MSE 498 HW 6

Proposal to replace coal-fired boilers in Abbott Power Plant with green hydrogen-fired gas turbines

Jacob Christensen
RJ Flores Mangaran
Chang Liu
Angela Pak
Devon Samuel

We propose replacing the three coal gasification boilers at Abbott Power Plant in Champaign, IL with a hydrogen (H_2)/natural gas-burning gas turbine. This will provide an immediate reduction in greenhouse gas emissions from the elimination of coal as fuel. To provide H_2 gas to the new turbine, electrolyzers will be installed near the University of Illinois Solar Farm 2.0 and powered by the solar farm, which will be expanded so it can completely power the electrolyzers. As additional hydrogen infrastructure is built in the US and H_2 gas production rises, the proportion of H_2 burned in the turbines will be increased, further reducing greenhouse gas emissions. Improvements in electrolyzer efficiency over time will reduce the energy consumption of the electrolyzers and allow some of the energy from the solar farm to be used directly for power on the Urbana campus.

Globally, there is an accelerating shift from fossil fuels toward renewable energy sources due to climate and environmental issues. Despite the increased attention, renewable energy currently accounts for only 14 percent of global energy use.[1] Many of the widely adopted renewable energy sources today also suffer from transient characteristics; wind and solar power, for instance, are difficult to store in the long-term and depend on weather conditions for on-demand use. In China, for example, approximately 20 percent of all generated solar power goes unused, with similar wind power inefficiency.[2] Thus, there is a need to be able to store energy generated by renewable methods for later use.

Renewable hydrogen power as an alternative fuel could provide efficient and abundant storage. Per unit mass, H_2 gas contains about three times as much energy as gasoline.[3] Globally, about 70 million metric tons of hydrogen fuel is already produced for various industrial processes,[4] but approximately 95 percent of this hydrogen is produced by high-carbon processes, referred to as "gray" hydrogen.[4,5] In contrast, "green" hydrogen is produced through renewable sources with at least a 70 percent decrease in emissions over fossil fuels. Electrolysis, the splitting of water with an electrical current, is the dominant and most efficient process for producing green hydrogen.[6,7,8] This method offers synergy with other renewable sources that produce electricity such as wind and solar energy.

Although green hydrogen is the most expensive to produce, it is the most transformative in the long run. Currently, about half the population in the US lives in places with air pollution that may cause adverse side effects. Hydrogen fuel from renewable sources can help alleviate this problem; when burned with oxygen, hydrogen only produces water vapor as an emission. Because of the advantages of hydrogen fuel, we propose the production of green hydrogen through electrolysis and replacing the coal boilers with hydrogen-burning turbines at Abbott Power Plant in Champaign, IL, providing immediate reduction in carbon emissions (Fig. 1). This will position the University of Illinois (UIUC) at the forefront of the field of hydrogen power, acting as a hub for future education and improvements for the industry.

Regarding new components, a hydrogen-burning power plant requires a hydrogen-compatible gas turbine; an H_2 gas source; storage for the H_2 gas; and pipelines to transfer gas between components. There is currently little hydrogen-transfer infrastructure in the US, so it will be necessary to produce H_2 gas on-site at least until that infrastructure is built out. To avoid the use of fossil fuels, the project's H_2 gas will be produced with electrolyzers powered

---

1 Parra, D., Valverde, L., Pino, F. J., & Patel, M. K. (2019). A review on the role, cost and value of hydrogen energy systems for deep decarbonisation. Renewable and Sustainable Energy Reviews, 101, 279–294. https://doi.org/10.1016/j.rser.2018.11.010

2 Chi, J., & Yu, H. (2018). Water electrolysis based on renewable energy for Hydrogen production. Chinese Journal of Catalysis, 39(3), 390–394. https://doi.org/10.1016/s1872-2067(17)62949-8

3 Yue, M., Lambert, H., Pahon, E., Roche, R., Jemei, S., & Hissel, D. (2021). Hydrogen Energy Systems: A critical review of technologies, applications, trends and challenges. Renewable and Sustainable Energy Reviews, 146, 111180. https://doi.org/10.1016/j.rser.2021.111180

4 Cho, R. (2021, January 7). *Why We Need Green Hydrogen.* Columbia Climate School. https://news.climate.columbia.edu/2021/01/07/need-green-hydrogen/

5 Hermesmann, M. & Müller, T. E. (2022). Green, turquoise, blue or grey? Environmentally friendly hydrogen production in transforming energy systems. *Progress in Energy and Combustion Science*, 90. https://doi.org/10.1016/j.pecs.2022.100996

6 Smolinka, T., Wiebe, N., Sterchele, P., et al.. (2018). *Industrialisation of water electrolysis in Germany: Opportunities and challenges for sustainable hydrogen for transport, electricity and heat.* Federal Ministry of Transport and Digital Infrastructure. https://www.now-gmbh.de/wp-content/uploads/2020/09/181204_bro_a4_indwede-studie_kurzfassung_en_v03-1.pdf

7 Bertucciolo, L., Chan, Al, Hart, D., et al. (2014) *Study on development of water electrolysis in the EU*. Fuel Cells Joint Undertaking. https://refman.energytransitionmodel.com/publications/2020

8 Godula-Jopek, Agata. Hydrogen production: by electrolysis. John Wiley & Sons, 2015.

by solar energy from the UIUC Solar Farm 2.0. When power from this farm is not being sold to the utility grid,[9] hydrogen can act as a storage medium, compressed in high-pressure composite containers for later use. This existing power infrastructure at UIUC lends itself well to the proposed conversion to H_2 gas turbines. Over the past two years, GE has demonstrated the successful conversion of four traditional power plants similar to the Abbott Plant to at least partially hydrogen-based systems even without additional solar sources.

The setup of the hydrogen power plant is in part determined by the available hydrogen-compatible gas turbines and the capacity of Abbott Power Plant. The plant has eight generators (two gas turbines, three gas-fired boilers, and three coal-fired boilers) with an average capacity of 10.5 MW/generator.[10] The variety of turbines/boilers, as well as additional sources of university power, makes the system ideal for staggering power outages or throttling usage during initial installation of a hydrogen gas turbine. The lowest-capacity H_2-burning turbines are rated at 30-35 MW, so one turbine will provide the power of all three coal-fired boilers. Currently, turbines in this power range are limited to about 50-75% H_2 by volume, so natural gas must be burned as well.[11] The lowest power output for a turbine capable of burning 100% H_2 is about 45 MW. Turbines capable of burning 100% H_2 should be more widely available by 2030.[12]

An example H_2 gas turbine is the TM2500 made by General Electric Company. With a power output of 34 MW, this turbine uses about 51,000 kg of H_2 gas per day when operated at its maximum of 75% H_2/25% natural gas (reduces CO_2 by 50% compared to natural gas alone; see Fig. 2).[13] At a common power consumption of 50 kWh/kg and overall efficiency of 60%,[14,14] about 100 MW of power must be supplied to the electrolyzers to produce this amount of gas. This is about two times the average production of the UIUC Solar Farm 2.0 (55 MWh). To make up for this deficit, the turbine could be run with a lower fraction of H_2 in the gas mix or another solar or wind farm may be constructed. It would not be economical to purchase electricity to power the electrolyzers; additionally, that may undermine the goal of green hydrogen production. The estimated combined cost of the components is \$126-220 million;[15] forgoing a new solar farm would save about \$20 million but increase CO_2 emissions from the higher amount of natural gas in the fuel mix. Regular operational costs would be dominated by the gas compressor system at about \$3/kg of H_2 compressed (~\$155,000 to compress enough gas for one day without additional generation).[16] The conversion process would take 2-4 years, based on construction time for UIUC Solar Farm 2.0, with expansion of the solar farm as the longest step.

The use of hydrogen poses several risks which cannot be entirely eliminated and must be managed by proper maintenance and training. Foremost is that H_2 gas is flammable at

---

[9] UIUC. (n.d.). *Solar Farm 2.0*. UIUC Facilities & Services. https://fs.illinois.edu/Projects/solar-farm-2-0/

[10] UIUC. (n.d.) *Abbott Power Plant*. UIUC Facilities & Services. https://fs.illinois.edu/abbott-power-plant

[11] General Electric Company (n.d.) *Aeroderivative and heavy-duty gas turbines*. GE Gas Power. https://www.ge.com/gas-power/products/gas-turbines; Siemens AG (n.d.) *Zero Emission Hydrogen Turbine Center*. Siemens Energy. https://www.siemens-energy.com/global/en/priorities/future-technologies/hydrogen/zehtc.html

[12] General Electric Company (n.d.) *6B.03 gas turbine*. GE Gas Power. https://www.ge.com/gas-power/products/gas-turbines/6b

[13] Goldmeer, J. (2019). *Power to gas: Hydrogen for power generation* [White paper]. General Electric Company

[14] Cummins. (n.d.) HyLYZER-4000. Cummins Hydrogen. https://mart.cummins.com/imagelibrary/data/assetfiles/0070328.pdf

[15] At a price of \$800-1500/kW for the electrolyzers (Department of Energy. (2020). *Cost of Electrolytic Hydrogen Production with Existing Technology*. https://www.hydrogen.energy.gov/pdfs/20004-cost-electrolytic-hydrogen-production.pdf) and \$10-20 million for the gas turbine (Forecast International. (2010). *The Market for Gas Turbine Marine Engines*. https://www.forecastinternational.com/samples/F649_CompleteSample.pdf)

[16] Christensen, A. (2020). *Assessment of Hydrogen Production Costs from Electrolysis: United States and Europe.* International Council on Clean Transportation. https://theicct.org/publication/assessment-of-hydrogen-production-costs-from-electrolysis-united-states-and-europe/

concentrations between 4 and 75% of air and has a low minimum ignition energy.[17] Hydrogen can also damage and leak out of metal containers and pipelines over time. Composites could be used instead of metal, but are much more expensive.[18] Some logistical problems are whether there would be space available in the power plant for the hydrogen turbine after removing the coal-burning boilers, whether it is feasible to incorporate the new piping for the hydrogen turbine, and the availability of processed water for the electrolyzers. The water needs could be offset substantially by condensing and feeding water from the exhaust back into the electrolyzers.[19] If air is used as the oxygen source, the exhaust will need to be treated because combusting hydrogen gas with air produces harmful NO_x gasses. Space will need to be found for the electrolyzer units, each of which would be the size of a small building.

This conversion from coal to hydrogen power fits well with UIUC's established climate action plan to achieve carbon neutrality by 2050. Additionally, it will support the role of UIUC in the Midwestern Hydrogen Partnership, which is committed to the expansion of all sectors of hydrogen infrastructure and is already making steps towards clean energy solutions such as the development of hydrogen fuel cell public buses. The continued use of hydrogen based fuel systems would only add positively to the university's reputation of clean energy and remaining at the forefront of engineering opportunities. With its diverse educational opportunities, UIUC would play a leading role promoting clean energies given that the public awareness/understanding was identified as the largest barrier preventing public acceptance of hydrogen energy.[20]

This proposal also generates new opportunities for collaborative research with abundant support. The advancement of materials involved in the setup (storage, transportation, electrolysis) calls for research involving intra/inter-departmental collaboration such as materials science, mechanical, civil, and chemical engineering. In terms of existing interest and funding support, the U.S. Department of Energy (DOE) Hydrogen Program raised a project of Hydrogen from Next-generation Electrolyzers of Water (H2NEW) focusing on making large-scale electrolyzers with improved durability, efficiency and lower price. Additionally, potential outreach to other energy resources encourages new collaborations with funding opportunities. As an example, the initiative H2@Scale raised by DOE aims at bringing stakeholders to advance affordable hydrogen production, transport, storage, and utilization to enable decarbonization and revenue opportunities across multiple sectors (Fig. 3). Finally, UIUC's long-time collaboration with Argonne National Laboratory, a lab known for its involvement in these DOE projects, will assist in propelling the burgeoning hydrogen research.

---

[17] Astbury, G. R. (2008). A review of the properties and hazards of some alternative fuels. *Process Safety and Environment Protection*, 86, 397-414. http://dx.doi.org/0.1016/j.psep.2008.05.001

[18] Capuros, T., Stefanizzi, M., Torresi, M., & Camporeale, S. M. (2022). Perspective of the role of hydrogen in the 21st century energy transition. *Energy Conversion and Management*, 251. https://dx.doi.org/10.1016/j.enconman.2021.114898

[19] U.S. Environmental Protection Agency. (2023). *Hydrogen in Combustion Turbine Electric Generating Units*. https://www.epa.gov/system/files/documents/2023-05/TSD%20-%20Hydrogen%20in%20Combustion%20Turbine%20EGUs.pdf

[20] DoE (n.d.) *Hydrogen Shot Summit*. U.S. Department of Energy. https://www.energy.gov/eere/fuelcells/hydrogen-shot-summit

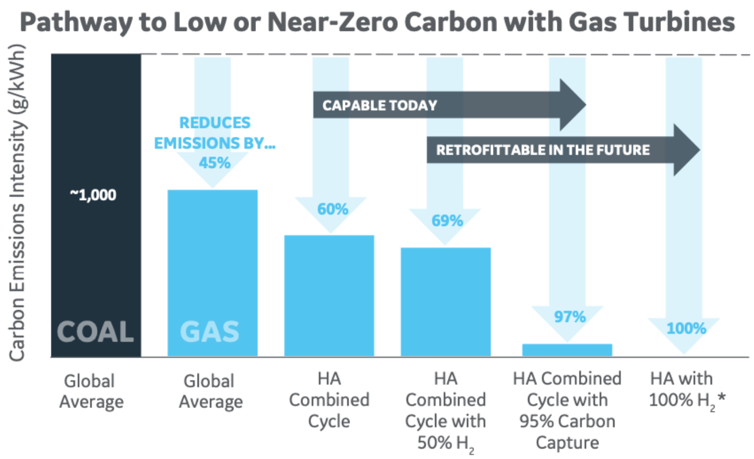

Figure 1: Reduction in CO^2 emissions from switching fuel away from coal.[21]

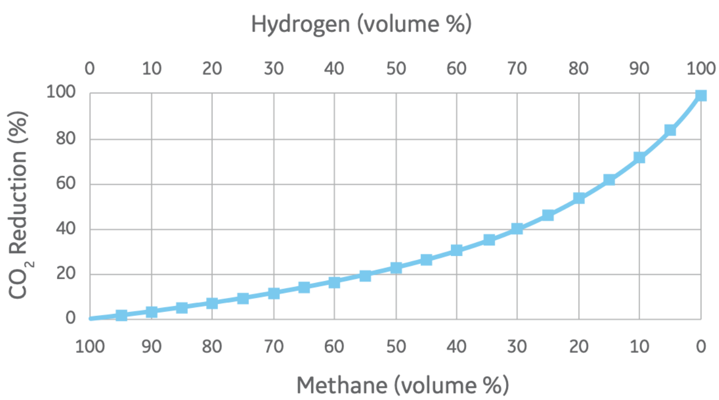

Figure 2: Change in CO_2 emissions as the H_2/methane ratio is changed.[21]

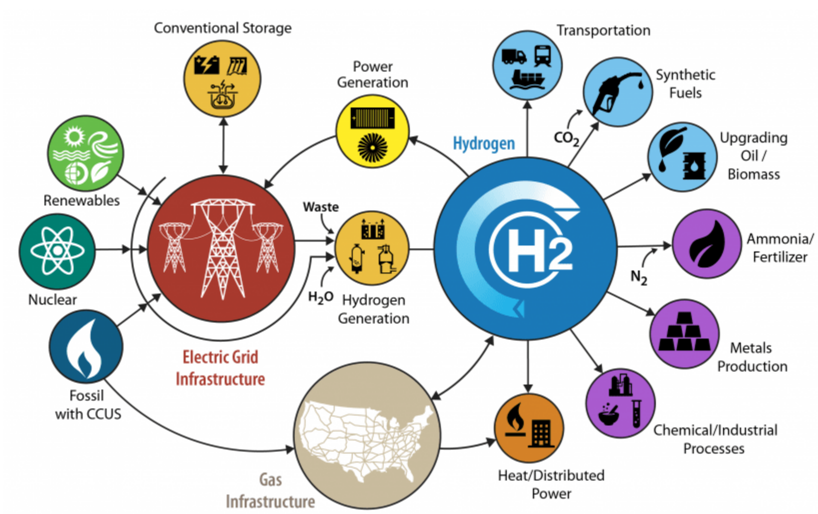

Figure 3: Connection of hydrogen to other energy resources and applications illustrated in H2@Scale.[22]

---

[21] Goldmeer, J. (2022). *Hydrogen for power generation.* [White paper]. General Electric Company

[22] DoE (n.d.) *H2@Scale*. U.S. Department of Energy. https://www.energy.gov/eere/fuelcells/h2scale