Design of an Autothermal Methane Reforming Blue Hydrogen Plant
Analysis of the Failed California Hydrogen Economy Blueprint Plan

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

This prospectus aims to aid in the development of a clean future for energy to address and mitigate climate change by studying the past failure of the California Hydrogen Economy Blueprint Plan alongside a proposed design of a blue hydrogen plant. Blue hydrogen is an almost emission-free source of energy, created by converting natural gas to hydrogen and carbon dioxide and capturing the carbon dioxide in the process. This plant will be run utilizing an autothermal methane reformer which can work continuously without outside heat input, further contributing to its eco-friendliness (Oni *et al.*, 2022*)*. This work will be completed in conjunction with an STS research project that aims to better understand the United States' governmental problems in relation to clean energy technology. This project will utilize Actor Network Theory to examine major factors of the California Hydrogen Economy Blueprint Plan failure, from the changes in executive administration to the sources of funding and research. Together, these two projects will address the major sociotechnical problem plaguing today's society: How do we stop climate change.

By studying the relationships between governments, citizens, and corporations, I hope to develop a way to avoid wasting time and resources in the planning and building of new clean energy technology. Further understanding the social standings of hydrogen as a clean fuel source will allow for its implementation as a major aid for climate change mitigation to proceed without further hinderance; therefore, this work should be seriously considered by any corporation and activist as a means of directing their approach to developing new hydrogen infrastructure in a world of research funded by volatile governments. Below, I describe the details of the blue hydrogen plant design and further analyze the advantages of studying the failure of the California Hydrogen Economy Blueprint Plan with respect to developing technology to fight climate change.

Technical Project Proposal

Hydrogen has seen growing potential in recent years as an energy source for electricity production in homes and vehicles as the development of other renewable sources and biofuels remain slow in many regions. Hydrogen is not abundantly available in nature, however, and instead has to be produced from other energy sources (Nikolaidis & Poullikkas, 2016). Traditional hydrogen production, often called 'gray hydrogen,' consists of reforming fossil fuels like coal and natural gas to create hydrogen gas and other emissions, including carbon dioxide (CO_2), a significant greenhouse gas. Steam methane reforming (SMR) is the most common strategy deployed in this production (Yu *et al*., 2021). In SMR, a high energy reformer converts hydrocarbons and steam into syngas which reacts to produce hydrogen and CO_2; however, the CO_2 is not captured and stored (Nikolaidis & Poullikkas, 2016). While this process has been widely used in industry, its large energy requirements and considerable CO_2 emissions make it unattractive for continued widespread use in producing hydrogen for a cleaner energy future.

The process we propose will instead produce blue hydrogen. This can be made in the same ways as gray hydrogen; however, the CO_2 produced during the reformation of methane is captured and stored, lowering the overall carbon emissions of the hydrogen plant. In a society whose concern over the effect our emissions are having on the environment is growing, this is a major step towards emission-free energy production (Alternative Fuels Data Center, 2021). However, carbon capture requires energy, which lowers the plant's efficiency and increasing costs of production. One way in which we are mitigating these effects is by using autothermal steam methane reforming (ATR). This method involves reacting pure oxygen and steam with methane to produce carbon monoxide and hydrogen, an exothermic reaction (Lamb *et al*., 2020). Therefore,

the heat generated through this reaction can be used to sustain the process with far less energy input than a typical SMR reactor, decreasing costs and overall carbon footprint. Oni et al. (2022) outline

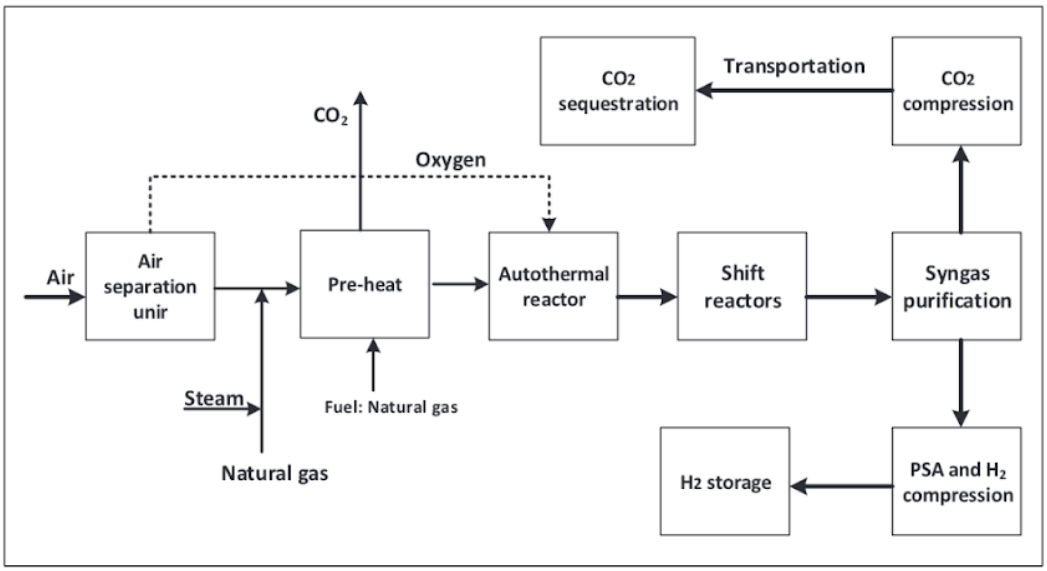

Fig. 1. Block Flow Diagram for Autothermal Reforming (ATR)

To perform autothermal reforming at the optimal reaction conditions, pure oxygen must be fed to the ATR unit to increase the efficiency and yield. For this project, industrial grade oxygen will be supplied from a third party, rather than building on-site air separation equipment, saving on capital cost and operational costs (BLS Data Labs, 2022). After the materials flow through the ATR, a water-gas shift (WGS) reactor will be used to convert the carbon monoxide produced into additional hydrogen gas and CO_2. Amine scrubbing will be used to remove sulfides from the feed and to separate CO_2 and H_2 in the product streams (Carver Pump, 2021). The CO_2 produced from the reactor will be refined to be sold for enhanced oil recovery (EOR). Although EOR is not the most environmentally conscious route for use of captured CO_2, it is currently the most profitable. 88% of total CO_2 use across the world in 2017 was "gaseous," meaning that it was directly used for fossil fuel recovery (Roberts, 2019). Keeping the captured CO_2 as a gas instead of liquefying

or solidifying it is also more cost effective, as it eliminates the need for additional condensers and pumps.

We plan to use Aspen Plus to simulate the complex chemical behavior and unit operations within our designed plant. Additionally, we plan to incorporate Microsoft Excel and PowerPoint for processing and presenting data. Design data will come from papers that have already performed basic economic analyses and conceptualized the entire process down to the unit operations (Oni *et al*., 2022). Economic analysis is crucial to determining the project's feasibility and influences several design choices (Khan *et al*., 2021). This project will be completed with a team of five students over the course of two semesters in the classes CHE 4474 and CHE 4476. Gantt charts will be used to organize our workflow and establish deadlines, and work will be divided equally amongst teammates.

STS Research Project Proposal

As awareness of the climate crisis continues to grow, ideas are being developed to help contain the issue. From renewable energy to carbon dioxide capture, companies and governments are putting billions of dollars into "green" energy. Cars are one of the major producers of greenhouse gases as they run by combusting gasoline to make power, producing CO_2 and CO; therefore, many options for reducing vehicles' emissions have been researched. Led by Governor Arnold Schwarzenegger, who promised Californians "hydrogen highways" that support hydrogen-powered vehicles, the California Hydrogen Economy Blueprint Plan was developed, which set goals such as building 100 hydrogen gas stations by 2010 (Renewable Energy World, 2003). This came at a time when the national government supported hydrogen-powered vehicles as a solution to climate change. During the George W. Bush Administration, $18 billion in funding for research and development of hydrogen-powered vehicles and other energy technologies was provided

(National Archives and Records Administration, n.d.). But with the end of the Bush administration, the Obama administration pulled over 80% of hydrogen vehicle funding, instead focusing on battery powered vehicles (EVs). The money being poured into hydrogen-based research alongside programs and speeches aimed at convincing the public that hydrogen-powered cars were the future, were exchanged with the new administration's plans. This change caused state and local government bodies, who had previously been preparing funding for infrastructure development projects to support the expected influx of hydrogen-powered cars, to find themselves scrambling to adapt, wasting years of research and billions of dollars (O'Dell, 2003). California was the most affected; the changes effectively rendered California's new hydrogen stations obsolete (Elliot, 2011).

The current understanding of this problem is derived from partisan bias. Due to the large scope of the climate problem, many people have their own opinions, educated or uneducated, which they strongly back. Furthermore, the Republican Party is envisioned as pro-fossil fuel while the Democratic Party pushes for EVs and renewable energy, further dividing the United States with each person mainly consuming sources of news that agree with their party's solution. Thus, the Bush administration's backing of a hydrogen economy was seen by many as a farce that would provide no changes in carbon emissions but would keep fossil fuel producers content (Mazovick, 2019). While this approach draws good conclusions about the source of the California hydrogen problem, it attempts to lay blame on one actor in a network that, by design, works against itself at every level.

By continuing to view the problem as we do, the climate crisis may continue to produce dead-end solutions. With each new administration, new ideas are funded while research that has been progressing for years is defunded. Until we understand how to distribute our resources and conduct

decades worth of expensive research with funding that is dependent upon the ever-changing government, we may continue to waste time and resources on technologies that will become obsolete with each change in leadership. I am proposing a different understanding of the California hydrogen problem than was previously stated that is based on Actor Network Theory (ANT). ANT is a social construct that looks at the interconnectedness of each piece of the network that is behind a given problem while also attempting to understand the goals of the actor who built the network and the consequences of this creation. These pieces or "actors" can be humans, organizations, technologies, etc. that work together to create the system that is being studied. The implication of this is that no single part of the network is wholly responsible for the problem; each actor and its connection to others must be studied to fully understand the issue (Cressman, 2009).

I will use this theory to look at the main actors of this system, the Bush Administration, the Obama Administration, the Schwarzenegger governance, the general public, and news sources. By studying these actors' connections to California's Hydrogen Economy Blueprint Plan failure, I will draw conclusions about the causes of the problem. The actors I will focus on as the root causes of the problem that are typically not considered are the general public, who typically lack the knowledge required to develop an informed opinion on the matter, and news sources, which often contain a great deal of biases and incomplete analyses of the issue. The actors that my research will designate as the network builders are the public, educated and uneducated, who built this network in order to solve the problem of climate change. Thus, my study will provide a look into the relationship between government officials, their political decisions, and the voters who aid in the making of these decisions. To supplement my work, I will use statements from key government officials, cost and feasibility data of hydrogen production, news articles, and political studies delineating the two-party system based on sustainable energy opinions. Finally, I will study a

variety of opinion-based articles from both sides of the hydrogen-power versus EV debate to broaden my view and minimize any previously held biases I may have.

Conclusion

The deliverable for the technical portion of this prospectus will be a fully designed blue hydrogen plant which runs at high efficiency, utilizing its own reaction energy to power the reactor. Furthermore, the plant will capture virtually all of its on-site carbon emissions and produce hydrogen fuel, which burns without creating greenhouse gas emissions. The STS research paper will attempt to define the sources of the California Hydrogen Economy Blueprint Plan failure by employing Actor-Network Theory. Using this sociotechnical theory, I will look at each of the major actors and consider the problematic relationships between them to develop a solution that will limit future occurrences. Overall, the STS problem will be used to further understand the societal problems hydrogen faces as a clean energy source to allow for the implementation of our blue hydrogen plant design to be successful in an ever-changing political environment, thus creating a useful and viable alternative to sources of energy that, left as they are, will ultimately destroy our environment.

Word count: 1895

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