BLUE HYDROGEN- AIDING IN THE RENEWABLE TRANSITION

THE GREEN THIRD WORLD- FANTASY OR FUTURE?

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
By
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October 27, 2022

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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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One of the greatest challenges mankind faces today is the global climate crisis. Lindsey & Dahlman (2022) found that “by the end of this century, global temperature will be at least 5 degrees Fahrenheit warmer than the 1901-1960 average, and possibly as much as 10.2 degrees warmer” (“Past and future change in global temperature” section, para. 3). Temperature increases of this magnitude will have catastrophic consequences on the environment, including rising sea levels and an increase in extreme weather. Swift action is needed to reduce greenhouse gas emissions to mitigate global warming, and alternative energy sources to fossil fuels will be critical to the future of our planet.

A promising alternative energy candidate is hydrogen, due to its accessibility and efficiency in power generation. Hydrogen can be produced from common materials, such as methane and water, and can be used in a fuel cell to generate electricity without the need for combustion.

Hydrogen is primarily created through steam-methane reforming (SMR), a process that converts natural gas into hydrogen, and produces carbon dioxide as a byproduct (Yu *et al.*, 2021). The carbon dioxide is often released into the atmosphere, contributing to more greenhouse gas emissions, but “blue” hydrogen captures the CO_2 it produces, decreasing the environmental impact of the process. Blue hydrogen is the focus of the technical project, and is an excellent step forward in progress towards cleaner energy. This process has the ability to produce large amounts of hydrogen while maintaining a relatively low rate of carbon emissions, making it an optimal choice for transitioning to renewable energy.

Ideally, all nations will eventually be able to meet energy needs through the use of renewable sources of electricity, but many countries in the developing world struggle to implement renewables due to a variety of factors. The STS research project will focus on the current and proposed strategies to implement green energy in developing nations, and will analyze the relationship between different entities involved in the implementation of this technology.

These two research subjects are loosely coupled, as they do not investigate the same technology, but share similar trends in their relationship to society and the groups involved in their design and implementation. Both developed and undeveloped nations experience similar struggles when implementing hydrogen and renewable technology, in the technical and sociotechnical spaces. Comparing and contrasting these two scenarios will be vital in discovering inequity between the countries, and more insight can be gained into what strategies can be successful.

While the STS portion of this research will be carried out independently, the technical project will involve a team of other undergraduate chemical engineering students at the University of Virginia. These additional team members are Collin Barbosa, Brenna Bartholomew, Jonathan Paul, and Alex Ton. The project will be supervised by Eric Anderson, technical advisor and lecturer for the University of Virginia Department of Chemical Engineering. Preliminary research for the technical design and STS projects will be conducted until December 2022, are to be completed by April 2023.

BLUE HYDROGEN

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 remains slow in many regions. Hydrogen is not abundantly available in nature however and instead has to be produced from other energy sources (Nikolaidis *et al*., 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 hydrogen production (Yu *et al*., 2021). In SMR, a high-energy reactor converts hydrocarbons and steam into syngas which is reacted to produce hydrogen and CO_2, and while hydrogen is captured as a product, CO_2 is released to the atmosphere, contributing to greenhouse gas emissions (Nikolaidis *et al*., 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 (U.S. Department of Energy, n.d.). However, carbon capture requires energy, lowering 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.

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 an on-site air separation, saving on capital cost and slightly operational costs (PPI Industry Data, 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. A generalized block flow diagram for the full process is displayed in Fig. 1, including all of the relevant process streams, compositions, and unit operations.

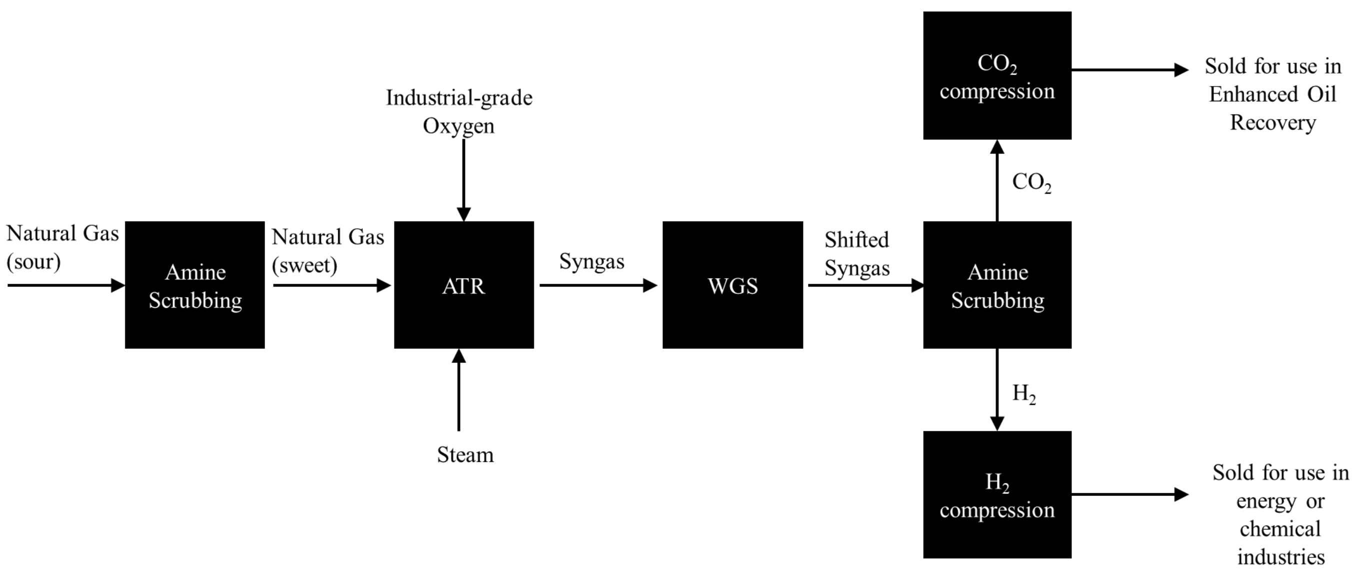

Figure 1: Block Flow Diagram for the Proposed Autothermal Steam Methane Reforming (ATR) Process. This figure shows the major unit operations for autothermal reforming, including process stream composition and end use of products.

We plan to use Aspen Plus to simulate the complex chemical behavior and unit operations within our designed plant. Additionally, we will incorporate Microsoft Excel and PowerPoint for presenting and processing data. Design data will come from papers that have already performed basic economic analysis and conceptualized the entire process down to the unit operations. Economic analysis is crucial to determining the project's feasibility, and influences several design choices. This project will be completed as 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.

GREEN ENERGY IN THE THIRD WORLD

A major challenge when tackling the global climate crisis is ensuring that all nations, regardless of economic status, are able to contribute to the reduction of greenhouse gas emissions through the integration of renewable energy technology. The difference in priorities between the developed and developing worlds is often stark, and this disparity can lead to conflict. For example, at the United Nations climate talks of 2009 in Copenhagen, Pakalitha Mosisili, the Prime Minister of Lesotho at the time, rejected the Kyoto climate proposal, stating that "[Lesotho] respectfully [reminds] rich countries- you have the responsibility for delivering a good climate deal, but we, the poor countries, have the right to refuse a bad deal" (Reuters, 2009, para. 2). The struggle between the developed and developing world to create fair, equitable climate policy is ongoing, and the relationships between these nations must be analyzed in order to bring all nations together in the fight against climate change.

Often, the cost of renewable energy for developing nations is often prohibitively expensive, due to other socioeconomic issues that take priority over cleaner energy. Research conducted by the Stockholm Environmental Institute and ExxonMobil found that “fossil fuels will be an increasing main source for primary energy for the needed development of [developing] countries for quite some time” (Bolin & Kheshgi, 2001, p. 4851). The difficulties these countries encounter in their technological progression must be taken into account when considering the implementation of green energy, and solutions must be oriented towards the nation’s specific needs.

Current implementation of renewables in developing nations is poor, despite the vast potential that many of these countries have to use this technology. For example, Morocco is a developing African nation that could potentially produce most of its power from renewables, due to its proximity to the Sahara Desert. In 2012, Morocco imported over 90% of its energy with only 4% of its electricity produced from renewables, but plans to encourage foreign investment to increase its solar and wind energy capacity (Vandaele & Porter, 2015, p. 2). This appears to be a sound strategy on its face, but foreign investment can often lead to a new set of problems. Sarkodie & Strezov (2019) found that “dirty industries migrate from high-income countries to low and middle-income countries through the trading of goods and foreign direct investment” (p. 862). It is clear that further research is needed to understand the effects of different energy strategies on developing nations, as each integration strategy can lead to further societal issues that must be addressed.

The objective of this research is to review current and proposed strategies for implementing green energy into developing nations, using a Social Construction of Technology (SCOT) framework and innovation diffusion analysis to analyze how these policies interrelate to relevant social groups. According to Pinch & Bijker (1984), Social Construction of Technology analysis imvolves looking at relevant social groups around the technology that all interpret & use the technology in different ways. When looking at renewable energy strategy in this way, an emphasis can be placed on the users of the energy rather than the energy technology itself, and allow strategies to be formed that better suit the people using the energy. This analysis will hopefully provide ethical and practical principles for formulating green energy implementation strategies in these nations, and will highlight the most effective strategies that balance technological, economic, and societal needs. Each strategy should be tailored to its nation of deployment, to best serve that country's interests. This means that not all developing nations will be addressed, but the best strategies could serve as inspiration for other developing countries looking to push towards more sustainable energy.

One such strategy to implement green energy in developing countries is off-grid renewable systems for use in rural areas. These systems use renewable energy resources to provide local power to rural areas not connected to a central power grid, depending on that region's needs- whether it be for cooking, heating homes, or running machinery (Urmee & Md, 2016). These types of systems are adapted to the people within the location that they serve, and provide a cleaner alternative to many of the polluting fuels used in these regions today, such as kerosene, charcoal, dung, wood, and local biomass.

These strategies will be viewed under a SCOT framework, which outlines the influence that relevant social groups have on the renewable energy strategy, and vice versa (Pinch & Bijker, 1984). Additionally, these social groups can influence each other through various means, and these relationships must also be addressed. Figure 2 provides a framework through which green energy strategies can be viewed through, denoting the groups influences on the strategy with arrows, and the ways that the groups influence each other. Industrialization and cultural exchange in particular will be interesting to study, as many unpredictable things can happen when a world power begins investing in a poorer country. The ethics of actions taken by foreign investors will be analyzed to identify previous mistakes in policy and rectify them in future strategy.

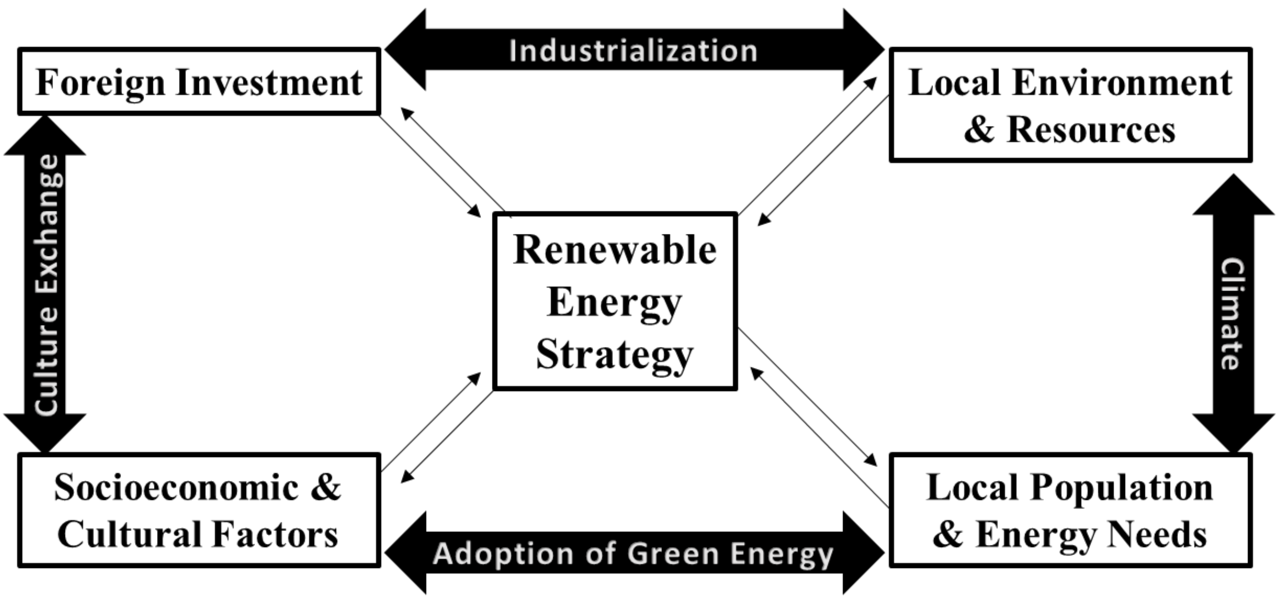

Figure 2: Social Construction of Technology (SCOT) Model for Renewable Energy Strategy in Developing Countries. The figure identifies major social groups that are interrelated to the strategy, and outlines how these groups can affect each other.

Urmee & Md (2016) also investigate the diffusion of these technological systems through a framework similar to Rogers *et al.* (2019), in their research on the diffusion of innovations. This framework provides an excellent level of analysis for renewable energy systems, as Urmee & Md (2016) use the concept of “early adopters” of a technology to formulate strategies to improve the integration of this technology into the society. When analyzing different countries’ renewable energy policy, identifying the early adopters of the technology is key to determining whether it will be successful in the long term. Any strategy that targets this group will be able to accelerate the diffusion of that energy system through the society, as early adopters of the technology are able to promote integration and acceptance of the system to their peers. Figure 3, adapted from Rogers (1983), demonstrates how targeting early adopters can lead to accelerating exponential growth of the technology, as the early majority follows the early adopters, and is a large fraction of the population. The figure denotes by color what the focus of the research will be, with the greatest focus being put on the early adopters in green, and the least focus on the laggards in red. The early and late majority are yellow and orange respectively, to show that they will not be a main focus of the research, but will certainly be considered. Innovators are colored gray to show that they will not be applicable to the research, as existing technologies will be used instead of new ones.

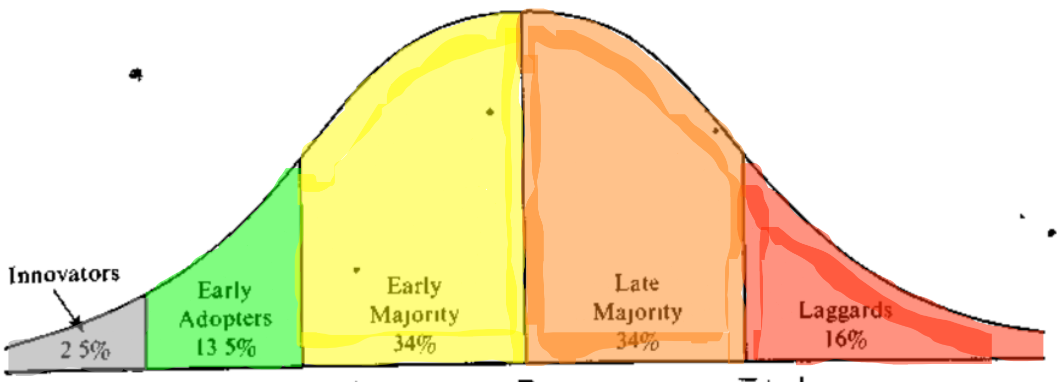

Figure 3: Categorization of Adopters in Diffusion of Innovation Analysis. This figure gives the categories outlined under diffusion analysis, and the percentage of each that make up the population adopting the technology, along with colors representing how much focus is to be placed on each category, with green denoting the highest level of focus. (Adapted by Jack Carroll (2022) from Rogers (1983, p. 247)).

This research paper will be written as a scholarly article, reviewing current strategy, discussing implications of proposed solutions, and analyzing the influence the technology will have on the local society.

A BLUE-GREEN FUTURE

The future of the planet depends on those willing to take action to drive forward technologies that reduce greenhouse gas emissions, whether they are policy makers, scientists, or engineers. Transitional technology like blue hydrogen can ease our effect on the planet in the short term, while long-term solutions require poor and wealthy countries to come together to find common ground solutions in the implementation of renewable energy. There is no doubt that these types of technologies are the future- the question remains whether society will be able to overcome the looming socioeconomic and technical obstacles to bring them into fruition.

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