UW | School of Energy Resources

HYDROGEN DEVELOPMENT WITH CCS IN WYOMING

A collaboration between the University of Wyoming School of Energy Resources and the Energy and Environmental Research Center, as part of the Plains Carbon Dioxide Reduction (PCOR) Partnership

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Definitions and Abbreviations

Black hydrogen: Hydrogen produced from coal through the process of gasification without any associated emissions capture.

Blue hydrogen: Hydrogen produced from natural gas or coal, with the resulting carbon dioxide byproduct then captured and permanently stored underground in a suitable geologic formation.

Brown hydrogen: Hydrogen produced using brown coal (lignite) through the process of gasification without any associated emissions capture.

CCS or CCUS: Carbon capture and storage or carbon capture, use, and storage.

Fuel cell: A device that converts the chemical energy of hydrogen into electricity by reacting hydrogen with oxygen.

DOE: U.S. Department of Energy

Electrolysis: A hydrogen production process that uses electricity to split water into hydrogen and oxygen. This reaction takes place in a device called an electrolyzer.

Green hydrogen: Hydrogen produced through renewable energy powered electrolysis.

Grey hydrogen: Hydrogen produced from natural gas via an energy-intensive process (primarily steam methane reformers) without any associated emissions capture (which differentiates it from blue hydrogen). Grey hydrogen production results in more emissions than any other type of hydrogen production method.

Infrastructure Investment and Jobs Act (IIJA): Also referred to as the Bipartisan Infrastructure Law, the IIJA is a seminal piece of federal legislation passed in November 2021 that appropriates funding for low-carbon technology development across the United States, among other items of spending.

Inflation Reduction Act (IRA): The IRA, passed by the United States Congress in August 2022, is a foundational climate change mitigation bill that appropriates significant federal funding for investments in domestic energy production, with a goal of reducing domestic carbon dioxide emissions by roughly 40% by 2030.

Net-zero: The objective of balancing greenhouse gas emissions with the amount eliminated from the atmosphere through carbon dioxide removal and other emission mitigation technologies.

Pink hydrogen: Hydrogen produced through electrolysis that is powered by nuclear energy. Nuclear-produced hydrogen is also referred to as purple hydrogen or red hydrogen.

Yellow hydrogen: Hydrogen produced by electrolysis, fueled by solar power.

Introduction

Hydrogen is one of the most versatile and abundant elements on the planet, rendering it a source of potentially limitless energy. In alignment with goals to reach net-zero, the International Energy Agency (IEA) projects clean[1] (low-carbon) hydrogen sources to account for at least 10% of global energy consumption by 2050.[2] Blue hydrogen, a low-carbon form of hydrogen production where hydrogen is produced from natural gas or coal and the resulting CO_2 emissions are captured and stored, is key to unlocking this potential.

With its significant natural resources and history of energy production, Wyoming is an ideal candidate for blue hydrogen deployment. As a national leader in energy innovation and generation, Wyoming produces 13 times more energy than it consumes and ranks among the top ten states for both natural gas reserves and production.[3] Wyoming also has significant potential for geologic storage and has enacted a legal framework that clarifies the requirements of CCS projects, including laws that establish pore space ownership, allocate responsibility for long-term stewardship of the CCS facilities, and establish a permitting framework for CCS projects. In 2020, Wyoming became only the second state, after North Dakota, to receive primacy from the U.S. Environmental Protection Agency (EPA) for UIC Class VI wells for the geologic sequestration of carbon dioxide.[4] Wyoming's existing energy transport network includes both extensive rail, pipeline, and interstate highway systems that have evolved in correlation with Wyoming's export of energy to high-demand markets across the West Coast and the Midwest. Each of these features make Wyoming an ideal location for a blue hydrogen economy.

This paper begins in **Part I** by providing an overview of existing and developing applications for hydrogen in a net-zero economy, a description of existing hydrogen production methods (aka the "Hydrogen Rainbow"), and the increasing demands and incentives for clean hydrogen deployment. Specifically, the paper analyzes funding provisions in the IIJA and IRA that aim to accelerate development of the clean hydrogen industry. In **Part II**, the paper turns to an analysis of the geographic, economic, legal, and regulatory features that render Wyoming a particularly well-suited location for a blue hydrogen economy. As discussed in **Part III**, numerous projects to advance blue hydrogen development are already underway in Wyoming, including, but not limited to, Tallgrass MLP's Blue Bison Project located near Douglas and Williams' Southwest Wyoming Hydrogen Hub located near Opal and Wamsutter. These projects intend to capitalize on synergies between Wyoming's natural gas supply and associated infrastructure and the state's potential for widespread CCS deployment. **Part IV** concludes with a brief summary of policy opportunities for the State of Wyoming to fulfill its potential as a global "hydrogen headwaters" through blue hydrogen deployment.

[1] "Clean" or low-carbon hydrogen is defined in key legislation, such as the IIJA, to mean "hydrogen produced with a carbon intensity equal to or less than 2 kilograms of carbon dioxide (CO_2)-equivalent produced at the site of production per kilogram of hydrogen produced." 42 U.S. Code § 16166(b)(1)(B). In September 2022, DOE released draft guidance for the Hydrogen Production Standard (CHPS), proposing to establish an initial target for lifecycle greenhouse gas emissions of 4.0 $kgCO_2e/kgH_2$. *See https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-production-standard.pdf/.*

[2] Hydrogen, INT'L ENERGY AGENCY (last visited August 1, 2023) *https://www.iea.org/reports/hydrogen.*

[3] *https://www.eia.gov/state/?sid=WY.*

[4] 85 Fed. Reg. 64053 (2020); WYO. STAT. ANN. §§ 35-11-313; 35-11-315.

The Role of Hydrogen in a Clean Energy Economy

Current and Potential Applications of Hydrogen: Fuel Source, Storage, and Manufacturing

Hydrogen has a diverse and promising range of potential applications in a net-zero energy economy, both as a fuel and as an energy carrier to increase efficiencies of other energy resources used by the electric grid. Like natural gas, hydrogen can be burned as a standalone fuel source in turbines or engines. But unlike natural gas, hydrogen produces no greenhouse gas byproducts when burned. Hydrogen gas can also be utilized in fuel cell devices, which generate electricity and water through the reaction of hydrogen with oxygen, emitting only water and heat as byproducts. (*Figure 1*). Fuel cell devices can be used in a wide array of small-to large-scale settings, including, but not limited to, transportation, material handling, and stationary, portable, and emergency backup power.[5]

In addition to its applications as a direct energy source via combustion or fuel cell use, hydrogen plays an important role in aiding the electric grid integration of renewable energy resources. Renewable energy resources, such as solar and wind, generate electricity only intermittently, with seasonal and geographic variations in supply rendering these sources unable to fully meet continuous electricity demands. A potential solution to this problem is using hydrogen produced with excess electricity generated during peak periods of production to be stored and utilized for electricity during periods when the electric grid demand exceeds solar and wind-generated capacity.[6]

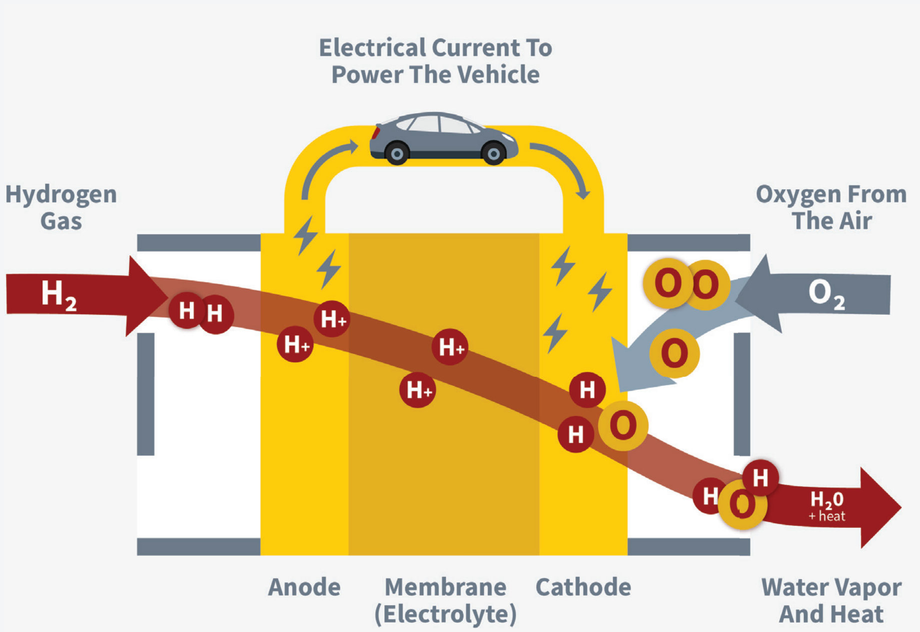

Figure 1: Hydrogen Fuel Cell anatomy for an electric car. DOE Fuel Cell Technologies Office.

[5] *Hydrogen Fuel Cells*, U.S. Dep't of Energy (last visited August 1, 2023) *https://www.energy.gov/hydrogen-fuel-cells#:~:text=Fuel%20cells%20can%20be%20used,portable%2C%20and%20emergency%20backup%20power.&text=Hydrogen%20can%20be%20used%20in,water%20and%20heat%20as%20byproducts.*

[6] *Answer to Energy Storage Problem Could Be Hydrogen*, Nat'l Renewable Energy Laboratory (June 25, 2020), *nrel.gov/news/program/2020/answer-to-energy-storage-problem-could-be-hydrogen.html*

There are also numerous non-energy uses for hydrogen across various industrial, energy, and manufacturing sectors. Currently, hydrogen is widely used as feedstock for ammonia and methanol production and for refining, which together account for more than half of its current demand.[7] Hydrogen is also used in the hydrogenation of fossil fuels, where it is combined with natural gas or other liquid forms of fossil energy to produce cleaner burning, more efficient fuels.[8] Demands for hydrogen are only expected to increase as technologies for its utilization continue to develop and evolve, with potential applications including, but not limited to, decarbonization of the iron, steel, chemical, and cement industries, from which emissions are especially difficult to abate through existing technologies.[9]

Methods of Hydrogen Production: The "Hydrogen Rainbow"

At the same time hydrogen is poised to fulfill a versatile and vital role in decarbonization efforts, methods of production primarily used today are extremely emission intensive. Currently, the most common method of production involves the extraction of hydrogen from coal through gasification or natural gas through steam methane reformation, which results in the release of significant CO_2 emissions.

To reduce emissions associated with hydrogen production, DOE predicts a shift in the next two decades toward new, less carbon intensive methods, including via electrolysis powered by wind, solar, and nuclear resources—as well as reformation of natural gas and gasification of coal with carbon capture. Given the growing diversity of hydrogen production pathways, technologies are frequently identified on a spectrum of color-coded categories, duly referred to as the "Hydrogen Rainbow." (*See Figure 2*).[11] Blue hydrogen is produced through emissions-intensive processes of steam methane reforming from natural gas or coal gasification, where carbon dioxide emissions are then captured and permanently stored underground, or repurposed for use in EOR, manufacturing, or other uses.

Figure 2: A non-exhaustive depiction of the hydrogen rainbow. As new production pathways develop, they are assigned new colors in the spectrum.

[7] *See supra* n. 2.
[8] Id.
[9] Pathways To Commercial Liftoff: Clean Hydrogen, Dept. Of Energy, 8 (March 2023).
[10] *Id.* at 3.
[11] *Good Jobs and a Just Transition into Hydrogen*, Industrial Global Union (last visited August 20, 2023) *https://www.industriall-union.org/good-jobs-and-a-just-transition-into-hydrogen*

Developing a technologically diverse clean hydrogen portfolio is critical to the Biden Administration's long-term energy strategy and security. As of 2022, "grey hydrogen"—which results in the highest level of unabated emissions, along with "brown and black hydrogen"—still accounted for 70% of hydrogen produced in the United States.[12] However, the IEA net-zero scenario projects that approximately 70% of hydrogen will be low-carbon by 2030, signaling a massive scale-up challenge for the industry—and for blue hydrogen in particular.[13] Indeed, the IEA projects that approximately 50% of the clean hydrogen supply in 2030 will be produced from fossil fuels with associated emissions capture through CCS (blue hydrogen).[14] As discussed below, the United States has taken steps to position itself as a leader in global clean hydrogen production, including massive investments to increase the global competitiveness of domestic clean hydrogen.[15]

China Leads Global Hydrogen Production

As of 2022, China led the global economy in total hydrogen production. The majority of China's production derives from coal (60%) and natural gas (25%). Although China's Sinopec Corporation announced in August 2022 that operations had commenced on China's largest hydrogen facility with CCUS, it only recently unveiled a cohesive national clean hydrogen strategy. The plan is notably modest, suggesting Chinese deployment of clean hydrogen may be lagging.

> *See Center for Strategic & International Studies, https://www.csis.org/analysis/china-unveils-its-first-long-term-hydrogen-plan*

Demand and Incentives for Clean Hydrogen Deployment

Efforts to grow clean hydrogen production in the United States are already underway with the support of landmark policy incentives under the Biden Administration. The IIJA and IRA, passed in 2021 and 2022 respectively, have energized ambitions for domestic production with attractive financial incentives to encourage industry growth before 2032. Passed in November 2021, the IIJA allocated a total of $9.5 billion USD in appropriations for clean hydrogen, $7 billion of which is dedicated to the development of six to ten regional clean hydrogen hubs across the country.[16] These hubs will aid in the acceleration of clean hydrogen by linking producers and consumers through a cohesive network of co-located pipeline and storage infrastructure.[17]

12 *Net-Zero by 2050*, Int'l Energy Agency (2021), *https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.*

13 *Id.*

14 *Id.* The IEA projects the remaining 50% to be supplied through pink and green electrolysis methods.

15 *Fact Sheet: Biden-Harris Administration Advances Cleaner Industrial Sector to Reduce Emissions and Reinvigorate American Manufacturing,* White House (February 15, 2022), *https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/15/fact-sheet-biden-harris-administration-advances-cleaner-industrial-sector-to-reduce-emissions-and-reinvigorate-american-manufacturing.*

16 *Clean Hydrogen Hubs*, U.S. Dep't Of Energy Off. Of Clean Energy Demonstration (last visited August 10, 2023), *https://www.energy.gov/oced/regional-clean-hydrogen-hubs.*

17 Joseph Majkut , Jane Nakano , and Mathias Zacarias, *Making Hydrogen Hubs a Success,* Center For Strategic & International Studies (July 29, 2022), *https://www.csis.org/analysis/making-hydrogen-hubs-success.* Rather than determining emissions at the point source, "lifecycle greenhouse gas emissions" is defined with reference to Section 211(o)(1) of the Clean Air Act, meaning the "aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." *See* H.R.5376 § 13204; 42 U.S.C. 7545(o)(1).

In 2022, the IRA subsequently implemented significant tax incentives to encourage the development of clean hydrogen and CCS/CCUS in the United States. These changes are set forth in two parts, including an addition to the tax code providing new incentives specific to hydrogen (26 U.S.C. § 45V ("Section 45V")) and changes to existing production credits for CCS/CCUS under 26 U.S.C. § 45Q ("Section 45Q").

Creation of Section 26 U.S.C. § 45V

Section 45V creates a two-tier, inflation-adjusted, ten-year production tax credit for clean hydrogen produced after 2022 at a "qualified facility" on which construction is initiated before 2033. For purposes of the IRA, clean hydrogen is "qualified" if it is produced through a process yielding a lifecycle greenhouse gas emission rate of 4 $kgCO_2e/kgH_2$, or less.[18] For every kilogram of qualified clean hydrogen produced by a taxpaying facility, the base tax credit rate is $0.60 per kilogram. The $.60/kg base credit is then adjusted for inflation and multiplied by a percentage which varies based on the lifecycle greenhouse gas emissions rate. Finally, Section 45V provides that if the producer satisfies prevailing wage and apprenticeship requirements (to the extent applicable), the available credit is multiplied by five. (See Table 1). Hydrogen producers demonstrating lifecycle emissions of less than .45 kg CO_2e/kgH_2 who satisfy workforce requirements may be eligible for a tax credit of up to $3.00 per kilogram.

Lifecycle CO_2 Emissions (kg CO2e/kg H2)	**Applicable Percentage based on Life cycle CO_2 Emissions**	**Initial PTC** ($0.60 base credit x applicable percentage) (shown in 2022$/kgH2)	**Total Available PTC*** (Initial PTC x 5)
2.5 – 4.0	20.0%	0.12	0.60
1.5 – 2.5	25.0%	0.15	0.75
0.45 – 1.5	33.4%	0.334	1.67
< 0.45	100%	0.60	3.00

Table 1: Section 45V production tax credits for clean hydrogen.

**Total Available PTC refers to the total available credit if prevailing wage and apprenticeship requirements are met.*

[18] 26 U.S.C.A. § 45V(c)(2)(A).

Revisions to Section 45Q

The IRA also includes a substantial increase in the value of the existing tax credit system for CCS/CCUS (section 45Q of the tax code). Under the IRA, CCS/CCUS facilities can now qualify for a two-tiered tax credit payment that includes a base payment for every metric ton of carbon that is used or sequestered, plus a bonus payment if the facility meets federal prevailing wage standards and certain apprenticeship requirements.[19] (*See Table 2*).

Table 2: Section 45Q production tax credits for CCS/CCUS.

	Carbon Capture & Storage Projects ($/metric ton)			Carbon Capture & Utilization Projects ($/metric ton)		
	Credits Pre-IRA	Credits Post-IRA for Industrial Capture		Credits Pre-IRA	Credits Post-IRA for Industrial Capture	
Year		Base	Bonus for fulfillment of prevailing wage and apprenticeship requirements		Base	Bonus for fulfillment of prevailing wage and apprenticeship requirements
2022	$37.86	$17.00	$85.00	$25.13	$12.00	$60.00
2023	$40.90	$17.00	$85.00	$27.59	$12.00	$60.00
2024	$43.94	$17.00	$85.00	$30.05	$12.00	$60.00
2025	$46.98	$17.00	$85.00	$32.51	$12.00	$60.00
2026	$50.00	$17.00	$85.00	$35.00	$12.00	$60.00
2027 +	$50.00 *as adjusted for inflation*	$17.00 *as adjusted for inflation*	$85.00	$35.00 *as adjusted for inflation*	$12.00	$60.00

In addition to its tax credit revisions pursuant to Section 45Q, the IRA also extended 45Q tax credit eligibility to projects that begin construction before January 1, 2033, as opposed to the earlier cutoff of January 1, 2026.[20]

[19] “Prevailing wages” in part refers to compliance with the Davis-Bacon Act, as codified in Title 29 of the U.S. Code of Federal Regulations, Subtitle A, Part 1: Procedures for the Determination of Wage Rates. This wage equals the wage paid to over 50% of laborers or mechanics for similar projects in an area over a given period and is determined by the U.S. Department of Labor’s Administrator for the Wage and Hour Division.

[20] 26 U.S.C.A. § 45V(c)(3).

Section 45V and 45Q are expected to work in tandem to spur the rapid development of new clean hydrogen facilities with associated CCS/CCUS. The legislation disallows taxpayers from claiming “stacked credits”, meaning that a qualifying taxpaying facility may not take advantage of credits for hydrogen production pursuant to 45V in addition to credits that may be earned under 45Q for carbon that is stored or used in relation to blue hydrogen operations, thus diluting the financial incentive for blue hydrogen producers.[21] While the U.S. Treasury has yet to conduct rulemaking to establish the parameters in which hydrogen producers may capture credits pursuant to Section 45V, the Treasury has collected public comment with new rules expected to be issued in October 2023.[22]

Why Hydrogen in Wyoming?

Although various states across the United States have already taken steps to position themselves as leaders in the clean hydrogen economy,[23] Wyoming is a natural fit for the deployment of these technologies. Indeed, in relation to its energy legacy in oil, gas, and mining, Wyoming possesses abundant reserves of natural gas needed for hydrogen feedstock and significant subsurface storage potential, as well as the policy, infrastructure, and trained workforce required to implement hydrogen production with CCS safely, efficiently, and within a straightforward legal framework.[24] Numerous new projects seek to establish the feasibility of clean hydrogen operations in Wyoming,[25] including, but not limited to, the Western Interstate Hydrogen Hub (WISHH)partnership submitted for DOE funding in May 2023 and the Pronghorn H_2 Project, which is slated to develop wind-powered green hydrogen in Wyoming by 2026.[26]

21 26 U.S.C.A. § 45V(d)(2).

22 U.S. Department of the Treasury, Internal Revenue Service, *Request for Comments on Credits for Clean Hydrogen and Clean Fuel Production*, Notice 2022-58 (2022).

23 Jim Magill, *California And Texas Vie To Be America’s Hydrogen Capital*, Forbes (February 23, 2021), *https://www.forbes.com/sites/jimmagill/2021/02/23/california-texas-vie-to-determine-which-will-be-us-hydrogen-capital/?sh=a3a8bd95006f;* CCS & Hydrogen, BP (last visited March 10, 2023) *https://www.bp.com/en_us/united-states/home/who-we-are/advocating-for-net-zero-in-the-us/ccus-and-hydrogen.html* (identifying opportunities in Illinois, Indiana, and Texas, but noting problematic regulatory barriers).

24 Carbon Management and Decarbonization Analysis, Great Plains Institute (last visited August 21, 2023), *https://carboncaptureready.betterenergy.org/analysis/* (citing relevance of geologic storage potential, current hydrogen production, industrial concentration, and many other factors that provide opportunities for siting carbon dioxide removal, carbon capture retrofit, and new zero-carbon hydrogen production for blue hydrogen project siting decisions); Carrie Haderlie, *Wyoming Eyes Hydrogen for Energy,* Wyoming Business Report, *https://www.wyomingnews.com/wyomingbusinessreport/current_edition/wyoming-eyes-hydrogen-for-energy/article_69a08579-f1dd-50fb-809b-380f46a66fc0.html*

25 *See* Haderlie, *supra* n. 24.

26 Hugh Cook, *A Hydrogen Facility That Will Produce Electricity will be Constructed in Eastern Wyoming by 2026,* Wyoming Public Media (February 13, 2023) *https://www.wyomingpublicmedia.org/natural-resources-energy/2023-02-13/a-hydrogen-facility-that-will-produce-electricity-will-be-constructed-in-eastern-wyoming-by-2026*

Abundant Hydrogen Feedstock in Proximity to Storage Reservoirs

Wyoming possesses the greatest abundance of natural hydrogen feedstock in the United States, even larger than its coal and natural gas reserves.[27] Indeed, Wyoming is the nation's top supplier of coal, the ninth largest producer of natural gas, and the overall third largest energy producer in the United States. Wyoming has led the United States in coal production since the 1980s, with exports accounting for an average 40% of the annual U.S. coal supply.[28] Even after more than a century of mining, approximately 165 billion tons of economically recoverable coal remain intact in the Powder River Basin.[29] With regard to its natural gas resources, Wyoming is similarly well-situated as it houses sixteen of the country's largest natural gas fields, including the Pinedale and Jonah Fields, which both rank among the nation's top ten largest fields. Even as natural gas production declined in Wyoming due to global economic factors, Wyoming's natural gas exports still accounted for almost 4% of gas production marketed in the United States in 2021.[30]

Not only are Wyoming's natural gas resources abundant, but they are also particularly well-suited for clean hydrogen development due to their relative low carbon intensity compared to other sources of natural gas in the United States. As a result of long-term collaborations between Wyoming researchers and natural gas producers, Wyoming natural gas has consistently achieved one of the lowest upstream carbon footprints in the western United States as measured in methane intensity.[31]

Presence of Geologic Storage Sites for CO_2 and H_2

In addition to its ample natural gas reserves that could be used as hydrogen feedstock, Wyoming has among the largest capacity for subsurface CO_2 storage in comparison to other regions in the United States (*see Figure 3*).[32] According to DOE/the U.S.National Energy Technology Laboratory (NETL), Wyoming's total subsurface storage capacity inclusive of oil and natural gas storage reservoirs, unmineable coal seams, and saline formations is between 153.12 and 1547.45 billion metric tons per year.[33] With financial support from DOE, the State of Wyoming and numerous project participants, researchers at the School of Energy Resources at the University of Wyoming (SER) to date have extensively investigated two areas in Wyoming for potential saline formation storage: (1) the Rock Springs Uplift (RSU) in southwestern Wyoming; and (2) a series of stacked formations just north of Gillette in northeastern Wyoming's Powder River Basin.[34]

[27] Glen Murrell, Wyoming Energy Authority, *Why Hydrogen? How It Fits into a Future Energy Economy and Why Wyoming Must Act Now, https://www.youtube.com/watch?v=5zlo8Rr1IJY* (June 29, 2021).

[28] *Wyoming Coal*, Wyoming State Geologic Survey (last visited August 10, 2023), *https://www.wsgs.wyo.gov/energy/coal.aspx.*

[29] *Coal*, Wyoming Mining Association (last visited August 13, 2023), *https://www.wyomingmining.org/minerals/coal/*

[30] *Wyoming State Profile and Energy Estimates,* U.S. Energy Information Administration (last visited March 2023), *https://www.eia.gov/state/?sid=WY.*

[31] Diana Burns & Emily Grubert, *Attribution of Production-Stage Methane Emissions to Assess Spatial Variability in the Climate Intensity of U.S. Natural Gas*, 16 Environ. Res. Lett. (2021)044059 (2021), *https://iopscience.iop.org/article/10.1088/1748-9326/abef33/pdf.* In 2021, Wyoming's Jonah Energy even became the first company in the United States to achieve the Gold Standard in the United Nations Oil and Gas Methane Partnership. *See https://www.prnewswire.com/news-releases/the-international-methane-emissions-observatory-announces-jonah-energy-is-first-us-company-to-achieve-gold-standard-emissions-rating-301425507.html?tc=eml_cleartime.*

[32] *An Atlas of Carbon and Hydrogen Hubs for United States Decarbonization*, Great Plains Institute (February 2022), *https://scripts.betterenergy.org/CarbonCaptureReady/GPI_Carbon_and_Hydrogen_Hubs_Atlas.pdf.*

[33] *https://www.netl.doe.gov/sites/default/files/2018-10/ATLAS-V-2015.pdf*

[34] *See, e.g., https://www.uwyo.edu/cegr/research-projects/project-wy-cusp.html; https://www.uwyo.edu/cegr/research-projects/wyoming-carbonsafe.html.*

SER researchers have determined that reservoirs in the RSU have a storage capacity of up to 14 to 17 billion metric tons of CO_2,[35] while the formations identified near Gillette have the potential to store at least fifty (50) million metric tons of CO_2.[36]

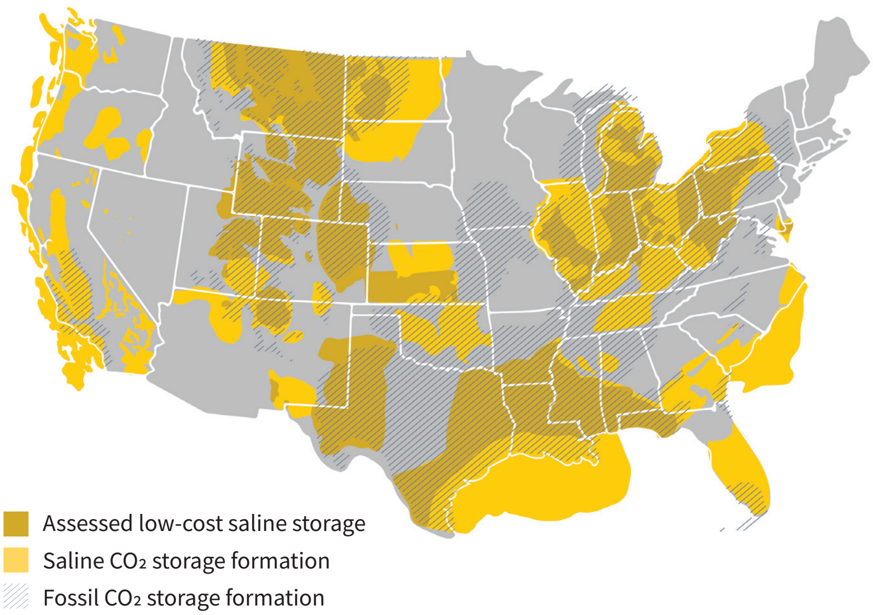

Figure 3: Geologic storage opportunity. *Source: An Atlas of Carbon and Hydrogen Hubs, GPI, 2022 by the Great Plains Institute.*

Building upon decades of carbon dioxide storage research, the Hydrogen Energy Research Center (H_2ERC) at SER has also begun investigating the geologic potential for the subsurface storage of hydrogen. Hydrogen storage is considered essential to help producers balance seasonal supply and demand discrepancies.[37] Because subsurface hydrogen storage is a new concept, not much is known with regard to the feasibility and reliability of storage in sedimentary formations. However, some projects have proposed storage of hydrogen in artificial caverns created within salt formations. Current research at SER is focused on the Green River Formation in southwestern Wyoming. The Green River Formation is the host rock for the world's largest natural trona deposit. Trona is a sodium bicarbonate mineral (salt) that is processed into soda ash. Through the mining process, large caverns are created underground. Researchers at H_2ERC are investigating the feasibility of large volume hydrogen storage within these caverns.

Existing Transportation and Export Infrastructure

Commonly cited barriers to the expansion of hydrogen markets are the cost and technical challenges associated with hydrogen transport. Hydrogen can be transported either in gaseous form by pipelines and tube trailers or in liquified form in cryogenic tanks carried by truck. Analysis by IEA has indicated that pipeline transportation of hydrogen is generally the most cost-efficient option for distances of less than 1,500-3,000 km,[38] depending on pipeline capacity. However, hydrogen pipeline construction typically requires large amounts of capital up-front, which (along with blockades for wildlife corridors, federal lands, and environmental protection) can impede development.[39] The lower energy density of hydrogen requires that either larger pipelines or larger compressors capable of increasing the flow rate of hydrogen

[35] *DOE-Sponsored Project Shows Huge Potential for Carbon Storage in Wyoming*, U.S. Dep't Of Energy Off. Of Fossil Energy & Carbon Management (2014), *https://www.energy.gov/fecm/articles/doe-sponsored-project-shows-huge-potential-carbon-storage-wyoming.*

[36] Erin Phillips, et al., *A Viable Path Forward to Carbon Capture and Storage in Wyoming,* Usa, U.S. Dep't Of Energy Off. Of Scientific And Technical Information (2018), *https://www.osti.gov/servlets/purl/1779865 .*

[37] *Underground Hydrogen Storage Remains a Key Research Topic For* Netl, Nat'l Energy Tech. Laboratory (AUGUST 22, 2022), *https://netl.doe.gov/node/11982#:~:text=Large%2Dscale%20geological%20hydrogen%20storage, %2Dto%2Ddecarbonize%20 industrial%20processes.*

[38] Fifteen-hundred to three thousand kilometers translates approximately to 932 and 1,864 miles.

[39] *Hydrogen Pipelines,* U.S. Dep't Of Energy, Off. Of Energy Efficiency & Renewable Energy (Last Visited August 10, 2023) *https://www.energy.gov/eere/fuelcells/hydrogen-pipelines* ; *Global Hydrogen Review 2021, Int'l Energy Agency* (2021) *https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf.*

in the pipeline will be required the same energy as compared to natural gas. Hydrogen pipelines also pose stubborn technical challenges, including steel embrittlement and leakage mitigation that require special seals, coating, and compressor valves' piston rings as well as additional maintenance.[40]

To overcome financial and technical challenges associated with hydrogen transport by pipeline, DOE has suggested that existing natural gas pipeline infrastructure can be repurposed for the transportation of natural gas blended with up to 15% hydrogen.[41] With additional efforts and investment, such pipelines could even be repurposed to transport hydrogen exclusively.[42] This means that Wyoming already possesses much of the export infrastructure needed to connect Wyoming's hydrogen production with major markets across the West Coast, Pacific Northwest, Midwest, and Front Range regions of the United States, where a large portion of Wyoming's natural gas is already transported. Wyoming's existing capacity for pipeline exports to the West Coast alone is approximately four billion cubic feet (bcf) per day, with an additional capacity for one bcf to the Midwest.[43] SER is currently conducting research to determine costs associated with pipeline repurposing, with particular attention to efforts needed to mitigate pipeline embrittlement.

In addition to transportation by pipeline, rail transportation of hydrogen may be feasible in the future. Wyoming currently uses its extensive railway system to transport large amounts of coal to its export customers across the United States. By using cryogenic or gas-compressed cars, Wyoming has the potential to add hydrogen to its existing network of railroad energy exports. (See Figure 3). A potentially precedential example of use of rail for new commodities before market maturation was the peak of crude oil transport via rail during the peak of the shale oil revolution in 2014. That year, railroads originated 493,146 carloads of crude oil—compared to 9,500 in 2009—a 52 times increase.[44] This exponential growth was necessitated due to delayed/extended pipeline construction times and capacities.[45]

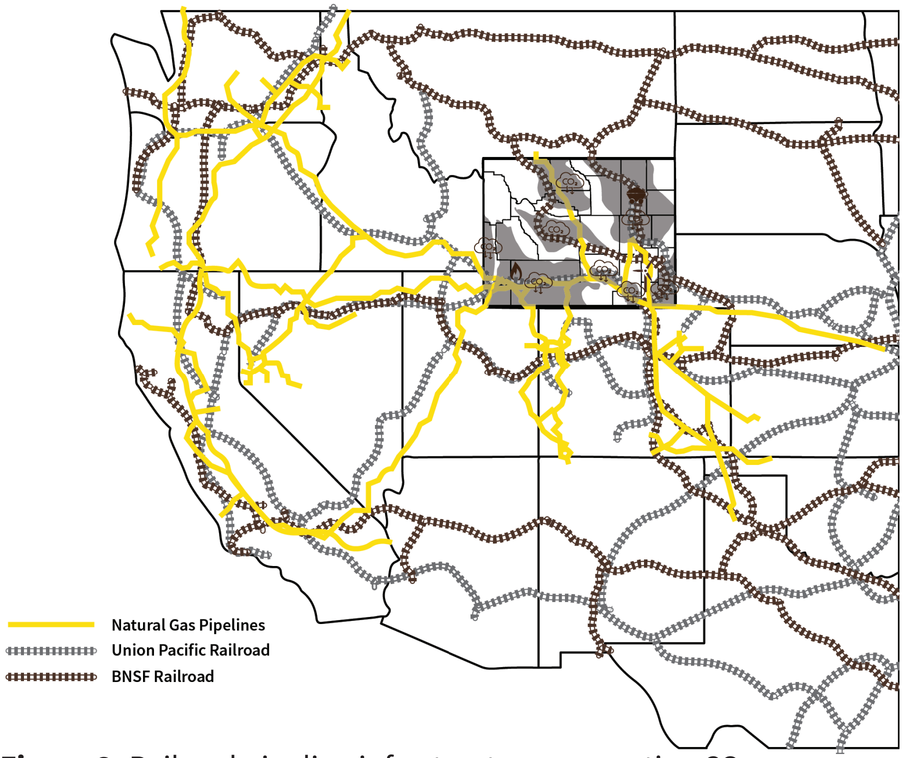

Figure 3: Rail and pipeline infrastructure connecting CO_2 storage reservoirs with high demand markets. *Illustration by Christine Reed, SER*

[40] J.L. Gillette & R.L. Kolpa, *Overview of Interstate Hydrogen Pipeline Systems,* Argonne Nat'l Laboratory, Envtl. Science Div. (2007), *https://corridoreis.anl.gov/documents/docs/technical/apt_61012_evs_tm_08_2.pdf.*

[41] *Supra* n. 39.

[42] *Id.*

[43] Glen Murrell, Wyoming Energy Authority, *Why Hydrogen? How It Fits into a Future Energy Economy and Why Wyoming Must Act Now, https://www.youtube.com/watch?v=5zlo8Rr1IJY* (June 29, 2021).

[44] *Crude Oil by Rail*, Association Of American Railroads (August 2023), *https://www.aar.org/wp-content/uploads/2020/07/AAR-Crude-Oil-Fact-Sheet.pdf.*

[45] *Id.*

In the case of hydrogen, increasing public trust in transportation systems would further accelerate the use of rail for hydrogen transport, particularly following high-profile rail accidents in 2023, including the derailment of a train carrying hazardous materials ("hazmat") in East Palestine, Ohio.[46] Despite the potential for incidents such as the East Palestine derailment to undermine public trust, the general safety and reliability of the U.S. rail system is unequivocal, with more than 99.99% of all hazmat moved by rail reaching its destination without a release caused by a train accident.[47]

In the future, technologies used for the rail transportation of hydrogen may also be applied to convey hydrogen via trucks traveling on interstate highways.[48] As Wyoming is transected by major national routes such as Interstates 80, 90, and 25, this technology may present additional advantages for Wyoming's hydrogen exports, particularly as the safety of hydrogen transport continues to improve and evolve.[49] Unlike railroad and interstate routes in many areas of the country, Wyoming is almost entirely rural, with both railroads and interstates designed primarily for the long-distance transport of coal to distribution hubs, and routed through primarily non-populous areas.[50]

Favorable Policy Environment for CCS and Need for Economic Diversification

Hydrogen As An Alternative Source Of Energy Revenue

The IEA notes that while export earnings from blue hydrogen may not replace oil and gas revenue in hydrocarbon-dependent economies, "low-cost renewables, natural gas and CCUS storage potential could provide a durable foundation for attracting investment in energy- intensive industrial sectors."

> IEA 2022 World Energy Outlook *(https://iea.blob.core.windows.net/assets/c282400e-00b0-4edf-9a8e-6f2ca6536ec8/WorldEnergyOutlook2022.pdf).*

Wyoming's historically strong energy economy means it is heavily hydrocarbon-dependent, with all state and county agencies relying to some extent on revenue from mineral royalties, severance, and ad valorem taxes to support government operations, public schools, health facilities, and more.   The fossil fuel industry supported almost 70,000 indirect and direct full- and part-time jobs in 2019, bringing in nearly $10 billion toward Wyoming's GDP.[51] As federal and global policy continues to incentivize the deployment of low-carbon energy technologies over traditional fuel sources that have supported the state's economy, Wyoming has an opportunity to diversify its energy economy and emerge as a national leader in promising low-carbon and renewable technologies.[52] At the forefront of Wyoming's "all-of-the-above" strategy is CCS, which can be developed in synchrony with its expanding clean hydrogen industry.

[46] *East Palestine, Ohio Train Derailment,* U.S. Env't Prot. Agency (last accessed August 21, 2023), *https://www.epa.gov/east-palestine-oh-train-derailment.*

[47] *See supra* n. 44.

[48] *Global Hydrogen Review 2021,* Int'l Energy Agency (2022) *https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf*

[49] *See generally* Hao Li a, Xuewen Cao a, Yang Liu a, Yanbo Shao a b, Zilong Nan b, Lin Teng c, Wenshan Peng d, Jiang Bian, *Safety of hydrogen storage and transportation: An overview on mechanisms, techniques, and challenges,* 8 Energy Reports 6258 *(2022).*

[50] *See https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Planning/Railroads/Wyoming%202021%20State%20Rail%20Plan.pdf* (Chapter 2 discussing routes developed around coal exports, and stating "[t]he vast majority of Wyoming rail freight, 74.9 percent in terms of tonnage, originates in Wyoming and is shipped out of state.").

[51] *See https://www.api.org/-/media/Files/Policy/American-Energy/PwC/API-PWC-Economic-Impact-Report.pdf* (detailing the economic value of the oil and gas industry in top-producing states for 2019).

[52] *See, e.g., https://content.govdelivery.com/accounts/WYGOV/bulletins/30a9e7a.*

States with comprehensive CCS legislation and policy, like Wyoming, will likely be the first locations for the deployment of blue hydrogen technology. Unlike Wyoming, most states have yet to develop a controlling regime for pore space ownership, carbon storage permitting, injection certification and monitoring, or liability for stored carbon dioxide. In 2020, Wyoming became one of only two states (alongside North Dakota) to be granted primacy over the permitting and oversight of CCS injection wells within its borders. CCS injection wells (aka "Class VI Injection Wells") are regulated under Class VI of the EPA's Underground Injection Control Program. Unless a state has been granted primacy, US EPA has primary enforcement authority. Wyoming's Class VI program is now administered through the Wyoming Department of Environmental Quality (WDEQ), which will efficiently implement the permitting process for all Class VI Injection Wells in Wyoming, including wells for the injection of CO_2 emissions captured from hydrogen production.[53] Although no Class VI permits have yet been approved, at least three are currently pending review with WDEQ.[54]

Trained Workforce

Finally, Wyoming's workforce is ready to meet the demands of clean hydrogen deployment. In determining selection for federal funding for hydrogen development, DOE has specifically placed priority on projects that are likely to create opportunities for skilled workers and long-term employment in high quality-of-life careers. This criterion is instructive for any clean hydrogen project, as the hydrogen generation process requires a uniquely skilled workforce with knowledge of production methods, industry best practices, and subsurface characteristics.

Many of the skills and training needed for hydrogen production are the same skills already possessed by Wyoming's oil and gas, and coal workforce, who have operated with success in the state's subsurface for nearly a century. Oil, gas, coal, and other energy jobs currently account for more than 15% of total employment in the state.[55] Many government and industry leaders expect clean hydrogen and other low-carbon energy projects to generate significant job growth and to recruit many already-trained oil, gas, and coal workers whose jobs may be displaced. As energy companies seek to penetrate the markets for Wyoming hydrogen production, there is a natural mutual benefit to Wyoming's workers and companies seeking to launch projects with the assistance of a trained workforce. Fossil fuel companies have a significant opportunity to leverage their existing workforces, infrastructure, business strategies, and knowledge of the state's subsurface to gain competitive advantages in the hydrogen market. Blue hydrogen, in particular, will provide companies with an attractive edge in comparison to green or pink hydrogen technology, which are not projected to be immediately cost-effective.[56]

[53] Wyo. Stat. Ann. *§ 35-11-313.*

[54] Wyoming Department of Environmental Quality, *Class VI* (last visited August 20, 2023), *https://deq.wyoming.gov/water-quality/groundwater/uic/class-vi/.*

[55] *Energy Employment by State: 2021,* U.s. Dep't Of Energy (2021), *https://www.energy.gov/sites/default/files/2021-07/USEER%20 2021%20State%20Reports.pdf.*

[56] *2022 Status Report,* Global CCS Institute (2022) *https://status22.globalccsinstitute.com/2022-status-report/analysis/.*

Wyoming's university and community college system have also adopted several programs to ensure that highly qualified engineers, and other technically skilled employees continue to graduate with skills to support the development of hydrogen and other innovative energy projects moving forward.[57] In 2022, SER launched a CCS/CCUS certificate program which will provide a streamlined track for training and certification in relevant science, technology, engineering, and mathematics (STEM) skills.[58] The University of Wyoming has also partnered with the Wyoming Community College Commission, the Wyoming Business Council, and the Department of Workforce Services to support programs for energy workforce readiness, as part of a project known as the Wyoming Innovation Partnership (WIP).[59]

Existing Clean Hydrogen Projects in Wyoming

Several midstream companies have already seized on the opportunity to explore Wyoming's potential for clean hydrogen development, including blue hydrogen. State leaders at the Wyoming Energy Authority (WEA) have also set forth statewide collaborative strategies, in concert with SER and DOE, to enhance and accelerate Wyoming's potential for widespread blue hydrogen deployment. Central to the state's hydrogen strategy is the H_2ERC, a Center of Excellence for research at SER, which was formed to assist energy producers and stakeholders in identifying and quantifying the relative competitive advantages of Wyoming in an emerging low-carbon hydrogen economy. This section provides a description of existing and emerging research and projects for clean hydrogen deployment across the state.

Integration of Produced Water Thermal Desalination and Steam Methane Reforming for Efficient Hydrogen Production

The objective of this $10M DOE-sponsored research project is to create a pilot scale field-demonstration of hydrogen production (capacity of 1 ton per day) using produced water (generated during oil and gas extraction) at a cost approximately 15% lower than hydrogen from existing methods, demonstrating the potential to reach the DOE's goal of $1 per 1kg of hydrogen by 2030. The produced water will be treated using supercritical water desalination and oxidation followed by steam methane reforming process (SMR) for H_2 production. The project will result in a containerized TRL6 pilot-scale demonstrator, which will encourage industry to adopt the technology at even greater scale, allow further optimization testing, and engage stakeholders to win local community support for use of this technology in their towns/industries.

57 *See, e.g., https://www.uwyo.edu/wip/* (allocating funds to establish renewable energy training programs in community colleges across Wyoming).
58 *See http://www.uwyo.edu/uw/news/2022/11/uw-trustees-approve-new-certificate-programs-in-carbon-capture,-land-administration.html.*
59 *See https://communitycolleges.wy.edu/wyoming-innovation-partnership/.*

Blue Bison Project

Led by Tallgrass MLP, this DOE-funded project, named Blue Bison, is an 18-month project that began on October 1, 2021. The $1.9M project is studying developing blue hydrogen production around existing gas facilities in Douglas. SER, along with Wyoming's legislative-funded Enhanced Oil Recovery Institute (EORI), are leading tasks to provide a site-specific CCUS feasibility assessment, develop economic models, and help with project management. The H_2ERC/EORI project team assessed data needs for the techno-economic analysis and determined the feasibility of CCUS at the study site.

Williams Southwest Wyoming Hydrogen Hub

H_2ERC and other University of Wyoming collaborators, including the Center for Excellence in Produced Water Management (CEPWM), are assisting Williams Companies Inc. with a feasibility study of deploying a green hydrogen production and transport hub in southwestern Wyoming. This project duration is 18 months, with a total project budget of ~$1.2M. H_2ERC and CEPWM will study southwestern Wyoming water sources and water treatments suitable for green hydrogen hydrolysis. The project is: 1) sampling wells within the Greater Green River Basin that could contribute water for green hydrogen production; and 2) assessing and testing water treatments to raise the quality of this water from ~10,000 mg/L salinity to the exacting near-pure standards needed for electrolysis.[60]

Net-Zero With Hydrogen Project

This DOE-funded research program, led by SER in collaboration with the WEA, aims to identify and quantify the relative competitive advantages of Wyoming in an emerging low-carbon hydrogen economy. Many states, as well as the Biden Administration, have announced goals to reach net-zero emissions by 2050.[61] Under all likely scenarios, achieving a mid-century net-zero target will pose challenges and create opportunities for Wyoming's energy sector. This research examines the economic impact of fossil energy production in Wyoming and provides various predictions for future energy mixes to achieve net-zero emissions in alignment with Wyoming's current domestic export markets, which include a growing number of states that have adopted net-zero targets. Preliminary work suggests that Wyoming-based hydrogen production could have significant economic benefits and job creation implications. This study will further assess Wyoming's opportunities to create hydrogen-based industries, assess economic impacts, identify knowledge gaps and research needs—with heavy reliance upon the H_2ERC to accelerate commercialization and deployment.

[60] *See https://www.williams.com/2021/04/15/harnessing-the-power-of-hydrogen-for-clean-energy/* ("Our ability to blend hydrogen into our existing system is a significant advantage and has the potential to accelerate the use of hydrogen in reducing carbon emissions.")

[61] *U.S. State Greenhouse Gas Emissions Targets,* Center For Climate And Energy Solutions (August 2022), *https://www.c2es.org/document/greenhouse-gas-emissions-targets/; Table of 100% Clean Energy States,* Clean Energy States Alliance (last visited August 10, 2023), https://www.cesa.org/projects/100-clean-energy-collaborative/guide/table-of-100-clean-energy-states/.

Advancing Blue Hydrogen Production And Transport Infrastructure In Wyoming

WIP funds this emerging project with a focus on computational systems engineering. UW and SER teams will examine technical, economic, environmental, social, and policy issues related to nuclear-powered hydrogen produced from conventional and renewable gas resources in Wyoming, explore the potential for sustainable development of a hydrogen hub in Wyoming, and develop an educational and workforce training program on hydrogen energy and the emerging hydrogen economy. The training program will be modularized for four levels of students: high school students, UW undergraduate and graduate students, community college students, and working professionals. In addition, the component will also investigate the feasibility of repurposing existing natural gas pipelines for hydrogen transport in Wyoming.

Building Capacity At UW: Request For Proposals Phase I And II. Hydrogen: Make, Move, Use Or Store

SER has issued a request for proposals (RFP) addressing hydrogen energy for current UW faculty members. Topics of interest for the proposals include all levels of the supply chain, such as hydrogen production, use, transportation, and storage. Proposals were considered that evaluate technology, policy, and/or economics for topics of interest. The funding opportunity covers a full calendar year and project proposals with budgets of up to $100,000 were accepted.

Twenty-one proposals on various topics related to hydrogen energy production, distribution, and storage were submitted and seven proposals were selected for funding. Kickoff meetings were held on October 12, 2022.

After a successful round of proposals in 2022, SER is issuing a Phase II RFP. This funding opportunity will cover two full calendar years, and up to three project proposals will receive a maximum budget of $150,000. The previously selected projects focused on hydrogen storage and hydrogen made from natural gas, while this RFP is focused on three potential areas of interest: hydrogen transportation; electrolysis hydrogen production systems; and hydrogen production from Wyoming's coal resources.

Conclusion: Generating Policy and Public Support for Hydrogen with CCS

Wyoming has significant potential to contribute to a net-zero clean energy economy through blue hydrogen production. Due to the enactment of the IIJA and the IRA, clean hydrogen production is more cost-effective than ever, and clean hydrogen is poised for development at a national scale.

Wyoming is geologically, economically, and socially well-situated to play a leading role in clean hydrogen deployment through the use of CCS/CCUS. As part of Wyoming's efforts to diversify its energy portfolio, policymakers and industry leaders should be aware of the potential for Wyoming's blue hydrogen economy and consider whether investments in CCS/CCUS infrastructure could be appropriate to support expansion of the industry. Specific policy priorities to boost the state's blue hydrogen economy could include development of core and adjacent infrastructure for the transportation, storage, and management of carbon and hydrogen.[62] Evaluating the costs, social risks, and tax credit requirements associated with such development may further aid in de-risking hydrogen deployment across the state.

In sum, Wyoming's existing infrastructure, abundant hydrogen feedstock resources, potential for geologic storage of CO_2, and skilled workforce make Wyoming well poised to lead the development of clean hydrogen production on the global path to a net-zero future. As current and new projects continue to develop, SER possesses the expertise and resources to assist industry partners in their navigation of Wyoming's regulatory landscape for CCS/CCUS and blue hydrogen.

Wyoming As A "Hydrogen Headwaters"

"[Wyoming's] economy and way of life are dependent on the energy and extractive sectors. Wyoming is, and plans to remain, an all-of-the-above energy state. . . *We see hydrogen as an important component of the energy future and envision Wyoming becoming a 'hydrogen headwaters state.'*"

- Dr. Holly Krutka, Director of the University of Wyoming School of Energy Resources, testifying before the U.S. Senate Committee on Energy and Natural Resources (July 19, 2022).

Policy & Research Focus Areas For The Success Of Wyoming's Blue Hydrogen Economy

- Identify costs and regulatory challenges associated with natural gas pipeline conversion for hydrogen transportation and railroad/roadway transportation;
- Assess and enhance cost-competitiveness and efficiencies of blue hydrogen in comparison to other production methods;
- Continue to support cutting-edge research that investigates and verifies the hydrogen and CO_2 geologic storage potential of Wyoming formations;
- Conduct proactive stakeholder engagement in communities well-suited for hydrogen production with CCS/CCUS, including education related to environmental and economic impacts and workforce opportunities;
- Align project development with federal wage and apprenticeship requirements to maximize funding advantages.

[62] *See Wyoming Hydrogen Roadmap*, Wyoming Energy Authority (July 2022), *https://wyoenergy.org/wp-content/uploads/2022/11/WEA_WyomingHydrogenRoadMap-FINAL-1.pdf* ("The roadmap is a multi-dimensional strategy which leverages the opportunities and addresses the challenges as Wyoming plays a major role for the domestic and global low-carbon hydrogen economy.").