Production of Green Hydrogen via Electrolysis for Microelectronic Usage

Pathway towards Integration of Green Hydrogen into Society

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Chemical Engineering

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November 3, 2023

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

As climate change continues to harm communities and environments, it is increasingly important to engineer solutions to power the world which assist ongoing decarbonization efforts. This shift, from fossil-fuel based to hydrogen-fueled power, is outlined in the Paris Agreement, which aims to reduce carbon emissions by 40% by the year 2030[14]. Ultimately, this plan was designed to keep the Earth below an 1.5^{o} C temperature increase, at which environmental disaster would occur. Green hydrogen, as a solution, has attracted substantial interest because it is both, by definition, carbon-neutral in production and carbon-neutral in its usage as a fuel. New processes, however, are required to mitigate economic, social, and governmental barriers associated with this process.

The technical component of this thesis will discuss the production of green hydrogen through electrolysis for commercial usage. Green hydrogen is defined as hydrogen which is produced using a carbon-neutral energy source, such as solar, wind, or hydroelectric power. Specifically, the hydrogen produced will be purified to industry standards and used for production of microelectronics (for etching and capabilities as a heat transfer agent) to ensure profitability of this process. At a high level, the electrolyzer produces hydrogen using water and electricity, with oxygen and water as byproducts. Beyond an electrolyzer, this process requires only water and carbon-neutral electricity, which will be sourced from stream water and on-shore windmills in Sweden, respectively. This location was chosen because it has the lowest cost of electricity and regional regulations which allow for facilitation of renewable energy usage. Prior to electrolysis, the Swedish stream water will require aeration and reverse osmosis to ensure contaminants are removed before processing. As electrolysis and water purification have a high price point, oxygen will be purified and sold for medical usage in hospitals to increase profits. Any water produced in this system will be re-purified (according to Swedish environmental regulations) and discharged back into the stream.

Although the technical component investigates the production of green hydrogen for usage in microelectronics, it is a natural application to use this hydrogen as an energy source. However, as society focuses on monetary profits as a measure of success rather than environmental benefits, green hydrogen faces significant obstacles in implementation due to (relatively) high prices of renewable energy and lack of necessary infrastructure. Beyond economic challenges, there is an extreme lack of cohesive legislative policy and established precedents on how to re-shape society's reliance on carbon-emitting energy fuels. Therefore, the STS portion of this thesis will investigate how governments can facilitate integration of green hydrogen fuel into society, by improving regulations, decarbonization incentives, influencing public opinions, and beyond.

Although the green hydrogen generated is not used for fuel in this specific technical write-up, by utilizing a low-cost production location and selling oxygen as a byproduct, our process promotes societal acceptance by minimizing associated prices without carbon emissions. As green hydrogen holds the stigma of being "too expensive", it is often overlooked by governments when considering realistic environmental policies. Both the social and technical components work together to decarbonize the Earth, ensuring the safety of environments, animals, and humans alike.

Production of Green Hydrogen via Electrolysis for Microelectronic Usage

Hydrogen is a crucial part of our modern economy, playing large roles in fertilizer production, semiconductors, and fuel cell use. Its role in fertilizer production cannot be understated, with over half of all hydrogen produced being used in the Haber-Bosch process to create ammonia[3]. Additionally, hydrogen fuel cells also serve as a potential future use of hydrogen; they provide a means to cleanly produce electricity without battery recharging, making them attractive for car use[4]. Lastly, hydrogen presents a large variety of uses in the electronics industry, where it is used for its heat transfer capabilities and as a reducing and etching agent[6]; it is, therefore, essential for our current way of life regarding electronics.

However, the current cheapest and most used type of hydrogen is sourced from fossil fuels (gray hydrogen) and uses steam methane reforming and the water-gas shift reaction to produce the hydrogen. As societal concerns regarding climate change grow, it becomes economically more viable to invest in technologies to reduce the carbon footprint in our hydrogen production. This can be achieved with green hydrogen production which uses renewable energy sources, such as wind and solar, to perform electrolysis of water to generate hydrogen and oxygen. This provides a clean and carbon-free process to meet our economies hydrogen needs. Currently, the major problem with green hydrogen is the cost; it is more than four times the cost of gray hydrogen, driving most use to gray hydrogen[11].

We will be sourcing our water from rivers in Sweden and purifying it using aeration and reverse osmosis techniques. Aeration will first be implemented to remove volatile organic chemicals and dissolved gasses such as hydrogen sulfide. Then, using a variety of filters in reverse osmosis, we will remove over 99% of chemical contaminants, bacteria, and other infectants[2]. Reverse osmosis will require an energy source (wind energy) to power the pumps. Another viable alternative is electrodialysis, which may be more energy efficient than RO. Desalination of ocean water and sewage water treatment would require more purification steps, so these water sources were not chosen. The degree of water purity needed for electrolysis will depend on the specific electrolyzer chosen, however, generally the purer the water, the less maintenance needed [5].

We have chosen to source our renewable energy from onshore wind production turbines in Sweden. To ensure feasibility of this project, we chose our renewable electricity based on geographic energy price and method of production. The cheapest form of renewable energy, according to the International Renewable Energy Agency (IRENA), is onshore wind production[1]. Although cost is an important factor, this choice also provides the critical benefit of consistency, a trait which other forms (such as solar photovoltaic energy) lack. Overall cost analysis (LCOE) is depicted in Figure 1 below, with onshore wind shown in dark gray. From this database, Sweden was determined to be the lowest-cost location for onshore wind production, shown in Figure 2.

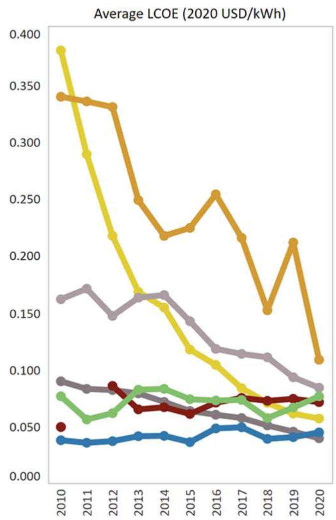

Figure 1: Overall Energy Costs for Various Renewable Electricity Forms (IRENA)

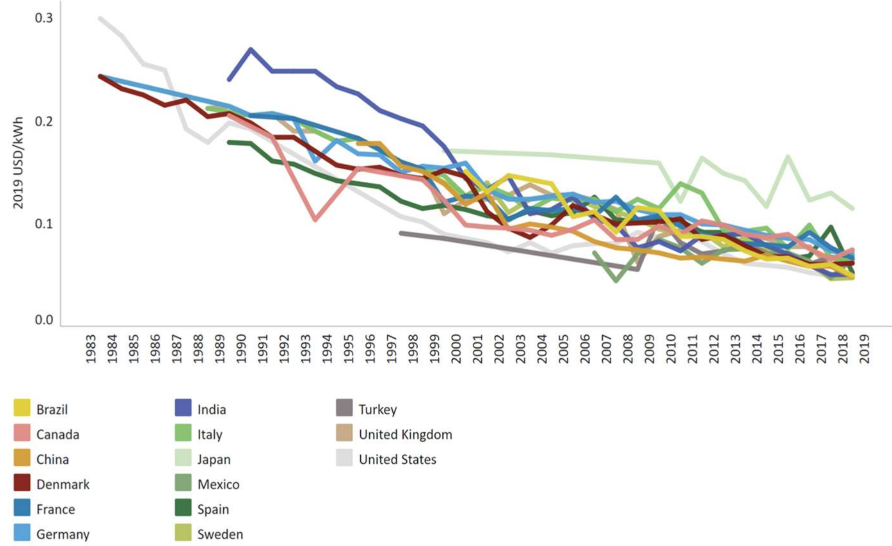

Figure 2: Weight-averaged LCOE of Newly Commissioned Onshore Wind Projects by Country (IRENA)

The key technology in this process is electrolysis, which will split the inlet water molecules into hydrogen and oxygen gas. There are two types of electrolysis technologies currently in commercial use: alkaline water electrolysis and proton exchange membrane (PEM) electrolysis. The biggest issues with these existing technologies is they are inefficient (low hydrogen production per Joule energy supplied to the electrolyzer) and their costly components translate to a higher price in the final product[12]. Recent laboratory developments have yielded new kinds of electrolyzers that improve upon both these deficiencies[13]. Anion exchange membrane (AEM) electrolysis and solid oxid water electrolysis have provided promising results, but neither of these technologies have been integrated into commercial processes. We aim to compare both the existing technologies with newer lab breakthroughs to assess which may be commercially and economically viable in the future. Combined with European wind energy infrastructure and purified river water, we hope to demonstrate reductions in the final cost of the green hydrogen.

After the electrolysis process produces hydrogen and oxygen, we will purify those streams. The purified hydrogen and oxygen specifications will be determined by an economic analysis that computes the greatest profit margins. We anticipate that we will produce the hydrogen gas for the microelectronics industry as ultrapure hydrogen is needed[8]. Ultrapure hydrogen costs the most to produce, but it sells for the most money per kilogram. Since the electrolysis process produces relatively pure product streams, we anticipate that the process of purifying the hydrogen to the ultrapure hydrogen standards will be economically viable[9]. Similarly, we anticipate that we will produce oxygen gas for the medical industry as the pure oxygen required for this industry sells for the most among all of the industries that require the use of oxygen gas[10]. After the purification processes are complete, we will compress the gasses and prepare them for shipping.

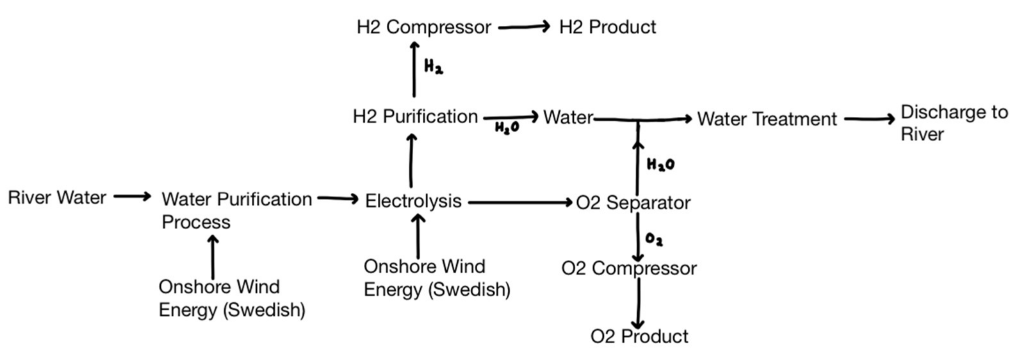

Figure 3: PFD of Green Hydrogen Production

Our green hydrogen project will be completed as a two-semester project through the courses CHE 4474 and 4476. As a group of five, we will split the work in this project to specialize on different operations in the process: Mara and Brian will work on water purification (pre- and post-electrolysis), Danny will work on purification of the oxygen, Abhi will work on purification of the hydrogen, and Amish will work on the electrolysis unit. Economic analysis will be done by each team member in their respective topics of focus. To ensure team members are keeping up to date on their work, we will have two weekly in-person meetings to maintain progress and quality of our project.

To accomplish our technical goals, we will be using Aspen for process modeling of processes such as water purification and electrolysis. Economic scale-up analysis, as well as other technical calculations, will be performed in MatLab and Excel spreadsheets. Cost of renewable electricity is determined from Swedish government standards, as well as public databases such as IRENA. Specifications for water purity, for the water to be discharged back into rivers, will be determined by purity specifications of local government municipalities[7]. The hydrogen product purity specifications will be obtained directly from the microelectronics producers, and the oxygen purity specifications from the medical industry standards.

Pathway towards Integration of Green Hydrogen into Society

It is essential to the safety of Earth to maintain a temperature increase below the 1.5^{o} C threshold (1.0^{o} C as of 2018[16]), to prevent exacerbation of the current economic crisis, biodiversity, forest fires, hurricanes, droughts, and beyond. The current global rate of carbon emissions is projected to result in this 1.5^{o} increase by the year 2040[15], and therefore immediate attention is required to mitigate this crisis. With the introduction of a “green hydrogen economy” to replace fossil-fuel reliance, comprising 84% of the current energy consumption market[18], this disaster can be avoided by decreasing carbon emissions between 90-99%[17]. However, as stated in previous paragraphs, green hydrogen faces multiple challenges which must be overcome before the development of a hydrogen-centric society. Because of this, the sociotechnical component of this paper will discuss how governments can facilitate the implementation of green hydrogen as fuel through development of regulations, new infrastructure, and efforts to change public perceptions.

It becomes apparent through a quick literature search that a predominant barrier for green hydrogen usage is a lack of existing large-scale infrastructure and government regulation. Although smaller-scale hydrogen projects have been created, these innovations have traditionally failed to consider scale-up of infrastructure in their design. This being said, there are (at least) 228 ongoing[18] government subsidized hydrogen research projects currently underway, with over half taking place in Europe. Unfortunately, the majority of these countries have failed to invest in the assessment of critical details of how to integrate this innovation into society, excluding factors such as storage and transportation. For similar reasons, as this is a novel technology, there is a lack of general legislation explicitly regulating hydrogen, leading to safety concerns and inefficient usage. These policies are essential for wide-scale hydrogen adoption, and will inspire other countries to develop their own regulations. This phenomenon was recently observed as the European Parliament developed a policy inspired by the United States’ tax benefits for renewables in the Inflation Reduction Act[19]. Furthermore, to ensure sustained market growth, governments need to provide substantial policy incentives and consider how large-scale trading of hydrogen could affect political relationships between countries.

One additional hurdle to adoption is the public perception of hydrogen. A favorable public opinion is essential to ensure that policies surrounding this topic are written and passed into law. In a study conducted in the United Kingdom, 64% of respondents were unable to demonstrate basic knowledge of hydrogen, and 34% believed that hydrogen was dangerous[20]. An estimated 77% of the public also claims that they would be "unable or unwilling" to pay more for electricity[20]. These statistics demonstrate the government's need to provide education to the public on green hydrogen energy, and reinforce the necessity for policy incentives to lower cost and improve public opinions.

This problem will be analyzed with a holistic perspective. This will consider how governments can succeed in implementing a green hydrogen economy within their own countries, and how different governments and people can influence each other. Evidence will be collected through journal articles, public opinion polls, relevant social statistics, and existing government policies. This information will be carefully reviewed, interpreted, analyzed and understood in its full context to fully grasp this sociotechnical issue.

Conclusion

As the fight against global warming continues, it is increasingly important to understand the scientific and social implications of green hydrogen production. In the technical component of this paper, green hydrogen is produced through electrolysis in

Sweden, for microelectronic usage, using stream water. This process was designed to ensure economic viability and environmental sustainability. Cost of production, amongst other factors such as lack of regulations, lack of infrastructure, and unfavorable public opinion are challenges which governments need to overcome in order to successfully use green hydrogen as a fuel for electricity. This implementation would lead to a decrease in carbon emissions by up to 99%, saving communities and biodiversity worldwide. I expect to find that our technical process is highly efficient, safe, and profitable, and that the sociotechnical aspect will prove the necessity for governments to provide further education to the public, standardize and incentivize green hydrogen legislature, in addition to developing a worldwide hydrogen infrastructure.

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