will be extracted from the syngas. Remaining monoxide and dioxide can be sell to other local consumers like cement producers.

Commented [4]: https://www.sciencedirect.com/science/article/pii/S0960148115301610

3.8. 3.8 Distribution

3.8.1. 3.8.1 Clients

Refineria La Pampilla will be provided with all the hydrogen from the gasification and electrolysis processes in order to use this in the fuel desulphurisation (gasoline, naphtha and diesel). Also we will store the methane gas in bottles to be sold, it is worth mention that the cost of production is less than the conventional since we will obtain it by solid waste gasification. This methane gas has various applications given that is the main component of natural gas in a proportion of 70-90 of 100 percent. It could be used in food processors, petroleum refineries and others [8].

Commented [5]: https://sciencing.com/uses-methane-natural-gas-6134860.html

4. 4 Technical assessment

In the following subsections the main parameters of the equipment and processes are listed.

4.1. 4.1 Seawater desalination

Seawater inlet flow rate	12.168 ton/h
Desalinated water outlet flow rate	24.336 ton/h
% of Desalinated water	50%
Power consumption	7.3 kWh/m3 of desalted water (768,81 MWh/year)

Table 2. Seawater desalination technical characteristics

4.2. 4.2 Oxygen production

Participation in O2	50.0%
H2O inlet flow rate	9.8568 ton/h
H2O converted	81%
O2 outlet flow rate	8.7624 ton/h
H2 outlet flow rate	1.0944 ton/h
H2O outlet flow rate	2.3112 ton/h
Power consumption	5 kWh/ Nm3_H2 (531321.07 MWh/year)

Table 3. Technical specification of oxygen production

4.3. 4.3 MSW treatment

MSW inlet flow rate	17.02 t/h (146378.88t/year)
Inlet humidity %	44%
Outlet humidity %	17.81%
MSW outlet flow rate	12.56 t/h (108037.17t/year)
Shredder power consumption	360 kW
Dehumidifier power consumption	0 kW
Annual treatment power consumption	3119.04 MWh

Table 4. Technical specification of the MSW treatment

4.4. 4.4 Raw Syngas production

% participation in H2 for refinery	50%
MSW inlet flow rate	12.56 t/h (108037.17t/year)
O2 inlet flow rate	17.5212 ton/h
Plasma torch air consumption	4.3128 ton/h
Vitrified outlet flow rate	3.15 ton/h
Syngas outlet flow rate	35.712 ton/h

Power consumption	144 kWh/ton_MSW(21234.68 MWh/year)

Table 5. Technical specification of syngas produced

4.5. 4.5 Raw Syngas cleaning

Raw syngas inlet flow rate	35.712 ton/h
Clean syngas outlet flow rate	35.352 ton/h
% extracted matter	1%
Power consumption	3 MW (25992 MWh/year)

Table 6. Technical specification of the raw syngas

4.6. 4.6 Hydrogen extraction

Syngas inlet flow rate	35.352 ton/h
% mass of hydrogen in syngas	1.76%
% rescued hydrogen	80%
Hydrogen outlet flow rate	0.4968 ton/h
Syngas residue outlet flow rate	34.8552 ton/h
Power consumption	15 MW (134078.11 MWh/year)

Table 7. Technical specification of hydrogen extraction

4.7. 4.7 Methane production

Hydrogen inlet flow rate	0.7236 ton/h
Syngas residue inlet flow rate	34.848 ton/h
Produced methane	1.67202 ton/h

Table 8. Technical specification of methane production

5. 5. Economic, Environmental and Safety Analysis

The economics, environmental and safety analysis is a crucial part in order to comprehend if the use of a new technology or implementation is feasible or not. Due this, is important make the next review:

5.1. 5.1 Investment costs

In order to have a better understanding of the prices, it was considered convenient to place the quotation of each of our equipment in a table in which it indicates the price and previous specifications.

Equipment	Cost per unit (USD)	Quantity	Cost (USD)
Desalinator	197,901.04	1	197,901.04
MSW dryer and triturator	237,736.9	1	3,450,974
Electrolyzer	38,690,295	3	116,070,885
Plasma Gasifier	27,454,076	1	27,454,076
Syngas Purification System	45,369,423	1	45,369,423
Hydrogen Purification System	192,000,000	1	.92,000,000
ASU-PSA	27,454,076	1	27,454,076
Methanation Reactor (complete system)	4,423,983	1	4,423,983

Table 9. Costs per equip

According to the table above is easily to say that is not economically feasible. However, the technology used is design to be part of a bigger plant with other flows.

5.2. 5.2 Operation and maintenance costs

The cost of producing hydrogen with our system including energy consumption and maintenance is 0.68 USD/Nm3_H2 which rivals with the hydrogen prices of Praxair.

5.3. 5.3 Environmental impact

In Perú, renewable energies are not developed like other European countries. However, oversupply makes the prices lower than usual. That is because of the mixed energy matrix which we have explained before. Because of this our work seeks to take advantage of this fact and use it to transform in gas to supply the hydrogen demand in “La Pampilla” refinery. In fact, one of the advantages of our project is that each compound will be used in any of our processes or will be sold and commercialized. Nevertheless, different pollutants are likely to be produced during the process of gasification and each one will be removed. The principal environmental emission offset in any plant is the drop of CO2. In our case the emission of CO2 is so lower because we need to respect laws and norms that regulate CO2 and CO. For example Kyoto Protocol is a protocol that various industries agreed to reduce emission of six gases of its greenhouse gases (GHG) initially by the end of 2012, carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), (HFC), (PFC), sulfur hexafluoride (SF6), contributed mainly by industrial activities [Generación eléctrica mediante gasificacion por plasma de residuos solidos- Tesis de emilio]. Other pollutants are dioxins, TCDD, PCBs, Hydrochloric acid and CO but this pollutants are produced in less quantities and these can be controlled[Technical and economic analysis of plasm].

5.4. 5.4 Safety considerations

Safety is an important step when designing systems and power plants, not only for the safety and well-being of operators and employees, but also for the public and the surrounding area. For example, when dealing with a highly flammable and combustible gas such as hydrogen, safety must be paramount in the design, operation and maintenance of the system under consideration because if it is not treated with care it can happen to the people who manipulate it.

Hydrogen gas incidences can be leaded to detonation events depending on the amount of hydrogen released. Therefore, it is very important that hydrogen gas is not leaked out into the open atmosphere as its low ignition energy means it can be easily ignited by sources such as static electricity discharge or any residual electric currents nearby.

Also we worked with plasm by gasification but to treated this we need to consider the following. First this equipment worked to high temperature (750-2000 °C) and maybe, if we work with higher temperatures than those provided, a thermal plasma melt would occur, causing damage to the devices that work with plasm. But this claim is unlikely to happen as the equipment has measure safety to prevent this.

Finally, methane gas is a flammable gas but not as flammable as hydrogen. To treated this gas we need to consider some safety measures. For example: this element at the slightest contact with the air could produce explosive mixtures and the heat of the fire would generate pressure in the place where the methane is being stored causing its rupture, that is why no part of the deposit where it is stored can be exposed to a temperature of 125 F but if the gas does not become controlled, risks of explosive reignition can occur, for this a team that stores methane must be equipped with pressure relief devices.

Failure mode and effect analysis						
Process Area	Failure Mode	Potential Causes	Likelihood of failure	Failure Effects	Risk Severity	Overall associated risk
Electrolysis	Oxygen accumulation	Oxygen gas vent blocked	5	Combustion, deflagration event, detonation event	10	50
	Water purification failure	Clogged purification membranes, high levels of impurity in source water	6	Impurity and water residue build up	2	12
	Gas leaks	Mechanical failures in valves or piping	5	Combustion	8	40
Process control and feedback systems	Uncontrolled inflow or outflow of gas in different components	Control system failures	6	Unequal pressure build up, electrolysis and compression failure	6	36
	Overpressure effects cause in components	Blockages in piping valve failures or compressor suction leaks	6	Combustion, deflagration event, detonation event	10	60
Gasification	Bad condition input flow	Human error	3	Poor syngas, combustion, deflagration event	8	40
	Excessive plasma torch	Cooling system error	9	Poor syngas	7	45

	temperature					
	Gas leaks	Mechanical failures in valves or piping	5	Combustion, deflagration event	8	40
Methane reactor	Gas leaks	Mechanical failures in valves or piping	5	Combustion, deflagration event	8	10
	Rupture of pipes	Corroded pipes or human causes	4	Combustion, deflagration event	10	60
Desalinator	Bad desalination process	Equip in bad conditions	4	Not well hydrogen and oxygen for the processes	8	50
Separation membrane	Bad separation of the syngas components	Equip in bad conditions	9	Mixed gases	10	80

Table 10. Failure mode and effects analysis

6. 6. Siting

"La Pampilla" is a refinery situated in the district of Ventanilla, in the constitutional province of Callao, Perú. It processes 102,000 barrels of crude per day [1], which is equivalent to more than the half part of peruvian demand. We chose this place because the final products that were obtained through the plasma gasification process will be used directly by the refinery. The hydrogen is destined to desulfurization processes of fuels that are produced in the same plant and the other gases together with the vitrification will be commercialized locally. On the other hand, this location is suitable to use it because of its advantages: is close to a port in the center of the country, and that will give facilities for transporting our products to the national market - or even to export.

Figure 3. La Pampilla refinery from Google Maps

7. 6. Regulatory Analysis

Developing a hydrogen generation facility inside a refinery must adhere to numerous regulations. The majority of codes and regulations in table 11 are taken from the local Supreme Decree Nº 051-93-EM a.k.a rules for the refining and processing of hydrocarbons.

Setback distances	OSHA Standard 1910.103, NFPA 55
Fire-resistant materials	ASTM E84, ASTM E136, ASTM C1396/1396/M, NFPA 55
Electrical equipment	NFPA 70, API RP-500, NFPA-77, OSHA Standard 1910.103, National Code of Electricity
Safety equipment	NFPA 52, NFPA 55, NFPA 68, WAC 296-24-31505
Piping and pumps	ANSI B31.3, ANSI B31.4, local National Technical Standard 399.012.1984, OSHA Standard 1903.103, ASME B31.12.
Heat exchangers	TEMA Class R and C, ASME Boilers and pressure vessels, API 660 AND 661.

Table 11. Regulatory analysis

At present there are no specific codes or regulations for plasma gasification processes so manufacturer recommended codes will be employed.

8. 7. Marketing and Customer Education

8.1. 7.1 Marketing

The marketing goal strategy is to emphasize our hydrogen produced because ours is made by practically thrash (MSW) and we are giving it an extra value. Also, it has less price than they usually buy to other companies. It is also to show the benefits of produce hydrogen in the same plant they consume it. A marketing video will be offered to the refinery in order to introduce the proposed project and create public awareness about its benefits. Posters will be placed around the community in high-traffic locations (i.e. gas stations, schools, etc.) to show the public (professional and non-professionals) the benefits of our project. The focus of the marketing campaign will be to bring potential clients (other refineries around Perú or even Latinoamerica).

8.2. 7.2 Education

The education strategy will go hand-in-hand with the marketing strategy. While the marketing strategy will focus primarily on the benefits of the proposed hydrogen to the refinery , the education strategy will take this a step further by as information about the benefits of use MSW as a source to produce energy, differents utilities of the hydrogen, and added value to their extra products (methane). Because the purpose of the use of hydrogen in the refinery is to increase the quality of its crude produced by this. This will engage the public with the project and demonstrate why such initiatives should be supported and how they can contribute to a greener future.

References

[1] Ministerio del Ambiente, «Informe anual de Residuos Sólidos municipales y no municipales en el Perú - Gestión 2012,» Lima, 2013.

[2] Osinergmin, La industria de la electricidad en el Perú: 25 años de aportes al crecimiento económico del país, Lima, 2016.

[3] Municipalidad Metropolitana de Lima, «Plan integral de Gestión Ambiental de Residuos Sólidos de la Provincia de Limna 2015-2025,» Lima, 2014.

[4] Hydrogenics, «Renewable Hydrogen Solutions,» 2016. [En línea]. Available: http://www.hydrogenics.com/wp-content/uploads/Renewable-Hydrogen-Brochure.pdf.

[5] Westinghouse corp, «Plasma Gasification,» 2018. [En línea]. Available: http://www.globalsyngas.org/technology/plasma-gasification/.

[6] Angstrom Advanced, «Hydrogen Plant by Pressure Swing Adsorption with Purifying System,» 2017. [En línea]. Available: http://www.angstrom-advanced.com/index.asp?page=hydrogenpurify.

[7] M. Götz, «Science Direct,» January 2016. [En línea]. Available: https://www.sciencedirect.com/science/article/pii/S0960148115301610.

[8] Sciencing, «Uses of Methane Natural Gas,» 24 April 2017. [En línea]. Available: https://sciencing.com/uses-methane-natural-gas-6134860.html.