Design of a Blue Hydrogen Process Utilizing Autothermal Reforming (ATR)
(Technical Topic)

The Effect of *Chernobyl* (2019) on the Perception, Development, and Current Implementation of Nuclear Energy in the United States
(STS Topic)

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
Collin Barbosa

December 9, 2022

Technical Team Members
Brenna Bartholomew, Jack Carroll, Jonathan Paul, and Alex Ton

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.

ADVISORS

Prof. MC Forelle, Department of Engineering and Society

Prof. Eric Anderson, Department of Chemical Engineering

Introduction

In 2014, the Intergovernmental Panel on Climate Change (IPCC) released their Fifth Assessment Report (AR5), an in-depth analysis on the effect of greenhouse gases (GHG) on global climate and the consequences it poses on society. Many of the conclusions found in the report were severely alarming. Observed increases in atmospheric greenhouse gas concentrations were discovered to raise the "likelihood of severe, pervasive, and irreversible impacts," seen in the form of rising sea levels, dangerous weather, longer droughts, decreased food production, and much more (IPCC Working Group II, 2014, p. 14). Not only was it extremely likely that human influence was the leading cause of these increases, but current energy practices were completely incompatible with the end-of-century target goal of reducing global temperatures by 1.5 to 2 degrees Celsius (IPCC Working Group I, 2014). What's even more concerning is that the IPCC's Sixth Assessment Report (AR6), whose studies have been released in the past year, doubles down on AR5's conclusions with some calling it "the starkest warning yet" (Harvey, 2021). If we're going to meet the target goal set by IPCC, reduce net GHG emissions, and continue to satisfy our ever-growing energy needs, transitioning to non-fossil fuel energy sources is a necessary change (United Nations, 2021).

In the United States, fossil fuels reign supreme as energy sources. Last year natural gas, petroleum, and coal made up over 70 percent of energy consumption by source (U.S. Energy Information Agency, 2022). While there remains an abundance of these natural resources for the foreseeable future, utilizing these sources for energy production generates carbon dioxide (CO_2), the GHG most responsible for global warming (U.S. Environmental Protection Agency, 2020). Now the obvious solution appears to be developing renewable energy like solar panels or wind turbines, however the full substitution of this kind of energy is simply not feasible right now. It may be a long-term solution, but nowadays there are issues of scale-up, costs being too expensive, lack of existing infrastructure, finding a suitable replacement for petroleum in the transportation sector, and much more (Wu, 2018). Therefore, efforts put into nuclear energy and more recently, carbon capture and storage (CCS) are incentivized simply because they don't require so much drastic change. Nuclear energy has plenty of existing infrastructure, and CCS technology can be retrofitted to existing processes.

Nuclear energy works by fissioning radioactive elements, most commonly uranium-238, to generate heat for steam production. This steam is then used by a turbine to generate electricity for the grid. Appeal for nuclear energy came from the fact that no CO_2 is emitted during the process, and because the fuel is recyclable (Rapier, 2022). However, radioactive waste is produced during the fission process requiring adequate storage, and potential disasters could be absolutely devasting. CCS is an umbrella term for processes that capture CO_2 formed during power generation before it is released to the atmosphere. The CO_2 is then sequestered and stored in geological formations underground, where it can stay there for thousands of years (Dunne, 2018). Both of these technologies will be investigated to solve the core problem of GHG emissions and their effect on our planet. The technical topic will explore the design of a hydrogen plant that utilizes CCS, while the STS (Science and Technology in Society) topic will investigate how HBO's *Chernobyl* (2019), a television show about the eponymous event, affected perception and growth of nuclear energy in the United States.

Technical Topic

Hydrogen has seen growing potential in recent years as an energy source for electricity generation in homes and vehicles, as the development of other renewable sources and biofuels remains slow in many regions. However, hydrogen is not abundantly available in nature 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 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 is reacted to produce hydrogen and CO_2, but the CO_2 is not captured and stored. (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 my capstone team proposes 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 that generally cares more and more about reducing their carbon footprint, this is a major step towards emission-less 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. A generalized block flow diagram developed by the technical project team for the full process is displayed in Fig. 1, including all of the relevant process streams, compositions, and unit operation.

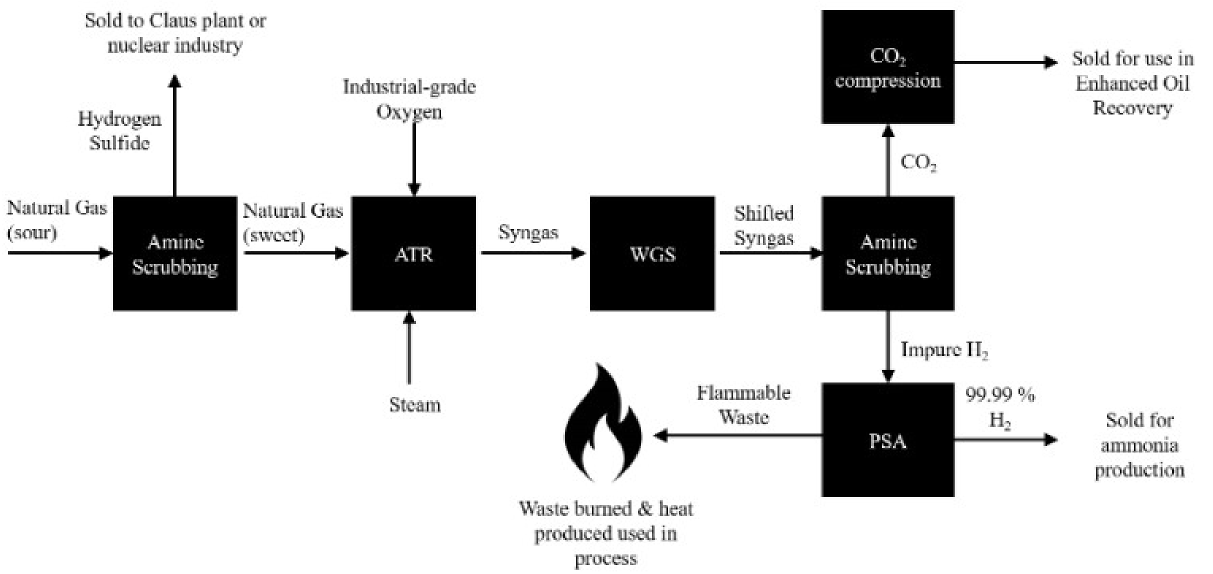

Figure 1: Block Flow Diagram for the Proposed Blue Hydrogen Process. This figure shows the major unit operations for autothermal reforming, including process stream composition and end use of products. From *Design of a Blue Hydrogen Process Utilizing Autothermal Reforming (ATR)* [Unpublished engineering capstone project], by C. Barbosa, B. Bartholomew, J. Carroll, J. Paul, & A. Ton. University of Virginia.

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 (U.S. Bureau of Labor Statistics, 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), which is currently the most profitable use of CO_2. 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, a simulation software that models chemical processes, to digitally replicate the complex chemical behavior and unit operations within our designed plant. Additionally, we plan to 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, of which is crucial to determining the project's feasibility, and influences several design choices (Ali et al., 2021; Oni et al., 2022). 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.

Our technical project relates to my STS problem in that they both address alternative forms of energy or processes that have been proven to have a positive impact on reducing GHG emissions. While my STS problem is more heavily focused on public opinion/perception, blue hydrogen also has to deal with support or backlash from the public and government officials. The particular way in which we design our process, including the location we choose for it, will have massive effects on how different groups view the project.

STS Topic

Like many proposed solutions to undesired phenomena, various alternative sources and technologies suggested to replace fossil fuels and their associated GHG emissions rarely have a unified opinion on them. Some critics view these measures as simply impractical, while others are opposed for economic and political reasonings, or comfort for the status quo (Gross, 2022). One that continues to split individuals and groups alike, especially in the polarized United States, is nuclear energy (Leppert, 2022).

Although oil and natural gas accidents are far more likely to occur than nuclear ones, the consequences of a worst-case scenario nuclear disaster are devastating due to the long-lasting effects of radiation (Gordelier & Cameron, 2010). No accident better encapsulates this consequence more than the nuclear disaster in Chernobyl. On April 26, 1986, near the city of Pripyat, Ukraine, the 4th reactor of Chernobyl Nuclear Power Plant experienced a meltdown which caused explosions and fires that released radioactive contaminants. While the true death toll is highly disputed and likely to remain unknown, it possible that thousands perished as a result of radiation exposure and cancer (Gray, 2019). The exclusion zone of Chernobyl, set because of the radioactive contaminants, won't be habitable again for another 20,000 years (Tedesco, 2022). Possibilities like this, however unlikely to occur again, can deter people from backing nuclear energy. Media depictions of nuclear energy, and more prominently their disasters, also can have an effect on how individuals and groups view the technology and industry as a whole (Hacquin et al., 2022). One such piece was HBO's *Chernobyl* (2019), a historical drama television show retelling the story of the eponymous disaster. *Chernobyl* was a huge success, both critically and commercially, with Google ranking it the fourth most popular show of 2019 (Venable, 2019). A major source of criticism for the show was its historical inaccuracies, where artistic liberty was used to exaggerate some of the events. My STS research project will seek to analyze how, if at all, the show affected public perception of nuclear energy, and by extension its implementation across the United States.

The STS problem relates to my technical team's project in that both involve technologies which are proven to work, but how different groups see them affects their development and use in our society. On the technical side nuclear energy has received a lot of safety updates and new innovations, though the core means of energy production has stayed the same, similar to blue hydrogen and its relationship to gray hydrogen. Much of the same can be said for television development, where increased budgets and better viewing mediums have led to a higher standard of immersion from audiences.

There are two STS theories/frameworks I will be relying on to investigate this STS topic. The first, and most important, will be the framework of Sociotechnical Imaginaries pioneered by Sheila Jasanoff and Sang-Hyun Kim. Sociotechnical Imaginaries are defined as "collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific and/or technological projects" (Jasanoff & Kim, 2009, p. 120). This framework is useful for explaining social opinions on technology and depictions of that technology, as well as the impact those have on shaping policy decisions. A secondary STS theory I plan to use is Langdon Winner's *Do Artifacts Have Politics?* where he argues that nuclear energy is an inherently political artifact requiring a particular political arrangement (Winner, 1980). This fits quite nicely within the framework of Sociotechnical Imaginaries, and can help bridge opinions of society and government with nuclear energy and *Chernobyl*. Each author cited also discusses nuclear energy and its complicated relationship to nuclear weapons within the lens of their respective framework/theory, which is especially relevant to my STS topic (Jasanoff & Kim, 2009; Winner, 1980).

Research Question and Methods

My research question is how did *Chernobyl* (2019) affect the perception, development, and current implementation of nuclear energy in the United States? Finding answers to this research question is vital to understanding the effect pieces of media have on particular technologies, and determining whether nuclear energy has a larger role in our society going forward. I plan to research and answer this question by using discourse analysis and literature review/synthesis primarily within the framework of Sociotechnical Imaginaries. More specifically, Jasanoff and Kim's framework will be incorporated through the lens of future societal and governmental dreams as opposed to in-depth analysis of policy enactments.

For discourse analysis, I intend to use various critic and audience reviews to gauge their emotions and takeaways of the show. Preference will be given to critic reviews, not because their opinions mean more than general audiences, but the fact that their reviews are viewed more and can sway individuals who haven't even seen the show (Greally, 2021). There will also be time spent ensuring that most of the reviews used in the final deliverable have something unique to say. While many reviews that state the same thing can be used for illustrating the magnitude of that takeaway, they unfortunately don't deepen or broaden the analysis. In regards to literature review/synthesis, I will investigate research papers that show the specific impact of *Chernobyl* on the three outlined characteristics of nuclear energy. Sources that also look at human psychology when it comes to disgust or anxiousness associated with nuclear energy, comparisons of the frequency of nuclear disasters to other energy source catastrophes, historical analysis of the impact of other media depicting real or fictional nuclear disasters, investigations into the artistic liberties HBO took, and national polls will also be used to provide context and explanation for the show's impacts. Both the research question and the methods will be addressed essentially under the framework of Sociotechnical Imaginaries, with Winner's Political Artifacts also providing a foundation.

Conclusion

As the effects of global warming and climate change increase in magnitude over time, significant changes in the U.S.'s energy portfolio will need to be made in order to stop and reduce CO_2 emissions. That being said, gradual changes or solutions that are easier to implement are more likely to be pursued in the near term. This research paper proposes two such solutions to this overarching problem, one technical and one related to STS: the development of a blue hydrogen production plant, and the understanding of how *Chernobyl* (2019) affected the perception, development, and current implementation of nuclear energy in the country. Designing a blue hydrogen process allows the U.S. to continue to use fossil fuels because the resulting CO_2 is captured, while the STS research can show how impactful pieces of media have on our emotions regarding certain technologies. I anticipate that the show had a negative effect on peoples' perception of nuclear energy, therefore contributing to decreased development and implementation of the industry in society. This in turn affects discussion about the energy transition and the problem at hand, since nuclear energy can no longer just be investigated for its energy capabilities.

References

Ali, K., et al. (2021) "A Framework for Assessing Economics of Blue Hydrogen Production from Steam Methane Reforming Using Carbon Capture Storage & Utilisation." *International Journal of Hydrogen Energy*, vol. 46, no. 44, 28 June 2021, pp. 22685–22706., https://doi.org/10.1016/j.ijhydene.2021.04.104.

Barbosa, C., Bartholomew, B., Carroll, J., Paul, J., & Ton. A. (2022). *Design of a Blue Hydrogen Process Utilizing Autothermal Reforming (ATR)* [Unpublished engineering capstone project]. University of Virginia.

Carver Pump. (2021, July 23). How Amine Treating Works - Amine Scrubbing System Overview. *Carver Pump*. https://www.carverpump.com/amine-scrubbing-system-overview/

Dunne, D. (2018, December 6). World can 'safely' store billions of tonnes of CO2 underground. *Carbon Brief*. https://www.carbonbrief.org/world-can-safely-store-billions-tonnes-co2-underground/

Gordelier, S., & Cameron, R. (2010). Comparing Nuclear Accident Risks with Those from Other Energy Sources [eBook]. In *Nuclear Development*. Nuclear Energy Agency, Organization for Economic Co-operation and Development. https://www.oecd-nea.org/jcms/pl_14538/comparing-nuclear-accident-risks-with-those-from-other-energy-sources

Gray, R. (2019, July 25). The True Toll of the Chernobyl Disaster. *BBC Future*. https://www.bbc.com/future/article/20190725-will-we-ever-know-chernobyls-true-death-toll

Greally, J. (2021, September 30). How Much Influence Do Movie Reviews From Film Critics Have On Audiences? *Big Picture Film Club*. https://bigpicturefilmclub.com/how-much-influence-do-movie-reviews-from-film-critics-have-on-audiences/

Gross, S. (2022, March 9). Renewables, land use, and local opposition in the United States. *Brookings Institute*. https://www.brookings.edu/research/renewables-land-use-and-local-opposition-in-the-united-states/

Hacquin, A., Altay, S., Aarøe, L., & Mercier, H. (2022, April). Disgust sensitivity and public opinion on nuclear energy, *Journal of Environmental Psychology*, 80, https://doi.org/10.1016/j.jenvp.2021.101749.

Harvey, F. (2021, August 25). Major climate changes inevitable and irreversible – IPCC's starkest warning yet. *The Guardian*. Retrieved March 5, 2023, from https://www.theguardian.com/science/2021/aug/09/humans-have-caused-unprecedented-and-irreversible-change-to-climate-scientists-warn

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jasanoff, S., & Kim, S. (2009, June 26). Containing the Atom: Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea. *Minerva*, *47*(2), 119–146. https://doi.org/10.1007/s11024-009-9124-4

Lamb, J., Hillestad, M., Rytter, E., Bock, R., Nordgard, A., Lien, K., Burheim, O., & Pollet, B. (2020). Traditional Routes for Hydrogen Production and Carbon Conversion. *Hydrogen, Biomass, and Bioenergy*, *3*, 21-53. doi: 10.1016/B978-0-08-102629-8.00003-7

Leppert, R. (2022, March 23). Americans continue to express mixed views about nuclear power. *Pew Research Center*. Retrieved October 13, 2022, from https://www.pewresearch.org/fact-tank/2022/03/23/americans-continue-to-express-mixed-views-about-nuclear-power/

Nikolaidis, P. & Poullikkas, A. (2016). A Comparative Overview of Hydrogen Production Processes. *Renewable and Sustainable Energy Reviews*, *67*, 597–611. doi: 10.1016/j.rser.2016.09.044

Oni, A.O., et al. (2022). "Comparative Assessment of Blue Hydrogen from Steam Methane Reforming, Autothermal Reforming, and Natural Gas Decomposition Technologies for Natural Gas-Producing Regions." *Energy Conversion and Management*, vol. 254, 15 Feb. 2022, p. 115245., https://doi.org/10.1016/j.enconman.2022.115245.

Rapier, R. (2022, August 27). Nuclear Power Could Cut The World's Carbon Emissions In Half. *Forbes*. https://www.forbes.com/sites/rrapier/2022/08/27/nuclear-power-could-cut-the-worlds-carbon-emissions-in-half/?sh=2228db737738

Roberts, D. (2019, October 2). Could Squeezing More Oil out of the Ground Help Fight Climate Change? *Vox*. https://www.vox.com/energy-and-environment/2019/10/2/20838646/climate-change-carbon-capture-enhanced-oil-recovery-eor.

Tedesco, L. (2022, January 12). Chernobyl: Over 35 Years On, Is It Actually Safe To Visit? *The Travel*. https://www.thetravel.com/is-chernobyl-safe-to-visit/#:~:text=How%20Long%20Will%20It%20Take,again%20is%20about%2020%2C000%20years.

Yu, M., Wang, K., & Vredenburg, H. (2021). Insights into low-carbon hydrogen production methods: Green, Blue and Aqua Hydrogen. *International Journal of Hydrogen Energy*, *46*(41), 21261–21273. doi: 10.1016/j.ijhydene.2021.04.016

United Nations. (2021). Theme Report on Energy Transition. In *United Nations*. https://www.un.org/en/hlde-2021/page/theme-reports

U.S. Bureau of Labor Statistics. "PPI Industry Data for Industrial Gas Manufacturing-Oxygen, Not Seasonally Adjusted." *BLS Data Labs*, U.S. Bureau of Labor Statistics, Sept. 2022, https://beta.bls.gov/dataViewer/view/timeseries/PCU325120325120A.

U.S. Department of Energy. "Hydrogen Benefits and Considerations." *Alternative Fuels Data Center: Hydrogen Benefits and Considerations*, U.S. Department of Energy, https://afdc.energy.gov/fuels/hydrogen_benefits.html#:~:text=Hydrogen%20can%20be%20produced%20from,water%20vapor%20and%20warm%20air.

U.S. Energy Information Administration. (2022, April). U.S. Energy Facts Explained - Consumption and Production. *U.S. Energy Information Administration (EIA).* https://www.eia.gov/energyexplained/us-energy-facts/

U.S. Environmental Protection Agency. (2022, May 16). Overview of Greenhouse Gases. *U.S. Environmental Protection Agency (EPA).* https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Venable, N. (2019, December 12). The 10 Most Popular TV Shows Of 2019, According To Google. *Cinema Blend*. https://www.cinemablend.com/television/2486624/the-10-most-popular-tv-shows-of-2019-according-to-google

Winner, L. (1980). Do Artifacts Have Politics? *Daedalus*, *109*(1), 121–136. http://www.jstor.org/stable/20024652

Woolgar, S. (1990, May). Configuring the User: The Case for Usability Trials. *The Sociological Review*, *38*(1_suppl), 58–99. https://doi.org/10.1111/j.1467-954X.1990.tb03348.x

Wu, S. (2018, May 10). Renewable Energy Is The Future. So Why Are We Still Stuck In The Past? *GBH News*. https://www.wgbh.org/news/commentary/2018/05/10/renewable-energy-is-the-future-so-why-are-we-still-stuck-in-the-past