Renewable Electrolysis in Texas: Pipelines versus Power Lines

Using wind and solar generation to power electrolysis facilities and produce "green" hydrogen at scale would require infrastructure investment. Using current technology, we identify at least one situation in which producing hydrogen at the point of electricity generation and transporting it to the point of use via pipeline costs about one third that of transmitting the electricity and generating hydrogen at the point of use. This raises the possibility that hydrogen pipelines might provide an alternative to high voltage transmission lines for connecting renewable generation with demand. In this white paper, we explore the tradeoffs of those two options.

Texas produces one-third of the United States' hydrogen—roughly 9 million kg per day[1,2] equivalent to 300 GWh of energy. Texas also has abundant undeveloped renewable resources—approximately 40% of the United States' economically-viable wind resources and 50% of its economically-viable solar resources[3] – much more than needed to meet its electricity demand. Using electrolysis to produce hydrogen via electricity could provide an opportunity to harness these excess renewable resources. Recent announcements of wind-powered electrolysis projects indicate that there is a burgeoning market for such clean hydrogen.[4]

Texas' best wind and solar resources, however, are located far from hydrogen consumers. This analysis reviews two options for connecting those renewable resources with hydrogen consumers: 1) use power lines to move the renewable electricity to electrolysis units near the hydrogen demand, or 2) locate the electrolysis facilities near the electricity source and move the hydrogen to its final consumers via pipeline.

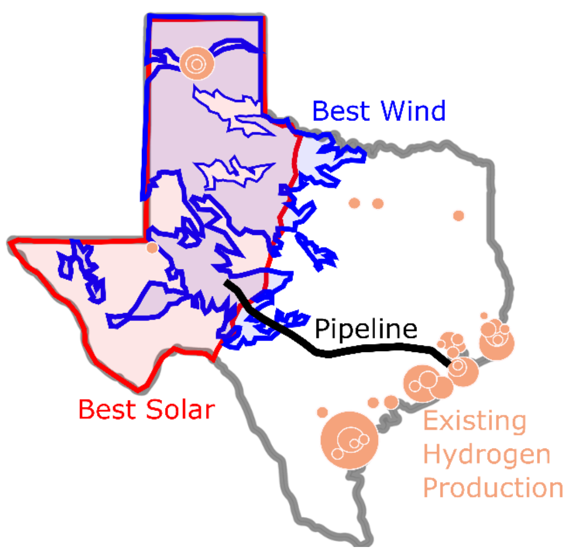

Figure 1: West Texas contains the best wind and solar resources . The Houston coast contains the greatest amount of existing hydrogen production and infrastructure . Here, a 400-mile long pipeline or transmission line connects them.

[1] https://www.energy.gov/eere/fuelcells/fact-month-may-2018-10-million-metric-tons-hydrogen-produced-annually-united-states
[2] Deetjen et al., "Market Competitive Electrolysis in ERCOT" (2021) https://sites.utexas.edu/h2/h2ut-white-papers/
[3] Brown et al. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results" National Renewable Energy Laboratory (2016) NREL/TP-6A20-64503
[4] https://www.utilitydive.com/news/developers-enter-largest-green-hydrogen-ppa-in-us-with-345-mw-of-wind-to-po/603366/

Using a case study of West Texas wind and solar resources along with Houston hydrogen demand, this paper explores key considerations for comparing these two energy transmission pathways. The conclusions show that hydrogen pipelines provide cost, energy storage, and other benefits when compared to power lines.

Scenario Comparisons

This section compares the delivery of renewable (green) hydrogen to hydrogen consumers in the Houston region using electricity generated in West Texas, where the best of Texas' wind and solar resources are. This analysis will use the existing Houston hydrogen demand as the baseline for the analysis, but additional future demands—including clean hydrogen exports—could further drive the development of these resources. Because both the pipeline and power line scenario utilize electrolysis, it was assumed that the bulk of their electricity needs would be similar.[5,6]

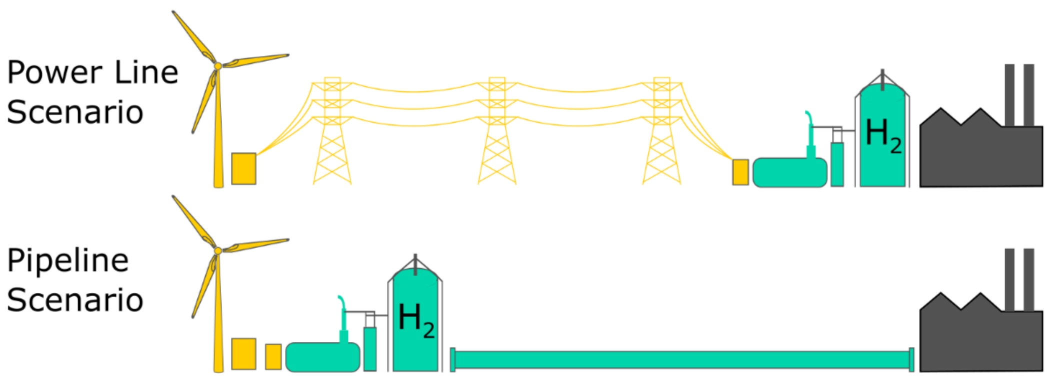

Figure 2: The two scenarios analyzed in this study. The Power Line scenario sites electrolysis near hydrogen consumers. The Pipeline scenario sites electrolysis near renewable electricity generators.

Power Line Scenario: Siting electrolysis near Houston hydrogen demand

If 25% of the daily Houston hydrogen demand—about 2.3 million kg—were met by local electrolysis, it would require an average of 4,000 MW[7] of *additional* electrical demand[8] in the region. This new electrical demand would increase the ERCOT Houston Load Zone's 2020 *peak* demand (19,700 MW) by 20% and increase its average demand (11,800 MW) by about 35%.

[5] Note that if brackish groundwater is used, there is an additional energy need to treat the water to a potable water standard assumed for the electrolysis. We quantify this cost later in the Qualitative Comparison section.
[6] Note that system-wide efficiency may increase by co-locating electrolysis with wind and solar facilities and feeding DC power directly from the generator to the electrolyzer, thus avoiding AC/DC conversion losses.
[7] Peak demand may actually be higher than this 4,000 MW, depending on the capacity of the electrolysis facilities. If the electrolysis facilities ramp up and down with wind and solar output, for example, their utilization would be lower than 100%, and a peak demand of greater than 4,000 MW would be required.
[8] Not including compression costs as it is assumed approximately the same amount would be needed for SMR as electrolysis.

Given the large increase in the amount of electricity demand for this scenario in the Houston region, it is likely that the transmission capacity into the region would need to substantially increase given the current levels of congestion.[9] If all of the excess power came from outside of the region, then approximately the same capacity of new high-voltage power lines—4,000 MW—would be required.[10,11]

The majority of high-voltage transmission lines in Texas are 345 kV lines, of which, a double circuit can move about 800 MW, depending on length and operating conditions. If all of the power necessary for this electrolysis were brought in via new lines, roughly 5 new transmission corridors of double-circuit 345 kV lines would be required[12].

Pipeline Scenario: Siting electrolysis near west Texas renewables

Alternatively, the electrolysis could be sited in West Texas and the renewable hydrogen transmitted to Houston via pipeline. A 36-inch diameter pipe operating at 600 psi can transmit about 2.1 million kg of hydrogen per day[13]—enough capacity to provide 25% of Houston's current hydrogen demand. This analysis assumes that such a pipeline would be constructed as a new-build. However, it could be possible to reuse some existing pipeline rights-of-way or repurpose natural gas pipelines for hydrogen transport.[14]

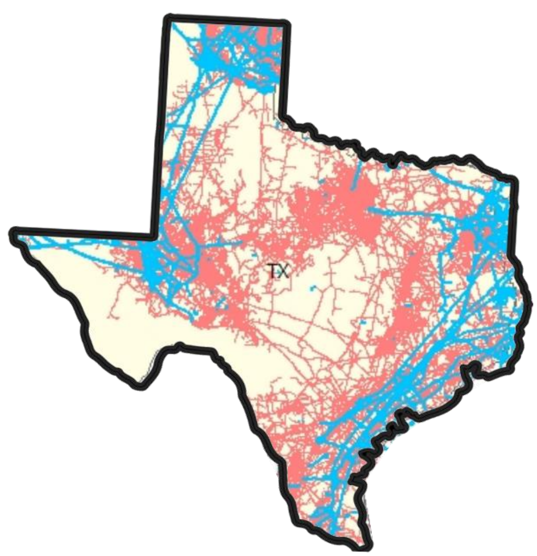

Figure 3: The natural gas infrastructure in 2013 (red=intrastate, blue=interstate)[1]. Existing pipeline right-of-way corridors may be useful for a potential hydrogen pipeline project.

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[9] ERCOT "Report on Existing and Potential Electric System Constrains and Needs" (December 2020)
[10] It is also likely that some distribution system upgrades would be required, but we assumed that the electrolysis systems would be large and directly connected to the transmission network.
[11] Because wind and solar capacity factors are less than 100%, it is assumed that the renewable electricity would be purchased through a Power Purchase Agreement on an annual volumetric basis and that there would be times where the power consumed by the constant electrolysis load would be provided by other types of generation resources.
[12] It is possible that the new electrolysis load could be operated flexibility and thus not require as many new lines, but that is beyond the scope of this white paper.
[13] https://www.energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf#page10
[14] https://www.siemens-energy.com/global/en/news/magazine/2020/repurposing-natural-gas-infrastructure-for-hydrogen.html

Siting the electrolysis in West Texas could avoid exacerbating the existing transmission congestion in the Houston region. In addition, since the curtailment of wind and solar generation in ERCOT has been steadily rising[15]—also because of transmission and reliability constraints—electrolysis located in West Texas would provide a local source of significant electricity demand that could provide a market for this curtailed energy and potentially support additional wind and solar development.

Capital Cost Comparison

Based on the assumptions in Table 1, the pipeline scenario has a lower unit capital cost than the power lines scenario. Table 1 shows assumptions for the cost analysis as well as the final hydrogen transmission cost on a $/kg basis for both options. We estimate that the electricity transmission scenario costs 0.46 $/kg of hydrogen, while the pipeline scenario costs 0.14 $/kg.

Table 1: Cost assumptions for each of the hydrogen transportation scenarios considered in this analysis as well as the per-unit cost for each kg of hydrogen delivered ($/kg). These costs exclude engineering components such as inverters, transformers, and compressors.

	4,000 MW Electricity Transmission	2.1M kg/day H2 Transmission
Cost Rate [16,17,18]	2,500 $/MW-mile	3.0 $M/pipeline-mile
# of new power lines/pipelines	5	1
Total Cost per Mile	$10,000,000	$3,000,000
Cost for 400 Miles	$4,000,000,000	$1,200,000,000
Annual Cost (6%, 20-yrs)	$348,000,000	$105,000,000
Unit Cost ($/kg-hydrogen)	$0.46	$0.14

Energy Storage Comparison: Line Pack

An oft discussed challenge of wind and solar generation is their intermittent generation that can be misaligned with the timing of electricity demand. This mismatch is generally balanced via dispatchable power plants, but it can also be balanced by flexible demand—e.g., electrolysis[19]—and energy storage.

[15] https://btuanalytics.com/power-and-renewables/ercot-wind-curtailments-how-much-and-where/
[16] Right-of-way costs are excluded from these costs. Right-of-way costs for transmission lines and natural gas pipelines are minor compared to total project costs, see Berry A "Getting Right-of-Way Right: Landowner Compensation for Electric Power Transmission Rights-of-Way, Lincoln Institute of Land Policy (2013) WP13AB1. Hydrogen pipelines may have a similar right-of-way cost if we assume they have imminent domain or they use existing natural gas pipeline rights-of-way.
[17] Transmission costs from Andrade J, Baldick R, "Estimation of Transmission Costs for New Generation," White Paper UTEI/2016-09-2, 2017, available at http://energy.utexas.edu/the-full-cost-of-electricity-fce/ edu/the-full-cost-of-electricity-fce/.
[18] Pipeline costs from Yang C, Ogden J, "Determining the lowest-cost hydrogen delivery mode." International Journal of Hydrogen Energy 32 (2007) 268-286--Table 7. Costs adjusted from 2006 to 2020 USD.
[19] In a previous white paper, we show that electrolysis facilities may operate at utilization rates as low as 65% without negatively impacting their production cost. See Deetjen et al., "Market Competitive Electrolysis in ERCOT" (2021) https://sites.utexas.edu/h2/h2ut-white-papers/

Gas pipelines can provide built-in energy storage through line-pack—where the pipeline operating pressure is adjusted within a minimum and maximum operating pressure range to account for imbalances between supply and demand on the pipeline system. Line-pack is commonly used, for example, to correct mismatches of supply and demand in the natural gas infrastructure.[20]

A 400-mile long, 36-inch pipeline has 14.7 million cubic feet of volume. If the pressure is increased from 500-psi to 1,000-psi, this pipeline would contain 1.0 million kg of additional, stored hydrogen[21]—a half-day of production in this example. Although actual line-pack practices may vary, such a pipeline could provide multiple hours of energy storage, which would improve the mismatch between renewable generation and demand.

The hydrogen itself could also be utilized as a primary or backup fuel for electricity generation. Current and emerging technologies for electricity generation from hydrogen include fuel cells, hydrogen-specific turbines, as well as burning natural gas and hydrogen blends in power plant turbines.[22]

The combination of electrolysis, line pack, and hydrogen-fueled turbines may provide an alternative pathway for increasing the demand for West Texas wind and solar, transmitting a low-carbon energy product to a major demand and export hub, and providing flexible load, energy storage, and dispatchable power for the electric grid.

Qualitative Comparison

Beyond cost and engineering metrics, there are other benefits of utilizing less infrastructure rights-of-way. In this analysis, the pipeline scenario uses one-quarter of infrastructure corridors as needed by the power line scenario. While permitting challenges can be difficult for all types of infrastructure, it is likely that the fewer throughfares needed for the pipeline scenario would be advantageous.

Scale Compared to Existing Infrastructure

There are approximately 5 major hydrogen pipelines[23] and 120 major oil, hydrocarbon gas liquids (HGL), and natural gas pipelines crossing into the greater Houston area[24,25,26] from other Texas counties, whereas only 34 large transmission lines cross the same boundary. Thus, routing 1 new pipeline to the Houston area would expand the existing energy pipeline infrastructure by less than 1%. Routing 5 new transmission lines to the Houston area would expand the existing transmission

[20] https://www.equitylifting.com/single-post/2017/10/25/linepack-explained
[21] H2Tools, Hydrogen density at different temperatures and pressures: https://h2tools.org/hyarc/hydrogen-data/hydrogen-density-different-temperatures-and-pressures
[22] Goldemeer, J "Power to Gas: Hydrogen for Power Generation: Fuel Flexible Gas Turbines as Enablers for a Low or Reduced Carbon Energy Ecosystem" (February 2019) GE Power, GEA33861
[23] According to data from the Texas Railroad Commission GIS Viewer: https://www.rrc.texas.gov/resource-center/research/gis-viewer/
[24] https://www.eia.gov/maps/layer_info-m.php
[25] https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines?geometry=-179.588%2C25.044%2C-12.156%2C49.180
[26] Includes Austin, Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller counties.

infrastructure by roughly 15%. Thus, the pipeline scenario may represent a minor increase in infrastructure, whereas the transmission line scenario represents a more major infrastructure investment.

Nimbyism / Right of Way

Building transmission lines is often harder than building pipelines. While there are famous examples of pipelines facing stiff competition (e.g., Keystone XL), until recently, the main resistances focused on environment, sensitive lands, and equity[27]. More recently, pipeline opposition has been led by groups opposing the use of fossil fuels, by equating pipeline construction with the increased use of fossil fuels and greenhouse gas emissions. Conversely, resistance to transmission lines is often focused on the aesthetics and the large right-of-way (ROW) implications that come with such large amounts of infrastructure above ground[28,29].

Given the extensive network of oil and gas pipelines that already connect West Texas to Houston, it seems unlikely that a hydrogen pipeline following an existing oil and gas corridor would meet much resistance. The right-of-way for a 36-inch diameter pipeline is much smaller than a high-voltage transmission line, and the visual impact on the landscape is also much smaller. Underground pipelines can also be more resilient to both natural and manmade disasters. It is also possible that, because the new pipelines could be seen as part of decarbonizing the energy system, they could face much less environmental push-back, if not outright support.

Water Requirements

Electrolysis requires access to purified water, essentially of distilled water quality. Assuming approximately 10 gallons of water are needed per kg of hydrogen produced[30], 2.1M kg/day of hydrogen would require about 21M gallons/day of freshwater to produce it.

One major disadvantage of siting electrolysis in West Texas is that the region is much drier than the eastern part of Texas where Houston is located.[31] While parts of West Texas are listed as having higher levels of water stress[32], vast amounts of brackish aquifers also exist in the region. These aquifers vary in their salinity levels, but are generally shallow. The Texas Water Development Board has estimated that the West Texas region contains about 450 million acre-feet of brackish water aquifers.[33] If desalinated, this volume of water would be sufficient for about 4,000 years' worth of water needed to meet Houston's current hydrogen demand using electrolysis.

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27 https://wagingnonviolence.org/2021/01/keystone-xl-tar-sands-pipeline-defeated-climate-movement/
28 https://www-sciencedirect-com.ezproxy.lib.utexas.edu/science/article/pii/S0272494410000174
29 https://journals-sagepub-com.ezproxy.lib.utexas.edu/doi/10.1177/0013916512440435
30 https://www.hydrogen.energy.gov/pdfs/review16/sa039_elgowainy_2016_o.pdf (slide 15)
31 Midland, TX (West Texas) receives about 15 inches of rain per year whereas Houston, TX receives about 50 inches of rain per year.
32 https://www.globalchange.gov/browse/multimedia/water-stress-us
33 Volumes of aquifers at 1,000-3,000 TDS quality for regions A, B, F, G, & O (Figure 2 of http://www.twdb.texas.gov/publications/reports/numbered_reports/doc/r363/b2.pdf)

Brackish water requires additional energy for desalination. Previous work has estimated that the cost of desalination powered by renewables in West Texas would cost about $4 per thousand gallons.[34] This extra step would add about $0.04/kg to the cost of hydrogen.

Alternate Pathways: Near-shore Wind or West Texas SMR+CCS

While this analysis has focused on renewables in West Texas, it is also possible to consider wind resources near the Texas Gulf Coast. Windspeeds along the Gulf Coast can rival those in the western parts of the state[35], and these wind farms can be sited much closer to the existing Texas hydrogen demand. Electrolysis facilities sited with near-shore wind farms could more easily connect to the existing Gulf Coast hydrogen pipeline network.

Instead of using electrolyzers in West Texas to produce "green" hydrogen, it is also possible to use SMR+CCS in West Texas to produce "blue" hydrogen: not to leverage wind and solar resources, but to leverage local natural gas production and CO_2 demand for enhanced oil recovery (EOR). The Permian Basin—which is generally located in the same area as Texas' best wind and solar resources—also has large amounts of stranded natural gas. While natural gas pipeline additions have allowed some of this stranded gas to come to market, flaring rates were as high as 660 MMcf/d in the first quarter of 2019. This amount natural gas could produce 4.3M kg/day of hydrogen if used as a feedstock for SMR. By coupling SMR with CCS, a producer could feed stranded natural gas into an SMR facility, use the produced CO_2 for local EOR, and transmit the hydrogen to Houston via pipeline.

This West Texas SMR+CCS hydrogen pathway provides an alternate set of arguments of producing hydrogen in West Texas. By combining these arguments with the previous discussion of a Wind/Solar+Electrolysis pathway, there may be numerous reasons to support the construction of a West-Coastal Texas hydrogen pipeline. Even if the "blue" and "green" hydrogen remain physically separated in independent pipelines[36], they could be designed, sited, and constructed as part of the same project.

Conclusion

Texas has an abundance of wind and solar resources that could be used to produce renewable hydrogen. Compared to electricity transmission lines, using a pipeline to transport renewable hydrogen from West Texas to Houston potentially has cost, energy storage, and other advantages. The construction of such a pipeline would enable wind and solar development beyond the existing electrical transmission constraints, provide energy storage through line pack, enable flexible electricity demand, and provide fuel for low-carbon dispatchable power plants. The construction of

[34] https://www.sciencedirect.com/science/article/pii/S0011916418309949?via=ihub#f0010
[35] https://www.nrel.gov/gis/assets/images/wtk-80m-2017-01.jpg
[36] Some international consumers, for example, may only be interested in importing zero-carbon, renewable hydrogen, in which case "green" hydrogen might need to remain separated from hydrogen produced via other methods.

such a pipeline may also enable the development of SMR+CCS facilities that consume stranded natural gas, provide CO_2 for enhanced oil recovery, and produce low-carbon hydrogen. In either case, a West-Costal Texas hydrogen pipeline could provide part of the necessary infrastructure for a zero- or low-carbon hydrogen market—whether for reducing the emissions of the existing Houston hydrogen system, serving new hydrogen demands such as heavy-duty trucks, or exporting to international markets. If hydrogen demand expands to other Texas cities, this initial pipeline could provide a backbone for a state-wide hydrogen pipeline network to build on.

Authors

Joshua D. Rhodes[1], Thomas A. Deetjen[2], Robert E. Hebner[2], Michael C. Lewis[2], Nico Bouwkamp[3], Brian Weeks[4], F. Todd Davidson[1], Alan C. Lloyd[2]

1. Ideasmiths, LLC, Austin, TX
2. Center for Electromechanics at the University of Texas, Austin, TX
3. Frontier Energy, Inc., San Ramon, CA
4. Gas Technology Institute, Houston, TX

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For general questions about the analysis work related to the UT H2@Scale project, please contact Dr. Thomas Deetjen, t.deetjen@cem.utexas.edu.

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