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Hydrogen

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Abstract

This work aims to study the use of hydrogen as a way to store energy for decentralized production of electricity. According to the best interest of the island related to the environmental and economic matter the chosen technique is the production of Hydrogen by electrolysis of water fuel by renewable energy source non pollutant that also can be named Clean Hydrogen.

The storage process and also the process of producing electricity from hydrogen by fuel cells were evaluated. The electric energy production efficiency is different to each type of fuel cell, despite this the overall efficiency of electrolysis plus the fuel cell processes is around 25%.

By considering these terms the values for levelized cost of electricity (LCOE) are 0.120€/kWh for storage of Hydrogen in form of compression gás, 0.146€/kWh for liquid storage, and 0.291€/kWh and 0.340€/kWh for final electricity energy that came from compress and liquid storage respectively, that already includes the LCOE from the energy source.

Introduction

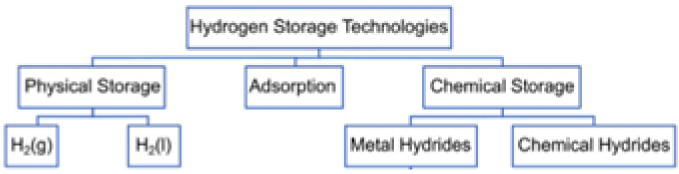
Being an energy vector the Hydrogen has a lot of potential to deliver to modern society. There are common applications such as industry, domestic use or mobility, but whatever is the application there is an issue related to this energy vector, the storage. The storage is what gives modern society troubles about this vector as a large scale application which is related to the low energy that can be stored by cubic meters of hydrogen and results in a significant amount of energy spent to store it when compared to the actual energy stored. Although there are different technologies to store Hydrogen, it was considered the compression of it (Ɛ=95%) and the liquefaction and compression in liquid form (Ɛ=70%), are the two most efficient ways to store it, so are the ones that are address on this report.

The way of producing Hydrogen also has a great share on this energy vector because the producing methods are not evenly in terms of development and efficiency. Its production can be supported by fossil fuels, which are steam reforming (Ɛ=70%), partial oxidation (Ɛ=50%), gasification of coal (dependent of the type of gasifier used), pyrolysis (dependent of the technique used) and all the electricity produced from fossil fuels to apply in electrolysis. If the previous techniques have a carbon trap technology it can be named Low Carbon Hydrogen. In addition there is renewable Hydrogen which represents the Hydrogen that is obtained from renewable sources of energy, such as the previous techniques if it uses biomass as a starter fuel or electricity from any type of renewables (electrolysis). The last two ways of producing hydrogen are thermal splitting of water (dependent on heat production technique) and anaerobic digestion which produce methane, Hydrogen carbon dioxide and other gases, and the methane is used to fuel the steam reforming process.

Because it is intended to evaluate the process of storage but also the process of electricity production from Hydrogen, there is a need for an explanation about fuel cells. A fuel cell is a device that can convert chemical energy into electric energy. There are different types of fuel cells suitable for different ends, the notorious ones are the Polymer Electrolyte Membrane Fuel Cells (PEMFC), with a good mobility applications, Alkaline Fuel Cells (AFC) and Phosphoric Acid Fuel Cells (PAFC), with good applications in small and medium sized electrical generators, Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells, that have a great applications on cogeneration applications.

Storage

There is a wide variety of possible ways of storing hydrogen, so it is important to divide them into categories. These categories are: storage in its gaseous or liquid state, in its pure molecular form; adsorption of molecular hydrogen on or in a material, maintaining relatively weak physical bonds; chemical bonding of atomic hydrogen.



We will only focus on physical storage technologies, that is the storage of hydrogen in its pure molecular form in its gaseous or liquid phase, as these are the technologies that are most developed today and the only ones to be used on a large scale.

Compressed hydrogen storage

This type of storage is normally used on a small scale with pressures that can be comprised between 200 and 250 bar for 50L tanks in aluminum or carbon (graphite). However, it can also be applied on a large scale and can reach pressures between 500 and 600 bar, increasing the storage density with increasing pressure.

This type of storage can be on the surface and underground.

The costs of storage of compressed hydrogen on the surface and on a large scale have much higher costs than storage in depth and occupy much more useful space that could be used for other purposes, so this type of storage is not the most used.

In the case of deep storage, there are already large amounts of hydrogen stored using salt cavity warehouses, as this type of storage is considered the most suitable because it has a low construction cost, low hydrogen leakage rate and low contamination risks by hydrogen. However, not all locations have geological conditions for this type of storage. There are other forms of in-depth storage such as using depleted aquifers, for example or using metal containers like those on the surface, but underground. In the case of metal containers, the cost will increase in relation to other options in depth, their maintenance will be more difficult and is more subject to corrosion overtime, so there are no great advantages in using this type of storage other than the reduction of usable space used.

Although there is not much experience in storing hydrogen on a large scale in metal containers, this is a very common practice in storing natural gas, so we can use some of these types of containers to store hydrogen. The types of storage normally used are reservoirs with storage pressures slightly above atmospheric pressure; spherical containers with maximum storage pressures up to 20 bar; and storage in tubes, with maximum storage pressures up to 100 bar.

Due to the higher storage pressure, the most promising option for large-scale storage of compressed hydrogen is tube storage. This type of storage consists of a series of tubes of varying diameter that are placed with the ends sealed. The total length of these tubes may be several kilometers, usually positioned a few meters below the surface. Using this type of storage, we can store up to 12t of hydrogen per km. However, for hydrogen storage, this type of storage is more expensive than for natural gas. There is also the possibility of using storage in coated rock caves, and this type of storage was only used for natural gas. This type of storage can have a maximum pressure of 200 bar and can store up to 740 t of hydrogen.

Storage of liquid hydrogen

Hydrogen is found in the gaseous state at room temperature and atmospheric pressure.

The main problem with liquid hydrogen storage is the high energy consumption for its liquefaction, so the energy required for the storage of liquid hydrogen is higher than for gas.

After the hydrogen is liquefied, it is essential that it is stored in such a way that the evaporation is minimal. For this reason, the liquid hydrogen storage containers normally used have a double wall with vacuum applied between the walls to minimize heat transfer by conduction and convection. Among these walls there are also other materials to decrease the heat transfer by radiation. Liquid hydrogen storage containers can reach storage capacities of up to 900 t, greater than those of compressed hydrogen. And despite the complexity of these containers, they have a lower cost than the storage of compressed hydrogen and much less possibilities of hydrogen leakage.

This type of storage should always be done in the vicinity of the places where the hydrogen is liquefied, to further minimize losses, and should also be done in underground tanks.

To make a proper evaluation about the storage it was made the economic evaluation on these two types of storage, but there are some points to consider on this matter. The economic evaluation considers an efficiency of storage for the energy needed to store the Hydrogen compared to the energy content in the Hydrogen being stored, the economic evaluation just take in account the energy available and not the infrastructure cost(except for the electrolyzers), the capital cost associated to electrolyzers are 900 kW/€, there are no electrolyzers with less power than 900 KW and the energy desired is about a kWh per hour . The time period considered was 10 years, the annual maintenance about 5% of the capital cost and the cost of electricity production is 0,049€/kWh (lower production cost obtained from the energy productions reports).

The results obtained were:

Storage		
	Compression	Liquid
Ɛ[%]	95	70
E[kWh]	1,50	2,04
Electrolyzers	2	3
Capital Cost[€]	2932	4398
Maintenance[€]	1132	1698
LCOE[€/kWh]	0,120	0,146

As can be seen in the previous table for the production of a kWh stored per hour there is a need to install 2 or 3 electrolyzers for the compression and the liquid storage technologies respectively. The energy needed from those situations are 1.50 kWh and 2.04 kWh which results in a LCOE of 0.120€/kWh for compressed Hydrogen and 0.146€/kWh for liquid compressed Hydrogen.

At this stage the Hydrogen has several applications such as industry, domestic in form of a gás, mobility usage and electricity production. In each application the Hydrogen is submitted to a specific process that reduces the amount of energy at the final stage.

Electricity application of Hydrogen

Due to the electrification of the modern society and being the best of interest for the island situation there is a need to know how should the production sector deliver to obtain a kWh per hour of electricity after being compressed.

As said before the overall efficiency of the conversion of electrolysis plus fuel cell is around 25%.

The results obtained were:

Storage+electricity production		
	Compression	Liquid
Ɛ[%]	24	18
E[kWh]	4,21	5,71
Electrolyzers	5	6
Capital Cost[€]	7330	8796

Maintenance[€]	2830	3396
LCOE[€/kWh]	0,291	0,340

As can be seen in the previous table for the production of a kWh of electrical energy per hour there is a change on the number of electrolyzers needed for 5 and 6 for the compression and the liquid storage technologies respectively. The energy needed from those situations are 4.21 kWh and 5.71 kWh which results in a LCOE of 0.291€/kWh for compressed Hydrogen and 0.340€/kWh for liquid compressed Hydrogen.

Conclusions

Hydrogen technologies are still not a viable solution due to the high costs of production and low efficiency electrical conversion rates.In terms of storage it is a really expensive option and we recommend the use of other technologies like electrical batteries or hydro pumping.For mobility hydrogen is also not a good option as the mobility problem can be solved with electric motors and batteries, only for the case of big transporting trucks can hydrogen be a viable option as hydrogen tanks are lighter than the batteries required for long distances.

In conclusion investing in hydrogen production only for storage is not recommended only if the island's industry requires hydrogen as a resource.

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