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Executive summary

The world is facing a great challenge in transitioning to new, clean energy systems to contrast climate change, while the global energy demand is continuously rising. Hydrogen could play a central role in this transition: even if until now its uses have been mainly limited to certain industrial applications, its potential is much larger than its present employment. The aim of this project is to investigate the competitiveness of plasmolysis as a technology to produce green hydrogen, which is hydrogen obtained from renewable sources. Plasmolysis consists in applying high-voltage electrical discharges to water or vapour, ionising its constituents and finally obtaining hydrogen and oxygen separately.

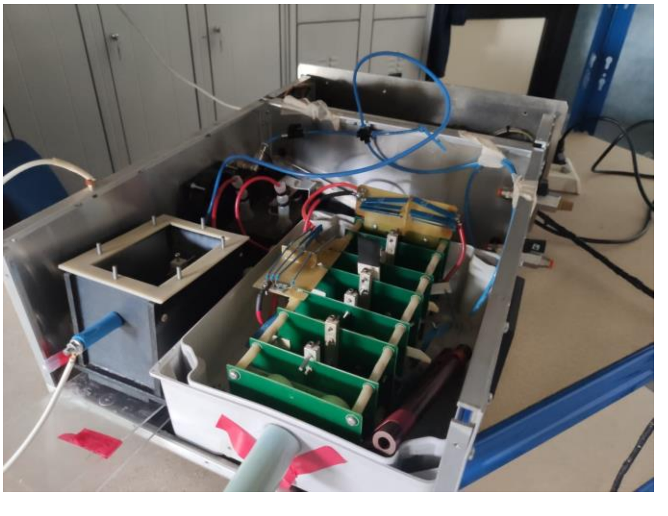
The two methods used in this project to assess the potential of plasmolysis are a techno-economic analysis and a case study envisioning the use of plasmolysis in a mountain hut disconnected from the electrical grid.

The results of the techno-economic analysis present plasmolysis as a technology that has the potential to compete economically with other green hydrogen technologies in specific scenarios, even if the future projections for the other technologies envision a quick reduction in costs that will cause the need for plasmolysis to quickly improve to remain competitive. For the economic aspect of plasmolysis to be sustainable in a wider range of scenarios, a reduction of the capital cost of the hydrogen generator and low electricity costs appear necessary, along with a high energy efficiency.

The case study of a stand-alone mountain hut shows some economical convenience for plasmolysis in the long run and a significant environmental benefit in the form of a reduction of carbon emissions. The complete self-sufficiency of the hut through hydrogen appears hardly feasible considering a realistic configuration, thus the presence of an auxiliary generator would not be easy to remove altogether, but its use could be greatly reduced.

Key Words

Hydrogen, Decarbonization, Renewable, Plasma



The electrical part of the hydrogen generator in development by IRIS s.r.l.

Project description written by the Principal Academic Tutor

Hydrogen and energy have a long shared history. Hydrogen is light, storable, energy-dense, and produces no direct emissions of pollutants or greenhouse gases. Its adoption is increasing in several sectors where is was completely absent, contributing to the clean energy transitions.

Supplying hydrogen to industrial users is now a major business around the world. Demand for hydrogen has grown more than threefold since 1975 and continues to rise.

Nowadays, the majority of hydrogen (~95%) is produced from fossil fuels by steam reforming of natural gas and other light hydrocarbons, partial oxidation of heavier hydrocarbons, and coal gasification. Almost 6% of global natural gas and 2% of global coal are employed in hydrogen production, causing CO_2 emissions of around 830 million tonnes of carbon dioxide per year. Hydrogen produced in this way is known as "gray hydrogen". The adoption of carbon capture systems at the end of this process would reduce its environmental impact, thus producing what is called "blue hydrogen". However, this raises new sustainability issues, both economic and environmental. Therefore, the only completely sustainable and commercially viable hydrogen is known as "green hydrogen," which is obtained through the electrolysis of water in special electrochemical cells powered by electricity produced from renewable sources. Green hydrogen represents the most promising energy carrier of the low-carbon economy and can truly help to speed up the energy transition where electrification is not possible.

The development of technologies associated with electrolysis and the massive industrialization effort for the industrial chain should lower the cost of electrolyzers and improve their efficiency. This, coupled with the increasing affordability of renewable electricity, could make the production of green hydrogen economically competitive with other technologies.

The objective of the HEIDI project has been a comparison between the ways to produce hydrogen from water through different technologies, such as electrolysis, thermolysis, photolysis for water splitting concept but also biological and thermochemical for biomass conversion. A new possible solution considered in this study is the plasma discharge in water instead of the traditional electrolysis. The HEIDI project performed a complete feasibility study for all the hydrogen production processes also including the plasma discharge.

This HEIDI project has been innovative because it includes all information (cost, yield, availability of the process in every sector) about the technology as well as environmental impacts. These data can be used to compare water splitting methods, energy forms (solar, electricity), energy efficiencies, raw materials and engineering systems, with the aim to propose a commercially feasible hydrogen production solution and to tailor the most suitable technology for each application.

Team description by skill

Alessandro Buzzi: electronic engineer with a focus on microelectronics, nanotechnologies, and nanofabrication processes; skilled in problem solving and used to team work.

Marco Crosato: energy engineer, specialized in renewable and innovative energy systems. Good communication and expression skills.

Nicolò Gavazzo: energy engineer, specialized in renewable energy systems. Proactive and result-oriented.

Matteo Monegaglia: energy and nuclear engineer, specialized in nuclear systems. Result-oriented and used to team work.

Andrea Vallieri: management and mechanical engineer with a focus on production system design and management. Used to work in team.

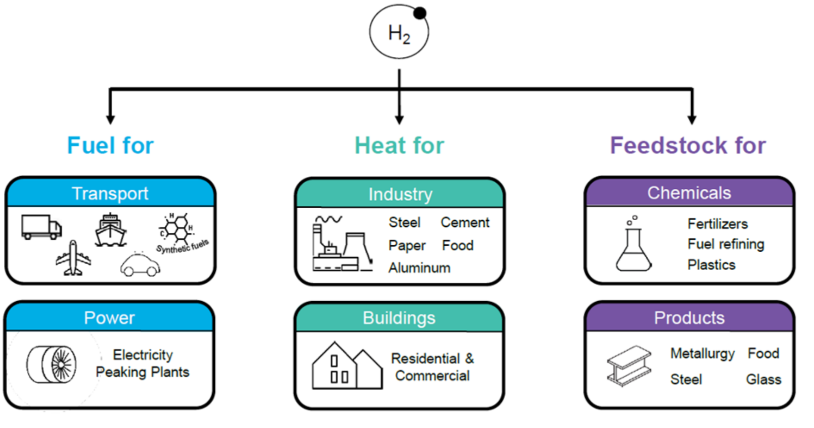
Goal

IRIS s.r.l., our industrial partner, is a small company trying to develop an innovative technology for hydrogen production: plasmolysis. This technology is promising but still at an early stage of development. The goal of this project was to assist IRIS in the initial phases of development of a hydrogen generator based on plasmolysis. To do this, we needed to help the company to gather information on hydrogen (from its production means to its final applications and market), to help IRIS to better understand its possible customers (as well as the economic potential of plasmolysis for the latter) and to give suggestions on how it would be possible to further test and improve the hydrogen generator prototype.

Understanding the problem

The demand of hydrogen has been steadily increasing in recent years, but its uses have been limited to some of the many possible ones. The latter are many but could be summarized as hydrogen acting as an energy vector (a form of energy that allows to transport and store the latter) and as an industrial feedstock. The great potential advantage of hydrogen is that it can fulfill many roles in different sectors in a low-carbon and clean way, making it an appealing option for the decarbonization of energy, transport and some industrial sectors. However, the current hydrogen production actually occurs through pathways that cause carbon emissions and that need to be replaced by more environmentally friendly alternatives.

Plasmolysis could be one of these alternatives, having the potential of being a renewable, sustainable and low-carbon way to produce hydrogen, while also satisfying the needs of many stakeholders in the hydrogen sector.



Graphical representation of possible hydrogen uses (Bloomberg, 2020).

Exploring the opportunities

It's important to note that there are many different pathways to produce hydrogen, not all of which are sustainable, low-carbon, and non-polluting. These pathways are usually identified with "hydrogen colours" and the most known colours are:

- Black hydrogen, produced from coal
- Grey hydrogen, produced from natural gas
- Brown hydrogen, produced from lignite
- Blue hydrogen, produced by fossil fuels with carbon capture, utilisation and storage (CCUS)
- Green hydrogen, produced from renewable feedstock and energy.

Hydrogen can also be produced from nuclear and grid electricity, but no colours are unequivocally associated with these pathways. Currently, hydrogen production is done mainly from fossil fuels without CCUS and therefore causes CO2 emissions.

Considering this classification, plasmolysis, as a technology, can produce green hydrogen, as long as the electricity used is produced through renewable means.

Considering that for plasmolysis a cost estimation of 6.36 $/kg and an efficiency of 79.2% have been reported in the literature, together with a possible reduction in equipment size and initial costs compared to electrolysis, plasmolysis appears to have the potential to be competitive with electrolysis. However, it is important to remember that these cost and efficiency estimations for plasmolysis are based on small-scale experimental studies, while in the case of electrolysis such parameters are estimated based on several large-scale prototypes and operative plants, therefore if plasmolysis will respect the potential shown by these early data remains to be seen.

Compared to blue hydrogen technologies, plasmolysis does not produce any direct emissions of carbon dioxide and has no necessity of fossil fuels, energy consuming carbon capture processes, pipelines and geological storage, which are instead needed for blue hydrogen. On the other hand, plasmolysis still has problems during the separation of hydrogen from argon while the methodologies applied to divide the different fluxes of hydrogen, carbon monoxide and carbon dioxide obtained through steam methane reforming are well known and efficient. For what concerns the costs, blue hydrogen prices were more convenient until recently, but in the present and near future the increasing cost of gas will be to a huge incentive for adopting green hydrogen production technologies.

Generating a solution

To better assess the potential of plasmolysis and its economic feasibility in different cases a techno-economic analysis and a case study of a mountain hut have been performed.

The results of the techno-economic analysis showed how the technology can be efficiently coupled with large renewable energy production systems or nuclear plants. Indeed, these two scenarios appear to be the only ones in which plasmolysis can reach costs of hydrogen competitive with electrolysis, the closest competitor of plasmolysis due to their similar feedstock requirements. In the other scenarios, the cost of plasmolysis appeared to be too high to compete with electrolysis, for the considered input data. Hydrogen production for off-grid users through plasmolysis appeared to be promising but its cost resulted to be still too high compared to electrolysis, due to the hydrogen generator based on plasmolysis still being too expensive. Scenarios considering hydrogen production through the use of electricity taken from the grid proved to be economically uncompetitive, due to the high assumed cost of electricity (which considered the price increase due to the recent energy crisis). Indeed, the latter is the decisive factor for these scenarios and it would need to be quite low for them to become appealing.

The scenario of off-grid users was analyzed more in detail (from both the economic and environmental point of view) through a case study considering the hydrogen production through plasmolysis in an off-grid mountain refuge powered by renewable energies, in particular a micro hydroelectric plant and photovoltaic cells. Different scenarios were taken into account showing the conditions under which the solution can be feasible.

The case study shows some economic convenience for plasmolysis in the long run and a significant environmental benefit in the form of a reduction of carbon emissions. The complete self-sufficiency of the hut through hydrogen appears hardly feasible considering a realistic configuration, thus the presence of an auxiliary generator would not be easy to remove altogether, but its use could be greatly reduced.

Moreover, an essential step in the development of plasmolysis is identifying the optimal operating conditions and the ideal setups. We have identified some critical parameters and technology choices and suggested some experiments that could help to improve the hydrogen generator prototype developed by IRIS. Some relevant adjustments in this regard concern the plasma power and voltage, the temperature, the typology of inert gas employed, the choice of the feedstock, the starting time and operation in pulsed discharge.

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