GLOBAL, DOMESTIC AND STATE OF WYOMING THE FUTURE OF THE HYDROGEN ECONOMY

A Situation Analysis

Executive Summary

March 2022

2020 and 2021 were record years in policy action and low-carbon hydrogen production, with ten governments around the world adopting hydrogen strategies. Close to 70 MW of electrolysis capacity was installed, doubling the previous year's record, and two facilities producing hydrogen from fossil fuels with CCUS became operational, expanding production capacity by ~15%. However, this progress falls well short what is needed in the Net Zero Emissions by 2050 Scenario. Moreover, low-carbon hydrogen demand for new applications remains low, limited to road transport only. More effort is required to generate demand and in reducing emissions associated with hydrogen production.

Cheyenne **LEADS**
The Cheyenne-Laramie County Corporation for Economic Development

WYOMING ENERGY AUTHORITY

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Introduction

In just a few years, hydrogen has gone from a "big idea" to the next big thing. The most abundant element in the universe, hydrogen is colorless, odorless and non-toxic. It consists of a single proton and a single electron. Each kilogram of hydrogen or H2 contains about 2.4 times as much energy as natural gas; although it's also highly combustible.

Hydrogen is a versatile fuel source that can be stored for long periods of time and also reduce the carbon intensity of power generation, heating systems, industrial production, and certain transport applications. Hydrogen also can serve as an energy carrier and can be stored for use seasonally during periods of low energy production.

Hydrogen cleanly and efficiently generates electricity and heat through an electrochemical reaction, with only potable water as a by-product. It is an efficient and safe medium for energy storage, offering possibilities for energy generation and distribution. Hydrogen also can be an important decarbonization solution for various sectors and end uses that are difficult to electrify, such as industrial uses, heavy trucking, iron and steel production, and marine shipping. And its use can displace fossil-based medium- and high-grade heat in industrial applications that do not lend themselves to electrification.

Hydrogen is considered a major component in the global drive to achieve Net Zero emissions by 2050 and has gained momentum on a global basis due to multiple factors including:

- ✓ Energy abundance and manageable cost emerging
- ✓ Vehicle electrification well along
- ✓ New applications emerging gas turbines, pipeline NG/H2, green steel, chemicals
- ✓ Investor/customer increasing aware

Demand for hydrogen has tripled since 1975**.** By 2035, more than 50% of global power generation will come from renewable sources. Hydrogen is expected to play a key role in a future climate-neutral economy on a global and national basis**,** enabling emission-free transport, heating and industrial processes as well as inter-seasonal energy storage.

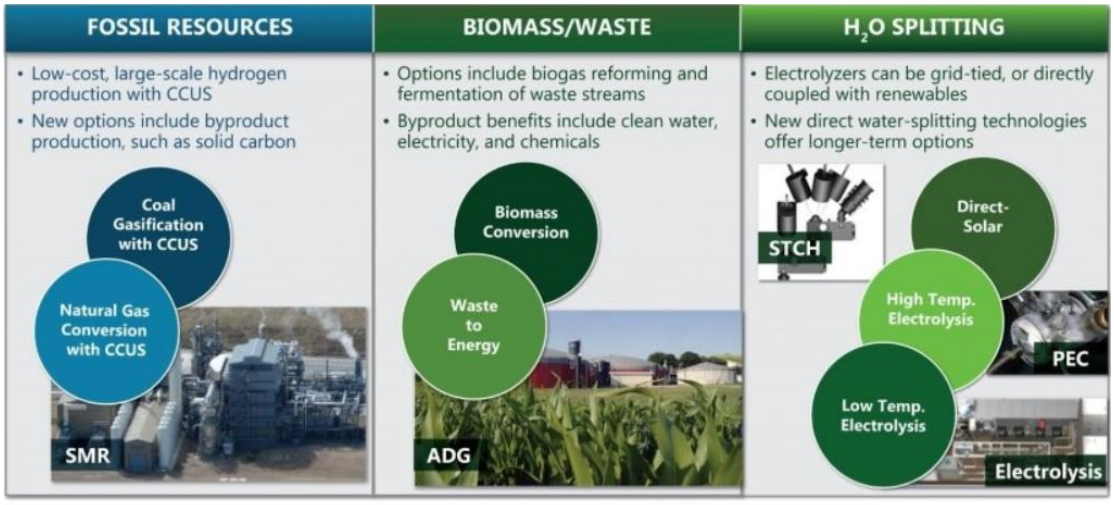
The future of the clean energy industry sector is dependent on making exponential improvements in hydrogen powered energy, as well as, making important investments in the necessary infrastructure. For global hydrogen markets to emerge massive scale up is needed across production pathways using both renewable and fossil-based feedstocks. As of the end of 2021, the total number of large-scale hydrogen projects in the pipeline is 359 according to the Hydrogen Council. Global Hydrogen production is approximately 70 MMT, with 76% produced from natural gas via SMR, 22% through coal gasification (primarily in China), and 2% via electrolysis. This is versus U.S. annual production at 10 MMT. Nearly all of it comes from fossil fuels: 95% from natural gas and 4% from coal. The remaining 1% is made with water.

The question is not whether there will be enough hydrogen to meet demand during the remainder of the 21st century, but how to produce and deliver the hydrogen. Specifically, the question is how can the State of Wyoming leverage this opportunity, develop an economic development strategy to attract and grow the business base to take advantage of this energy source and global movement to clean energy and the expected to trillions in economic value, and how can Wyoming can make the business case to be a key driver in a multi-state hub as well as development of cluster hubs internally. Consequently, in late 2021 Cheyenne LEADS engaged a strategic planning and economic development consultant, Susan Payne, to undertake a Situation Analysis of the burgeoning hydrogen economy from several perspectives including global, domestic and State of Wyoming with a focus on issues relevant to a business case for advancing Wyoming as a continued energy leader in the nation.

This Situation Analysis is the result of the consultant's literature review and interviews with more than 30 industry leaders and state-wide stakeholders that provide the project partners with an understanding of the trends in the leading sources of demand, production and consumption patterns, competing suppliers at the global and regional levels, supply chain dynamics, and changing regulatory environment and incentives at the federal level. This information will provide a baseline to identify gaps and create a framework for an economic development strategy and business case as the State of Wyoming continues to be an energy leader.

Hydrogen Production

There are several ways to produce hydrogen:



Fermentation Using Biomass/Waste
Biomass is converted into sugar-rich feedstocks that can be fermented to produce hydrogen.

H_20 Splitting
Hydrogen is produced via electrolysis, which uses electricity to split water into hydrogen and oxygen. It is powered by zero carbon energy sources, like renewables and nuclear power. Frequently referred to as green hydrogen, it has a role to play in the path towards net zero carbon, providing de-carbonization solutions in the most challenging parts of the carbon abatement cost curve – including long-haul transportation, steel, refining, chemicals, heating, and long-term power storage.

Several hydrogen production methods involving H_20 splitting are in the development stage.

- **High-Temperature Water Splitting:** High temperatures generated by solar concentrators or nuclear reactors drive chemical reactions that split water to produce hydrogen.
- **Photobiological Water Splitting:** Microbes, such as green algae, consume water in the presence of sunlight and produce hydrogen as a byproduct.
- **Photoelectrochemical Water Splitting:** Photoelectrochemical systems produce hydrogen from water used in special semiconductors and energy from sunlight.

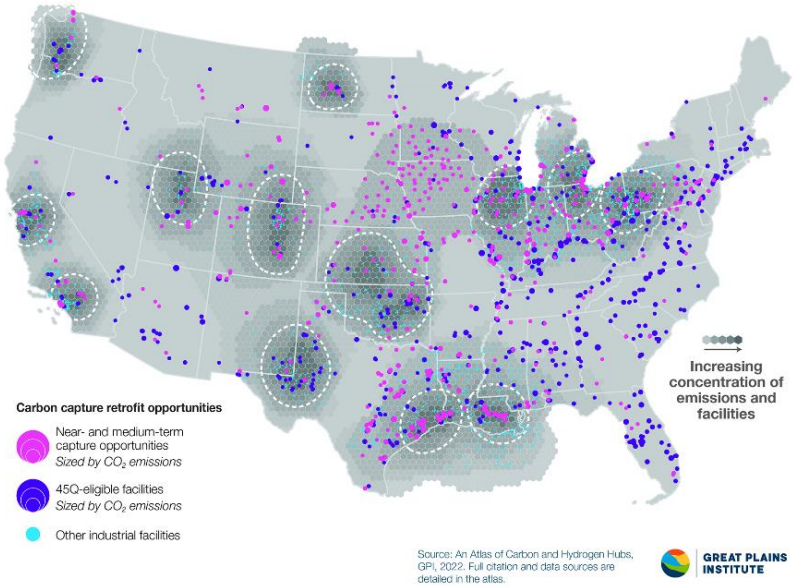
Fossil Resources

- Natural Gas Reforming/Gasification**:** Synthesis gas—a mixture of hydrogen, carbon monoxide, and a small amount of carbon dioxide—is created by reacting natural gas with high-temperature steam. The carbon monoxide is reacted with water to produce additional hydrogen. This method is the cheapest, most efficient, and most common. Natural gas reforming uses steam accounts for the majority of hydrogen produced in the U.S. annually. A synthesis gas can also be created by reacting coal or biomass with high-temperature steam and oxygen in a pressurized gasifier. This converts the coal or biomass into gaseous components—a process called gasification. The resulting synthesis gas contains hydrogen and carbon monoxide, which is reacted with steam to separate the hydrogen.

- Carbon Capture Utilization and Storage (CCUS) is the process of capturing CO_2 that would otherwise be released into the atmosphere from industrial activity, and injecting it into deep geologic formations for safe, secure and permanent storage. In North America today, much of hydrogen is produced adjacent to, or onsite at petroleum refineries and ammonia plants using SMRs or catalytic reforming (without CCUS). CCUS is the most efficient process of capturing CO_2 that would otherwise be released into the atmosphere from industrial activity, and injecting it into deep geologic formations for safe, secure storage. CCUS can remove more than 90% of industrial CO_2 emissions.

The United Nations Intergovernmental Panel on Climate Change and the International Energy Agency agree CCUS is one of the most important low-carbon technologies required to achieve societal climate goals at the lowest cost. CCUS also is one of the only technologies that could enable some industry sectors to decarbonize, including the refining, chemicals, cement and steel sectors; and it's one of the critical technologies required to achieve net zero emissions and the climate goals outlined in the Paris Agreement.

CCUS-equipped power plants also have the potential to act as “anchor projects” for the development of industrial CCUS hubs, with large quantities of CO_2 creating economies of scale for shared infrastructure development.

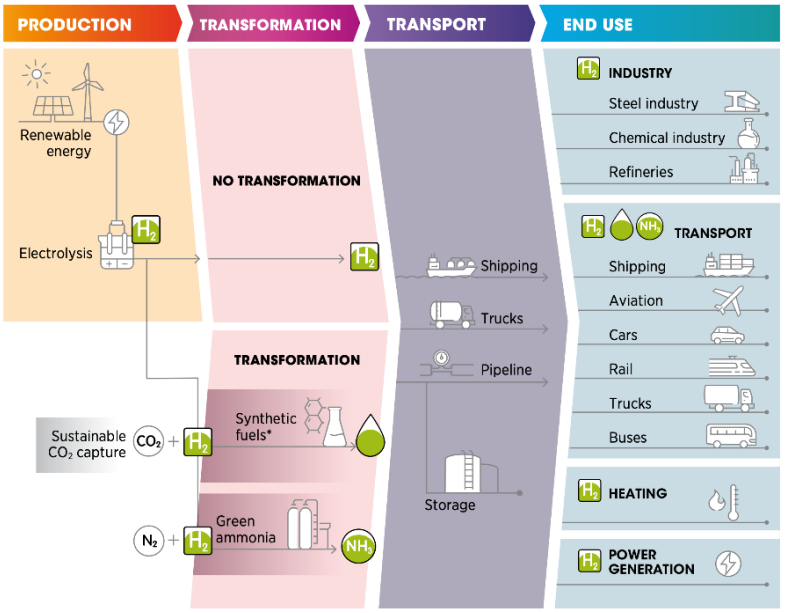


Carbon Capture Retrofit Facilities Identified by The Great Plains Institute

The Great Plains Institute identified 542 facilities as prime candidates for carbon capture retrofit over the next 10 to 15 years. “These facilities represent a launching point for investment in carbon capture and storage, where the economics of capture appear favorable for near-term investment. Additional 45Q-eligible facilities that are expected to continue operating and provide employment through midcentury should also be considered opportunities for retrofit after the initial 10–15-year period.

Hydrogen Transport

There are several methods of transporting hydrogen from production to end users.



1. Via trucks (in gas or liquid form) for short- and long-distance delivery, respectively. The cost of trucking hydrogen is twice as expensive as delivering it via a pipeline; however, the upfront cost of the pipeline must be amortized by a large amount of hydrogen throughput for this to be true.

2. Purpose-built pipelines are the most cost-effective way to transport hydrogen in high demand, but they are estimated to be 10-20% more expensive than new natural gas pipelines. Purpose-built pipelines exist in Texas and Louisiana, for the expressed purpose of transporting grey hydrogen to refineries and chemical plants, and currently operate as private carriers. Retrofitting existing gas pipelines to transport hydrogen is potentially feasible but determining costs and compressor/pipeline material compatibility needs further calculation.

3. Shipping by train in storage tanks (in gas or liquid form) is physically possible and there are viable routes in the U.S., but no planned projects or estimates on costs are available.

4. Hydrogen will be transported by ships to support an international hydrogen market.

Hydrogen Storage

Hydrogen contains some of the highest amounts of energy per unit mass of any fuel but has a very low energy per unit volume, which makes hydrogen storage costs more expensive than natural gas storage costs. And hydrogen's extremely low boiling temperature makes long-term liquid hydrogen storage impractical and means liquefaction is very expensive.

Key challenges to hydrogen storage are:

- ✓ weight and volume
- ✓ efficiency
- ✓ durability
- ✓ refueling time
- ✓ cost
- ✓ codes and standards applicable for hydrogen storage systems and interface technologies. Improvement in these areas will allow for greater implementation and commercialization to ensure both safety and public acceptance, which at present has not been established.
- ✓ lifecycle and efficiency analysis, as currently there is a lack of analysis of the full life-cycle cost and efficiency for hydrogen storage systems.

Options for storage include salt caverns, depleted gas fields, saline aquifers, and hard-rock caverns. According to the Department of Energy, the U.S. has the physical capacity to permanently store thousands of years of this country's emissions at current levels in secure saline geologic formations. However, local site characterization will be needed to identify suitable CO_2 injection sites for project development. Site access and cost of injection also will factor into geologic storage access for each potential project.

Global Perspective

Hydrogen: Momentum as a Renewable Energy

By early 2022 a total of 359 large-scale projects had been announced globally; with more than 50% in Europe. The total investment into projects and along the whole value chain amounts to an estimated $500 billion through 2030. Of this investment, 30% can be considered "mature" – meaning the investment is either in a planning stage, has passed a final investment decision, or is associated with a project already under construction

The global hydrogen generation market is set to reach $201 billion by 2025, from an estimated $130 billion in 2020, at a CAGR of 9.2%. Market growth can be attributed to increasing fuel cell power generation application, demand for long-term power storage and the need to decrease greenhouse gas emissions from hydrogen production methods.

The global renewable energy market is expected to continue its upward growth, reaching $1.1 trillion by 2027. Environmental concerns regarding fossil fuels, rapid urbanization, and economic growth in emerging regions are major factors contributing to the projected market growth.

The Hydrogen Council said global demand for renewable and low-carbon hydrogen could grow by 50% by 2030, but a significant scaling up of production, infrastructure and end uses is needed to meet this demand.

In the Net Zero Emissions by 2050 Scenario, total hydrogen demand from industry is expected to expand 44% by 2030, with low-carbon hydrogen becoming increasingly important (amounting to 21 Mt in 2030).

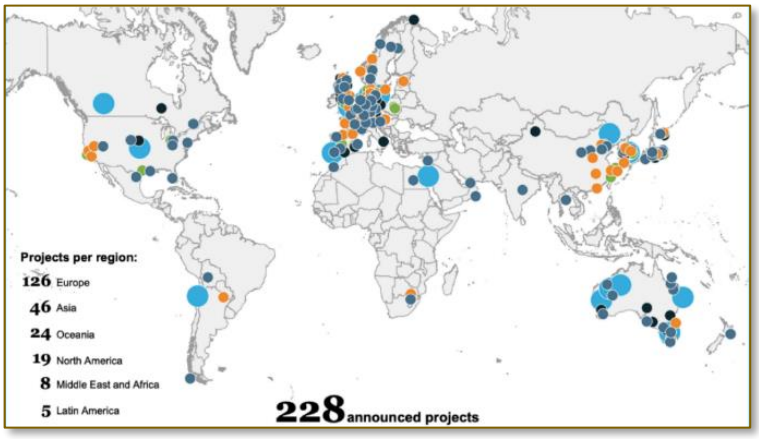
Hydrogen Targets and Roadmaps

There are 75 countries with net-zero carbon ambitions and over 30 countries with hydrogen roadmaps. An increasing number of countries committed to decarbonization targets and large-scale hydrogen projects amounting to over ten million tons of total capacity is projected by 2030 or about a third of total hydrogen demand growth. For example:

- ✓ The EU Commission target is 1.8 euros per kg, and it targets annual production of 10 million tons of Hydrogen in 2030 by investing in hydrogen production.
- ✓ The European Commission's gas package issued in December 2021 proposed new rules boosting hydrogen and biomethane access to existing grids, targeting an 80% cut in methane emissions by 2030.
- ✓ The UK government has set a target of 5 GW of hydrogen production capacity by 2030 to cut the transport sector's 29.8% share of the country's CO_2 emissions.
- ✓ China is emerging as a potential hydrogen giant following its announcement to target net-zero emissions by 2060. China plans to achieve "peak carbon" in various sectors, including aviation and steel before 2030.
- ✓ Japan's Green Growth Strategy has a goal to reach 1 GW of power capacity based on hydrogen by 2030.
- ✓ Korea has a target of 1.5 GW of installed fuel cell capacity in the power sector by 2022; and 15 GW by 2040.
- ✓ Australia's hydrogen roadmap has a goal to become a major hydrogen exporter by partnering with other countries to attract investment, build supply chains and advance research and development.
- ✓ The UAE announced a target of 25% of the hydrogen market by 2030.
- ✓ Over 20 countries signed the Clydebank Declaration to develop at least six green shipping corridors between two or more ports by 2025 and "many more" by 2030.
- ✓ In Latin America there are more than 25 projects.

Global Investments to Meet Demand

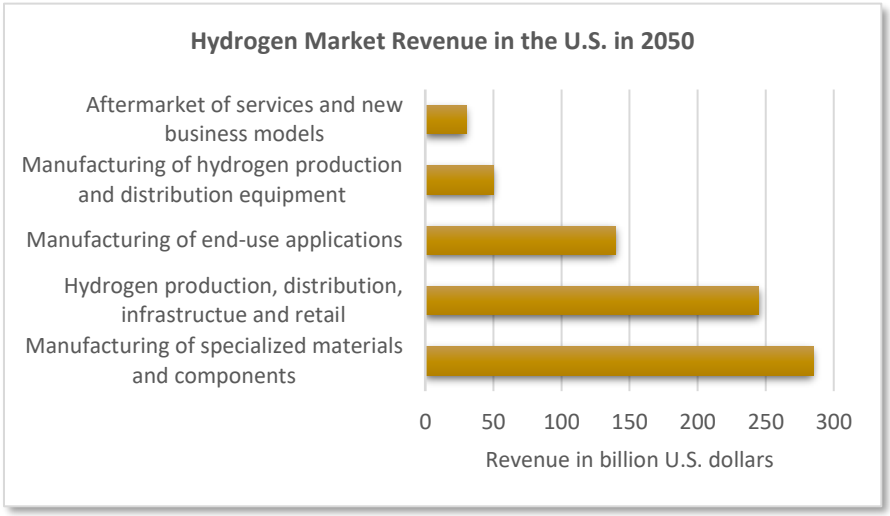
Between December 2020 and August 2021 alone, the scale of green hydrogen projects increased more than three-fold. Of the 228 large-scale hydrogen projects announced across the value chain (industrial, transport and infrastructure), 85% are located in Europe, Asia, and Australia. Just 19 projects are planned to be built in North America.



National Perspective

Markets

Within the U.S. hydrogen market, manufacturing of specialized materials and components is the sector forecasted to generate the highest revenue in 2050, at a total of $285 billion. Ranking second is hydrogen production, distribution, infrastructure, and retail projected to generate a further $245 billion. Combined, these two sectors would be responsible for 70% of the total hydrogen market revenue by 2050.



Supply

GlobalData estimates low-carbon hydrogen production in North America is expected to almost triple by 2030 to around 1.4 million tons per annum. Other research suggests the potential for low-carbon hydrogen to generate revenues of between $130-170 billion per year by 2050.

Demand

The *Road Map to a U.S. Hydrogen Economy*, estimates hydrogen could account for 14% of U.S. energy demand by 2050.The refining sector accounts for the greatest share of hydrogen consumption in the U.S. Hydrogen is used mainly as a feedstock within the manufacturing and chemicals industry; however, it holds great potential as a source for transportation fuels, energy generation, and energy storage as well. By 2050, transportation fuels could become the most common end use for hydrogen in the U.S.

Production and Forecasted Revenues

An August 2021 report by GlobalData estimates low-carbon hydrogen production in North America is expected to almost triple by 2030 to around 1.4m tons per annum (“mtpa”). Other research suggests the potential for low-carbon hydrogen to generate revenues of between $130–170 billion per year by 2050. To put this into context, in 2018 the total revenue of the U.S. oil and gas industry came to around $181 billion.

Challenges to Achieving Hydrogen Deployment

R&D: Increased investment in research and development is crucial. In the U.S., research and development is underway at several of the National Laboratories, universities and the private sector. Since 2000, DOE has invested $4 billion in hydrogen and related areas. In addition, DOE is taking the lead on the Hydrogen at Scale Initiative and the Hydrogen Program Plan. One of the goals of the Plan is to achieve the affordable production and delivery of hydrogen uses in a variety of feedstocks, processing methods and delivery options, ranging from small local to large centralized production. In July 2021 the Department of Energy announced $52.5m of funding for 31 projects to advance next-generation hydrogen technologies and to support the Hydrogen Energy Earthshot.

Additional Federal Government Investment: The process is underway to invest $8 billion in regional hubs.

Regulatory Framework at the Federal and State Levels: The future deployment of hydrogen in the U.S. will depend on the policy landscape at both federal and state levels. Currently, the federal agencies with the most extensive regulation of hydrogen are FERC, OSHA, EPA, and PHMSA. However, hydrogen regulations are not a central part of any of these agencies' missions. This is compounded by the fact there are gaps in the regulations. For example, the Federal government has yet to make a determination about how it will regulate the construction of infrastructure. Also, there is need to set criteria for description of hydrogen as green, and acceptable carbon limits for describing hydrogen as blue or low carbon. In addition, it will be important to define criteria for projects that are consistent with global standards. Ideally, the U.S. would work with the European Union and Asian countries to set global standards allowing for a traded market similar to crude oil and LNG.

Infrastructure: The U.S. requires a significant investment in infrastructure to accommodate hydrogen, particularly pipeline infrastructure. Hydrogen is challenging and expensive to store and transport. It is a highly flammable gas with a low volumetric density, requiring investment in specialized pipelines and carriers.

Hydrogen Demand: The U.S. will need to stipulate hydrogen usage more affirmatively, especially in terms of policy that will stimulate demand in order to make hydrogen a viable alternative energy option.

Specialized Workforce: The rise of hydrogen will create new job opportunities, but many workers lack the specific skills to support the hydrogen economy. A shortage of specialized workers could hinder its progress.

Investment and Financing: To meet market demand, organizations will need to scale up and improve their plant designs, which is costly and complex. Limited knowledge about optimum design and return on investment is hindering bankability. Furthermore, many of these large hydrogen facilities are built within existing industrial clusters, which adds another dimension of design to ensure limited impact on existing operations during the eventual transition to green hydrogen. And the U.S. government and industry will need to work together to ensure the regulatory environment does not pose an unnecessary barrier to investment.

Political Environment: Major initiatives such as the *Hydrogen Energy Earthshot* are part of a broader effort to drive breakthroughs in emerging energy technologies. However, the lack of both regulation and proper incentives currently limits the development of a hydrogen economy. For example, locking down a tax credit would be significant but would require the cooperation of Congress. The House and Senate did approve a range of hydrogen credits in H.R. 133, the coronavirus stimulus bill, though not the kind the industry seeks.

Increased Demand: The green hydrogen industry has been open about the important role of the Federal government to "push the demand side and pull on the supply side" if hydrogen technology is to succeed in reducing the country's carbon emissions.

Overall Strategy: There is currently no comprehensive hydrogen strategy for the U.S.; however, the Department of Energy's Hydrogen Program Plan has been published with the attempt to realize the potential of hydrogen use through committing to research and development, in addition to increasing demonstrations and deployments with the private sector. The Plan only is a strategic framework incorporating the research, development, and demonstration efforts of DOE's various offices.

Regulatory Environment and Authority

FERC (Federal Energy Regulatory Commission)
The FERC has stated its role is to react to actions in energy markets and ensure there is a level playing field for all energy technologies and resources. FERC has full jurisdiction over the siting of interstate natural gas pipelines but no jurisdiction over siting electric power transmission lines, except in limited cases. If hydrogen ultimately falls under the purview of FERC, so too will the operation of the interstate hydrogen pipeline systems.

OSHA (Occupational Safety and Health Administration)
OSHA is responsible for creating Occupational Health and Safety Standards, housed in Title 29 of the C.F.R. Subpart H of Title 29 covers the Occupational Health and Safety Standards for Hazardous Materials – including compressed gases and hydrogen. 29 C.F.R. § 1910.103 covers the installation of hydrogen systems, regulating several aspects including location; containers and piping characteristics; safety relief devices; equipment assembly; marking; and testing, among others. There are other sections that could regulate hydrogen. For example, hydrogen will likely be compressed or liquefied in several situations, which may implicate OSHA safety standards for compressed gases and flammable liquids.

EPA (Environmental Protection Agency)
The EPA regulates substances that have an impact on human health and the environment. This mandate includes a broad array of substances, including hydrogen. Primary regulation of hydrogen by EPA is found under the Mandatory Greenhouse Gas Reporting Program ("GHG Reporting"), Effluent Standards under the Clean Water Act, and Chemical Accident Prevention program. In each instance, hydrogen is listed not due to any systematic consideration by EPA of regulations that may be needed for hydrogen under the agency's mandate, but instead because of hydrogen's relationship to that program.

PHMSA (Pipeline and Hazardous Materials Safety Administration)
The PHMSA mission is to protect human health and the environment by promoting the safe transportation of energy and other hazardous materials by creating national policy, setting and enforcing industry standards, and conducting research. PHMSA currently regulates approximately 700 miles of hydrogen pipelines via 49 C.F.R. Part 192. These regulations are primarily focused on natural gas, but the definition of gas under this provision includes "flammable gas", which brings hydrogen into play. However, because the primary focus of these regulations is natural gas, certain characteristics of hydrogen are not included in some of the existing regulations' design requirements. PHMSA has stated it has a "need to focus on supporting activities to ensure hydrogen is transported safely" and identified that it needs a "clear technical focus regarding safety implications of infrastructure materials, designs and systems; preparations to address any regulatory barriers towards a hydrogen economy; research in support of additional industry consensus standards; [and] efforts to educate and prepare emergency responders."

DOE (Department of Energy)
DOE will likely continue to play a significant role in the development and testing of new hydrogen technologies. The DOE Hydrogen Program Plan describes the strategy for fostering the hydrogen economy by funding research and development. The Plan analyzes potential uses of funding for hydrogen development, primarily focusing on hydrogen's role in power generation and transportation. The Plan also discusses potential advances to be made in chemical and industrial processes, where hydrogen traditionally has been used. DOE also envisions itself playing a role in incentivizing the use of hydrogen in fuel cells, especially for long-haul trucks. In addition, the Plan examines the production, storage, and transportation of hydrogen, specifically methods to make carbon-neutral or carbon-negative hydrogen an affordable reality. This means evaluating all possible methods of producing hydrogen – fossil fuels, renewable energy, nuclear energy, and methanol.

The Issue of Cost and Investment

One of the main challenges facing hydrogen is cost. Costs to hydrogen buyers may be lowered if:

- ✓ breakthroughs in technology reduce costs or improve the efficiency of electrolysis.
- ✓ electricity prices drop.
- ✓ an import/export market for hydrogen develops.
- ✓ alternative zero-carbon hydrogen production technologies are commercialized and surpass electrolysis in their cost-effectiveness.
- ✓ there is a significant investment by government agencies in the pipeline infrastructure.

In 2020, the global hydrogen market received nearly $1.5 billion in investments, driven by fuel cell vehicles and buses, refueling stations and electrolyzers. In 2021 there were $72.8 billion in deal values.

By early 2022, 359 large-scale projects had been announced globally: up 131 since the first half of 2021. More than 50% are in Europe. The total investment into projects and along the whole value chain is projected to amount to an estimated $500 billion through 2030.

It is estimated the total associated investment through 2030 will amount to $500 billion based on:

- ✓ $130 billion investment directly associated with the announced projects.
- ✓ $120 billion additional direct investment needed to reach government targets that exceed announced projects.
- ✓ $250 billion implied investment from OEMs and suppliers to support the direct investment from publicly announced projects and government targets out of the total investment, $150 billion or 30% can be considered “mature,” meaning that the investment is either in a planning stage, has passed a final investment decision, or is associated with a project that is already under construction or currently operational.[1]

For example, members in the Hydrogen Council are planning a sixfold increase in their total hydrogen investments through 2025 and a 16-fold increase through 2030. They plan to direct most of this investment toward capital expenditures (capex), followed by spending on merger and acquisition (M&A) and R&D activities.

According to McKinsey’s 1.5-degree-pathway scenario, over the next decade $750 billion is needed to flow to CCUS, $200 billion to EV infrastructure, and $700 billion to hydrogen-production capacity. Renewable power will require capital expenditures of $8.5 trillion to build the solar and on- and offshore wind capacity required from 2020 to 2030. Further, McKinsey forecasts investments will need to increase $3.5 trillion per year for the next 30 years for an annual total of $9.2 trillion. And the Energy Transitions Commission forecasts that to build a hydrogen economy accounting for 15-20% of energy consumption would require an investment of $15 trillion between now and 2050.

Workforce Challenges

Demand for solar and wind technicians is expected to roughly double over the next several years. Also growing are jobs such as environmental engineers, scientists, and workers needed to address pollution and restore natural environments. It will be necessary to develop a workforce development strategy to support the hydrogen economy with the following key elements.

- Training for building and operations staff to properly operate and maintain building systems.
- On-the-job training for new energy workers.
- Internships for students looking to gain hands-on skills at an energy company.
- Curriculum development to meet the demands of energy employers.
- Creation of a sustainable talent pipeline that can reduce the business cost of hiring new workers.

[1] Hydrogen Insights. Hydrogen Council and McKinsey. July 2021.

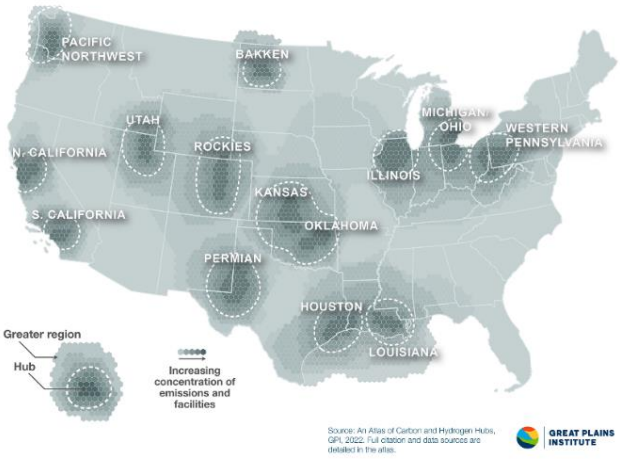
Concept of Hydrogen Hubs

The National Hydrogen Strategy supports the creation of hydrogen hubs in regions where hydrogen users, producers and potential exporters are co-located**.** With a geographical advantage, these hubs are expected to unlock hydrogen's distribution and storage challenges and be a catalyst to drive the hydrogen mobility sector from niche to mainstream adoption.

Hubs are expected to allow for a more modest infrastructure build out and where suppliers can share investments and risks, driving down costs throughout the equipment value chain. Multiple hydrogen off-takers within the geography of a cluster can piggy-back on the lower-cost hydrogen supply.

In February 2022, The Great Plains Institute released its *Atlas of Potential Carbon and Hydrogen Hubs Across the U.S.* These hubs have the potential to co-locate new hydrogen facilities in areas with existing hydrogen and ammonia distribution infrastructure, natural gas pipelines, biomass feedstock resources, and permanent geologic CO_2 storage potential. They offer initial target areas to focus investment and coordination to scale low- and zero-carbon hydrogen production and use from initial commercial demonstration to eventual deployment.

The Great Plains Institute Fourteen Potential Carbon and Hydrogen Hubs Across Eight Regions of the U.S.



Such hydrogen cluster hubs are expected to be the key to get the trucking industry moving forward rapidly with the use of hydrogen powered fleets. Such hubs are being developed in California, Mississippi, and North Dakota.

In addition, "hydrogen cluster" hubs will emerge with large-scale hydrogen off-takers at their core.

- Industrial centers that support refining, power generation, and fertilizer and steel production
- Export hubs in resource-rich countries
- Port areas for fuel bunkering, port logistics, and transportation

The International Energy Agency suggests such hubs will be the "nerve centers" scaling up hydrogen.

1. Make Industrial ports the nerve centers for scaling up the use of hydrogen.
2. Build on existing infrastructure, such as natural gas pipelines.
3. Expand hydrogen in transport through fleets, freight and corridors.
4. Launch the hydrogen trade's first international shipping routes.

Hydrogen and the State of Wyoming

An Energy Leader in Past Centuries … Now Positioning to be a Global Leader in the 21st Century

Wyoming ….

- ✓ Produces 14 times more energy than it consumes and is the largest net energy supplier in the U.S.
- ✓ Has been the top coal-producing state since 1986, accounting for about 39% of all coal mined in the U.S. in 2019, and the state holds more than one-third of U.S. coal reserves at producing mines.
- ✓ Was the eighth-largest crude oil-producing state in the nation in 2020, accounting for slightly more than 2% of U.S. total crude oil output.
- ✓ Was the ninth-largest natural gas producer and accounted for 4% of U.S. marketed gas production.
- ✓ Its large energy-producing sector and small population help make the state first in per capita energy consumption and gives it the second most energy-intensive state economy, after Louisiana.
- ✓ Produces more natural gas from federal leases than any other state and the second-highest amount of crude oil from onshore federal leases.
- ✓ Is named first of 11 states in the Mountain West and Pacific Northwest regions by the National Renewable Energy Laboratory (NREL) for Developable Nameplate Wind Power Production by Class; and ranks 3rd, after Texas and Iowa, in the amount of wind powered-generating capacity that came online in 2020. Fifty percent of the best quality wind capacity in the continental U.S is located in Wyoming, with the most wind projects with 3.2 GW built wind projects, plus 1 GW in the queue.
- ✓ Is a crossroads for pipelines bringing Canadian and Rocky Mountain crude oil to refineries in the Rocky Mountain and Midwest regions and for pipelines shipping refined products to markets in those regions.
- ✓ Is well positioned to become a "hub" and an initial magnet for investment in carbon removal and hydrogen production that could minimize financial and logistical barriers to market development.
- ✓ Is one of the largest emerging hubs for CO_2 pipeline infrastructure and projects, with the new Pipeline Corridor Initiative, including the recent designation of more than 1,100 miles of federal lands throughout Wyoming as corridors for potential new pipelines, and another 900 miles identified on private and state lands.
- ✓ Is strategically positioned to become both a major source of CO_2 captured from industrial facilities and power plants, as well as a hub for the beneficial use and geologic storage of captured carbon.
- ✓ Will be home to a first-of-its-kind nuclear demonstration project.

> ***Wyoming is strategically positioned to become both a major source of CO_2 captured from industrial facilities and power plants, as well as a hub for the beneficial use and geologic storage of captured carbon.*** The Great Plains Institute. 2022

Wyoming's Energy Resources

Wyoming's Abundant Anthropogenic CO_2 Sources

According to the Great Plains Institute report (January 2022), decarbonizing manufacturing and chemical use processes, fuel use, and installed equipment "*will require new or alternative forms of low-carbon fuels, advanced technologies, and modified equipment or production configurations. Given the vast number of active industrial facilities that contribute to the economy of local communities and the nation, solutions to industrial emissions will need to be deployed at scale and at considerable speed in order to achieve alignment with international climate modeling scenarios and U.S. midcentury goals. Many of the technologies and advanced production processes needed for industrial decarbonization are still in the research and development or pilot demonstration phases. Meanwhile, it has become increasingly clear that achieving global climate modeling scenarios that limit temperature increases to 1.5–2°C will require significant amounts of negative emissions through carbon capture, biomass-based energy, and carbon removal via direct air capture. Like industrial decarbonization solutions, carbon removal remains a nascent technology that is just now growing into the commercial demonstration phase.*

Negative emissions through carbon capture and carbon removal will also require the transport of carbon dioxide (CO_2) to locations with access to permanent and secure geologic storage."[2]

Given this scenario, Wyoming is well positioned to become a "hub" and an initial magnet for investment in carbon removal and hydrogen production that could minimize financial and logistical barriers to market development. For example, Wyoming has the potential to become a major source of economically captured anthropogenic CO_2 from industrial facilities and power plants. Carbon capture retrofits can lead to significant environmental and economic benefits. CO_2 producers also can sell captured CO_2 and create new revenue streams.

Renewable Energy: *Wyoming installed the third-largest amount of wind power generating capacity in 2020, after Texas and Iowa.*

Wyoming has abundant wind and solar resources, which could be a key factor related to the opportunity for the cost-effective production of low-carbon hydrogen, especially because the costs of hydrogen from renewable electricity are expected to decline in the future. Additionally, when deployed at scale, the lowest cost way to transmit and store hydrogen could potentially utilize some of the gas pipeline and geologic storage systems that already exist in the state.

In 2020, renewable energy sources generated about 15% of the electricity in Wyoming, with wind power accounting for four-fifths of the state's renewable electricity. Wyoming has some of the greatest wind resources in the nation, especially in the southeastern corner of the state. Sustained winds are funneled through the state's mountain passes and out across the high prairie, which enables Wyoming wind farms to operate at high-capacity levels. In 2020, the amount of wind powered-generating capacity installed in Wyoming nearly doubled to almost 1,800 megawatts.

Wyoming ranked third, after Texas and Iowa, in the amount of wind powered-generating capacity that came online in 2020.

50% of the best quality wind capacity in the continental U.S is located in Wyoming on shore before wind capacity. Wyoming is one of the states with the most wind projects with 3.2 GW built wind projects, plus 1 GW in the queue. Wyoming was named first of 11 states in the Mountain West and Pacific Northwest regions by the National Renewable Energy Laboratory (NREL) for Developable Nameplate Wind Power Production by Class.

Wind companies have invested $5 billion in Wyoming. There are 8 gigawatts (GW) of proposed and under construction wind energy in Wyoming, and 472 GW of technologically possible capacity. The proposed 8 GW is enough energy to power almost 6 million homes, 20 times the number of households in Wyoming.

Nuclear Energy

TerraPower's Natrium reactor project is a partnership with Rocky Mountain Power, PacifiCorps and the U.S. Department of Energy. Unlike traditional nuclear facilities, the project will be smaller, modular and designed to replace existing plants when they retire. It will use the Natrium technology, which is one of the fastest and lowest-cost paths to achieving Net Zero goals.

Energy on Tribal Lands

Wyoming's Wind River Reservation, home to both the Northern Arapahoe and the Eastern Shoshone tribes, is the third-largest Native American reservation in the U.S. at more than 3,500 square miles. It is Wyoming's only reservation and occupies most of the Wind River Basin in the west-central area of the state. The Wind River Reservation has produced crude oil and natural gas for well over a century.

The state's first oil well was drilled in the Wind River Basin in 1884, south of the reservation's boundary. About fifty years later, several oil seeps were discovered within the reservation, and crude oil and natural gas production on tribal lands followed. Most current crude oil production occurs in the western half of the reservation while most natural gas production occurs in the eastern half. The Biden administration's executive order in January 2021 to suspend new leasing agreements and permits for oil and natural gas development on federal lands does not apply to tribal lands.

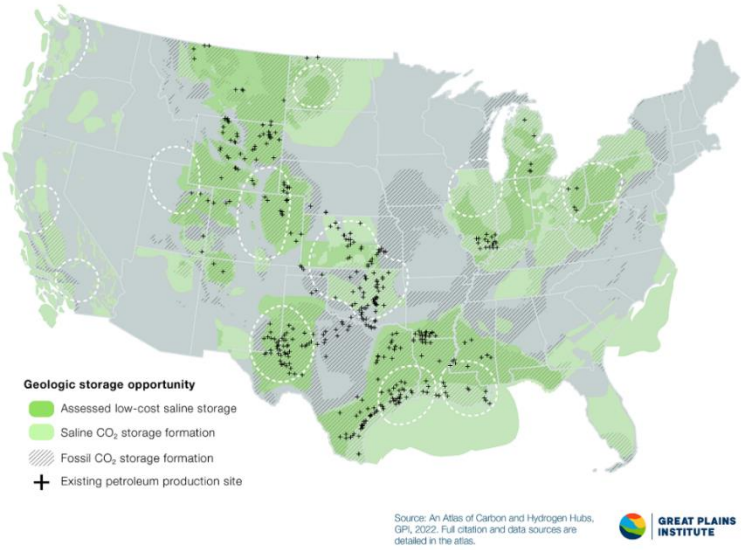
[2] An Atlas of Carbon and Hydrogen Hubs for United State Decarbonization. Great Plains Institute. February 2022.

There are two utility-scale electricity generating facilities owned by the US Bureau of Reclamation on the reservation. Both are hydroelectric dams; with generation capacity of 15 megawatts and 1.6 megawatts.

The Wind River Reservation also has significant wind energy resources for potential electricity generation, especially along the mountain ridges that border the reservation. The Wind River reservation is also one of the top 15 reservations in the nation with the best potential to generate electricity from solar energy resources.

Wyoming's Storage Capacity

The Rockies Region has the potential to act as a major carbon storage destination for capture facilities and carbon removal. According to The Great Plains Institute, Wyoming has among the largest capacity for CO_2 storage as compared to other states and regions in the country. And the states of Wyoming and Colorado have the combined potential to store 773 billion metric tons of CO_2 in secure geologic saline formations, and also have extensive capacity for carbon storage in geologic fossil basins such as oil and gas fields.



Geological Storage Opportunities Identified by The Great Plains Institute

Wyoming Pipeline Corridor Initiative

Among its greatest assets related to advancing a Hydrogen Economy in Wyoming is Wyoming's commitment to pipeline infrastructure. Approximately 2,000 miles of pipeline corridors already exist throughout central and western regions of Wyoming have been identified as essential for future production and distribution of the State's resources. And the Wyoming Pipeline Corridor Initiative is now underway.

The Wyoming legislature first appropriated funds for the Wyoming Pipeline Corridor initiative in 2012. In January 2021, the U.S. Bureau of Land Management issued a federal record of decision, designating more than 1,100 miles of federal lands throughout Wyoming as corridors for potential new pipelines. Another 900 miles of corridors have also been identified on private and state lands but will not be a priority during the initial stages of the project.

In addition to transporting oil and natural gas products, the new pipeline corridors were designed to incorporate associated infrastructure, such as enhanced oil recovery, carbon capture, and even broadband technology. The Wyoming Pipeline Corridor Initiative will optimize future pipeline construction timelines through the designated corridors, helping the oil and gas industry capitalize on these new connections to transport products within and out of Wyoming. The WPC is working through the process of authorizing these corridors with BLM with the goal of reducing the time and cost it takes for developers to permit these large infrastructure projects, while also balancing the environmental concerns associated with these lands by reducing the disturbance footprint.

WPCI consists of 25 segments, covering BLM, private and state land. However, the current WPCI effort will only apply to BLM administered lands. The WPCI project is compatible with additional uses such as broadband infrastructure, which could be acceptable at the outer boundaries of the approved corridors. And Wyoming is well positioned to connect with the pipelines in surrounding states.

Rail in Wyoming
Due to Wyoming's geographic location and comparatively low and snow-free summits, a substantial percentage of transcontinental traffic moves through the state by rail between the West Coast and destinations in the Midwest and East. The Wyoming freight-rail system is operated by two Class I railroads, one Class II (regional) railroad, and two Class III (or short-line) railroads. The system consists of 1,750 route-miles, excluding trackage rights agreements between railroads. Nearly all rail is owned by two Class I carriers: BNSF Railway and the Union Pacific Railroad.

In 2021, the Wyoming Department of Transportation (WYDOT) developed the Wyoming Statewide Rail Plan. The plan states the WYDOT will work toward the following initiatives.

- ✓ Continue to promote and enhance rail safety through public awareness, coordination with railroads, and infrastructure improvements.
- ✓ Provide advocacy for rail shippers, encouraging multimodal cooperation and collaboration between shippers and railroads
- ✓ Continue to work with neighboring states on freight and passenger rail initiatives that benefit the region.
- ✓ Support the study of new intercity passenger rail initiatives could enhance mobility options for Wyoming.

Wyoming's Research and Development

Integrated Test Center
Among the largest in world, the Integrated Test Center (ITC) provides space for researchers to test Carbon Capture, Utilization and Sequestration (CCUS) technologies using 20 MW of actual coal-based flue gas at Basin Electric facility. Along with testing capture technologies, additional research will look at taking flue gas and turning it into a marketable commodity. The ITC is one of the few research and testing facilities at an operating coal-fired powered plant, allowing for real-world testing at an active power plant, alleviating typical concerns over being able to transfer technology from a lab to a plant

University of Wyoming
The State of Wyoming has a tremendous asset in the University of Wyoming School of Energy Resources (SER), which directs and integrates cutting edge energy research and academic programs at University of Wyoming (UW) and bridges academics and industry through targeted outreach programs. SER's mission is to promote energy-driven economic development for the state of Wyoming. SER leads UW's talent and resources for interdisciplinary research and outreach, fulfilling Wyoming's promise to be a global leader in a thriving and sustainable energy future. SER is further committed to advancing the directive set forth by Wyoming's Governor Mark Gordon to strive toward net-negative carbon emissions through all methods of energy development and production. And most recently the SER established the Hydrogen Center of Excellence.

There a several Centers of Excellence at the UW focused on energy, including:

- ✓ **Center for Economic Geology Research**: CEGR engages in the research and development necessary to keep Wyoming at the cutting edge of geological CO_2 storage. Through various research projects and cooperative initiatives, CEGR aims to speed the development & deployment of successful, safe geologic CO_2 storage, both in Wyoming and elsewhere.

- ✓ **Center for Energy Regulation & Policy Analysis**: CERPA conducts interdisciplinary research to produce value-added working papers, publications, and discussions on energy-related policy, law, and regulatory issues in Wyoming.

- ✓ **Center for Carbon Capture & Conversion:** The Center supports the future of Wyoming coal, creating economic development and diversification opportunities by 1) enabling continued use of Wyoming coal in thermal applications, advancing fossil energy-based systems and technologies, and 2) investing in carbon engineering processes and product technologies that consume large volumes of coal and add value.

- ✓ **Hydrogen Center of Excellence**, with a principal objective to identify and quantify the relative competitive advantages of Wyoming in an emerging low-carbon hydrogen economy.

- ✓ **The Wind Energy Research Center** (WERC): Focus areas include experimental aerodynamics, micro-scale modeling, high fidelity Computational Fluid Dynamics (CFD) modeling, and wind resource modeling.

- ✓ **Hydrogen Energy Research Center** (H_2ERC): The center will focus on low-cost coal by gasification, natural gas resources by methane reforming, and wind energy by electrolysis, as well as potential for solar and nuclear power**.** H_2ERC will look to lead applied research and collaborate with Wyoming stakeholders to support growth of a hydrogen industry focused on serving the state's existing energy customers and growing new markets. Research will focus on all forms of clean hydrogen including:

    - low-cost coal via gasification
    - natural gas resources via methane reforming
    - high-capacity wind energy via electrolysis
    - potential for solar and nuclear

There are several research areas under investigation by the H_2ERC including:

- ✓ **Creating Hydrogen from Wyoming Natural Resources**: Wyoming has the potential to utilize abundant, existing resources and transform them into potential feedstock for clean hydrogen including low-cost coal, natural gas, wind, solar and uranium.

- ✓ **Investigating Novel Transportation Approaches**: With existing transportation infrastructure and a vast network of natural gas pipelines, research will be geared toward optimizing hydrogen transportation networks in Wyoming.

- ✓ **Evaluating Options to Use Produced Water**: Water usage and availability are key for most hydrogen manufacture. Research will seek to use produced water as a feedstock for hydrogen production, conserving freshwater resources in Wyoming.

- ✓ **Techno-Economic and Market Assessments:** As a major energy exporter, researchers will work to identify new and emerging markets for hydrogen, placing Wyoming at the forefront of hydrogen development for state-wide economic diversification.

In addition, the U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM) awarded a $644,000 grant to UW to assess the economic impacts of fossil energy production in Wyoming and evaluate opportunities and research needs to deploy clean hydrogen technologies. The study also will include direct outreach and engagement with local tribal nations and other traditionally marginalized groups to ensure that the study's findings represent a diverse set of perspectives.

Wyoming's Workforce Development

The shift to a Net Zero economy will impact the day-to-day operations of businesses, whether it's a strategy for new and existing products, managing supply chains, assessing risk and making capital allocations, or workforce development. There is the potential for job creation in several of Wyoming's emerging energy sectors, from wind to carbon capture to retrofitting existing facilities and more. Wyoming has several existing programs and initiatives to support the demand for a skilled workforce to support businesses.

Wyoming Innovation Partnership

The Wyoming Innovation Partnership is a multi-year initiative that leverages the collective efforts of the state's nine institutions of higher education to improve Wyoming's economic prosperity through the coordinated efforts. WIP aims to grow the economy through entrepreneurship, research, computing education, and workforce development by collaborating with industry and governmental partners.

Unemployment Insurance Trust Fund

The UI Trust Fund is unique to the State of Wyoming. The training funds available to businesses in the form of grants are generated from the interest of a trust fund established by the state, which now has assets of $50 million. An estimated $2 million is available annually for workforce training.

Colleges
Wyoming is known for its higher education resources. The state provides one of the highest educational appropriations per full time equivalent student in the country. And the state's seven community colleges serve more than 26,000 students and are well positioned to play a key role in workforce development.

The University of Wyoming offers more than 200 areas of study in its ten colleges and schools. Another example is Laramie Community College with its array of technical training programs and centers such as Technical Training Programs in Welding, Industrial Maintenance, CDL, Alternative Energy; the Lab for Wind Energy; the Advanced Manufacturing Center, and the Fabrication Lab.

Training, Internships and Apprenticeship Programs
The Workforce Development Training Fund (WDTF) is a unique Wyoming-based program connecting employers with professional development opportunities to increase employee skill attainment. The Wyoming Department of Workforce Services also administers the federally funded Apprenticeship State Expansion program. A business designated as a Registered Apprenticeship Sponsor is eligible to receive funding for training related instruction costs and one-time reimbursement to offset job learning expenses.

Higher Education Scholarships
The Hathaway Scholarship Program provides partial tuition for persons who have graduated from a Wyoming high school and can be used toward a degree program at a community college or University of Wyoming. And the Wyoming Tomorrow Scholarship program is designed to support persons who seek to return to college (community college or University of Wyoming) to complete a degree program. It is estimated there are nearly 90,000 Wyoming residents who have not finished a college degree.

NextGen Sector Partnerships
Next Generation Sector Partnerships are industry-led, community-supported partnerships that strengthen regional economies and connect people to jobs. The Workforce Development Council launched Next Gen Sector Partnerships as a collaborative effort with the Wyoming Department of Workforce Services, the Wyoming Business Council, the Wyoming Department of Education and the Wyoming Community College Commission. Its outreach efforts are designed to promote workforce initiatives tailored to the selected growth industries.

Support for Community Development Infrastructure
The Wyoming Business Council administers the Business Ready Community (BRC) grant and loan program, which provides financing for publicly owned infrastructure that serves the needs of businesses and promotes economic development within Wyoming communities.

Policies and Regulations
Supportive government policies can accelerate the deployment of key technologies and scaling of hydrogen production, storage and transport at the pace and scale required for businesses to thrive. Wyoming was among the first states to enact comprehensive carbon capture and storage legislation and is currently one of only two states with a regulatory program for the injection of CO_2 into deep geologic formations for long-term storage. Wyoming also has the necessary regulatory agencies in place to facilitate investments in hydrogen including:

- Wyoming Pipeline Authority
- DEQ
- Wyoming Infrastructure Authority
- Geological Survey
- Enhanced Oil Recovery
- Environmental Quality Council

Wyoming Energy Authority and Wyoming Energy Resources Council

The Wyoming Energy Authority (WEA) was created in 2020 by the Wyoming State Legislature by merging the Wyoming Infrastructure Authority and the Wyoming Pipeline Authority, effectively consolidating Wyoming's energy program into one entity that works to advance the state's energy strategy by supporting Wyoming's full energy portfolio. The WEA is charged with advancing Wyoming's energy strategy by driving data, technology, and infrastructure investments. Focusing on an "all-of-the-above" energy mix, the WEA's strategy includes products Wyoming's legacy industries, along with the newer players of renewable energy and emerging opportunities in hydrogen, advanced nuclear, geothermal, and rare earth elements.

The Wyoming Energy Authority's objectives are to:

- Promote and support the development of commercial energy projects.
- Preserve existing markets while identifying and pursuing new areas for market development.
- Promote Wyoming's energy resources and provide education, data and resources with the benefits of Wyoming's energy assets.
- Leverage financial opportunities to develop efforts conducive to the sustainability of the energy sector in Wyoming.
- Leverage Wyoming's diverse energy resources for the benefit of Wyoming citizens while preserving environmental stewardship.
- Support the transition of innovative technologies and practices into the Wyoming energy sector.
- Navigate the Wyoming energy sector through emerging opportunities and help frame best practices for other communities and state.
- Develop and promote public policies and regulation to ensure sustainable use of Wyoming's energy resources.

Projects have been funded with approval by the Wyoming Energy Resources Council and administered by WEA.

- ✓ The Williams Companies is conducting a feasibility study to evaluate water access, compatibility and asset integrity in support of green hydrogen production and transport in the vicinity of Wamsutter and Opal, Wyoming. It is in collaboration with the University of Wyoming and external laboratories that will explore commercial production in Wyoming. The results could enable development of green hydrogen production and/or synthetic natural gas production.
- ✓ Tallgrass Energy's "Eastern Wyoming Sequestration Hub" Project involves studying the potential to sequester CO_2 in the Wyoming Denver-Julesburg Basin in support of the development of a commercial scale sequestration hub in Eastern Wyoming. The information from this phase will provide the basis for full implementation of a regional sequestration hub that includes Tallgrass' development of a multi-state transmission system. This project will provide a platform to increase the visibility of Wyoming and its suitability for commercial deployment of CCUS.
- ✓ The North Shore Energy and Starwood Energy Group's "Project Phoenix" is a joint exploration in the development of a state-of-the-art ammonia complex with on-site carbon capture and sequestration capabilities at existing depleted hydrocarbon reservoirs and processing facilities near Evanston, WY. When fully developed, the project will be a very low-cost producer of low carbon ammonia, will permanently store CO_2 underground, will re-purpose existing infrastructure.
- ✓ The 8Rivers 8RH2 Process for Producing Clean Hydrogen with Autothermal Reforming and Carbon Capture project will conduct a Pre-Front-End Engineering Design (Pre-FEED) study for a new-build 8 Rivers Hydrogen (8 RH2) plant aiming for an eventual FEED study followed by project construction. The facility would use autothermal reforming to produce 100 MMSCFD of clean hydrogen with up to 99% carbon capture, for sequestration in Evanston, Wyoming.

Another project is underway to further assess challenges and opportunities; specifically, to identify how responsibly sourced natural gas from Western States and Tribal Nations can:

- Support goals for reducing global greenhouse emissions in the short-term (next 10 years).
- Support long-term societal goals for the energy transition to carbon neutrality (10+ years).
- Enhance indigenous community participation in the energy economy.
- Allow the U.S. to position itself as a major player in the world energy market, and to provide labor and employment opportunities for the U.S. workforce.
- To identify key energy infrastructure that currently exists and supports rural economic development; and can be developed to provide safe, reliable, affordable and carbon-neutral energy for decades, including natural gas with carbon capture and low-carbon hydrogen production.

Examples of Private Sector Investment

Many energy businesses in Wyoming are adjusting their asset and product portfolios to target divestments, re-purpose assets, and focus on new technology and investments in lower-emission solutions.

- ✓ ExxonMobil is undertaking a $400 million investment in expansions of carbon capture at its LaBarge operation. The location currently represents nearly 20% of all CO_2 captured in the world each year. The expansion will further mitigate emissions by capturing up to an additional 1 million metric tons of CO_2 each year, in addition to the 6-7 million metric tons captured each year. Operations could start as early as 2025.

- ✓ Clean Energy Corporation acquired Energy Star in the Evanston area and is in the R&D phases of hydrogen.

- ✓ Ekola Flats Wind Energy Project is a subsidiary of the state's largest utility, Rocky Mountain Power and has begun erecting 270-feet tall turbines.

- ✓ Nordex U.S.A. is planning to break ground on a privately funded $2.2 billion clean hydrogen extraction/fuel plant located in Niobrara and Converse counties by late 2025 or early 2026.

- ✓ Anschutz North America is undertaking the Chokecherry and Sierra Madre Wind Energy Project, which involves constructing the nation's largest wind power project in Carbon County and developing the West's largest high-voltage interregional electric transmission system. The wind and transmission projects are at the center of a planned initiative called the Wyoming Clean Power Center. The center is being designed as a fully integrated green energy hub for the giga-scale production and transportation of clean, renewable electricity and associated clean power-produced products, such as green hydrogen.

- ✓ Petroleum refining companies such as Holly Frontier are making significant investments to create their own hydrogen by taking methane natural gas and stripping it out to get hydrogen. In 2022, Holly Frontier's refinery in Cheyenne was converted to renewable diesel production. The company also is pursuing products in support of global demand for sustainable aviation fuel.

- ✓ North Shore Energy and Starwood Energy Group is undertaking the "Project Phoenix"; a joint exploration project involving development of a state-of-the-art ammonia complex with on-site carbon capture and sequestration capabilities at existing depleted hydrocarbon reservoirs and processing facilities. When fully developed, the project will be a low-cost producer of low carbon ammonia, will permanently store CO_2 underground, and will re-purpose existing infrastructure.

- ✓ Rocky Mountain Power PacifiCorp is working to explore the feasibility and design of a carbon capture, utilization and sequestration facility or facilities to remove carbon dioxide from exhaust gases for the company's Wyoming operating coal-fueled generation facilities and subsequently utilize and/or sequester all removed CO_2.

- ✓ In 2021, TerraPower announced plans to build its Natrium reactor at a retiring coal plant in Kemmerer, Wyoming. The Natrium Project design represents the future of advanced nuclear reactor technology. The U.S. Department of Energy plans to invest nearly $2 million to support the licensing, construction and demonstration to be available in 2028.

- ✓ In 2021, Williams New Energy Ventures was launched with a focus on commercializing innovative technologies, markets and business models; and to implement projects to grow its clean energy business. Williams is investigating development of green hydrogen production and/or synthetic natural gas production that could lead to construction of a billion-dollar hydrogen hub in southwest Wyoming.

- ✓ Tallgrass Energy is undertaking the Eastern Wyoming Sequestration Hub project, which involves assessing the potential to sequester CO_2 in the Wyoming Denver-Julesburg Basin in support of the development of a commercial scale sequestration hub in Eastern Wyoming. The information from this phase of the project will provide the basis for full implementation of a regional sequestration hub which includes Tallgrass's development of a multi-state CO_2 transmission system. This project will provide a platform to increase the visibility of Wyoming and its suitability for commercial deployment of CCUS.

A National Leader in the Emerging Hydrogen Economy: Wyoming's Competitive Advantages

Wyoming has significant potential to leverage its industrial emissions, geologic storage, transport infrastructure and comprehensive approach to meet the nation's net-zero goals with its strategy to leverage wind, solar, nuclear and its vast array of natural resources.

Wyoming has the energy ecosystem, know-how and commitment to be a leader in the U.S. Hydrogen Economy and is a natural fit with its natural resources, existing infrastructure, supportive policies and focused R&D.

- ✓ Wyoming has the potential to utilize abundant, existing resources and transform them into potential feedstock for hydrogen including low-cost coal, natural gas, wind, solar and uranium.

- ✓ Experienced and scale: Wyoming is among the largest energy producers in the country and is being looked to as a "headwater" state in development of the Rocky Mountain Region's hydrogen strategy. Wyoming has the major components of a carbon and hydrogen hub including:
  - High concentration of large industrial emitters of high quantities of fossil fuel used for on-site industrial energy production.
  - Presence of 45Q tax credit-qualifying facilities for carbon capture retrofit, as well as identified near- and medium-term capture opportunities.
  - Current reported production of hydrogen and ammonia.
  - Large geologic saline and fossil formations for permanent and secure CO_2 storage.
  - Existing multimodal commodity distribution infrastructure such as pipelines, freight railroads, and interstate highway freight truck routes.
  - Existing conventional fossil fuel distribution infrastructure for hydrogen blending and established rights-of-way for low-impact CO_2 transport infrastructure.

Specifically:

- ✓ Governor Gordon has given the Wyoming Energy Authority, the University of Wyoming and other state resources a directive to strive toward net-negative carbon emissions through all methods of energy development and production and to identify opportunities to diversify the state's economy.

- ✓ The Wyoming Energy Authority is leading the state's position of "Wyoming is All Things Energy" and supports an all of the above philosophy for development of energy. The WEA is charged with advancing Wyoming's energy strategy by driving data, technology and infrastructure investments. There is a focus on oil and natural gas, coal, wind, solar and uranium; and most importantly, the WEA is the primary drive of Wyoming's hydrogen energy strategy.

- ✓ Wyoming's large energy-intensive fossil fuel resources and production capacity can help make the state a leader in Carbon Capture Utilization and Storage (CCUS).

- ✓ With its CCUS capacity and knowledge, Wyoming is positioned to become a major source of economically captured anthropogenic CO_2 from industrial facilities and power plants. The state is strategically positioned to become both a major source of CO_2 captured from industrial facilities and power plants, as well as a hub for the beneficial use and geologic storage of captured carbon.

- ✓ Wyoming is rich in stocks of natural capital such as ample sunlight and wind, forestland, mineral resources, and CO_2 sequestration potential.

- ✓ As one of the first states to enact legislation on carbon capture utilization and storage, Wyoming now has among the most comprehensive carbon capture incentives and legislation in the nation. In 2020, the Wyoming State Legislature enacted a nation-leading CCUS Standards for Electricity Generation focused on the existing coal fleet: the "Reliable and Dispatchable Low-Carbon Energy Standards". Carbon capture retrofits can lead to significant environmental and economic benefits, allowing CO_2 producers to sell captured CO_2 and create new revenue streams. Wyoming also has an established regulatory and risk management framework in place for large-scale CCUS projects.

- ✓ Using its natural resources, Wyoming has the potential to match large-scale, clean hydrogen production with local and regional baseload demand from the industrial, transportation, heating and agricultural sectors.

- ✓ Wyoming has abundant natural gas feedstock for clean hydrogen including low-cost coal, natural gas, wind, solar and uranium.

- ✓ The state's oil and gas industry is actively examining what concentrations of hydrogen can be supported and what modifications may be necessary for their infrastructure.

- ✓ Wyoming has ideal geology for safe, secure, and permanent storage of carbon dioxide at low cost.

- ✓ The new Pipeline Corridor Initiative will be important to strengthening the infrastructure critical to connecting Wyoming's hydrogen to other state and export terminals. And in 2021, the U.S. Bureau of Land Management issued a federal record of decision, designating more than 1,100 miles of federal lands throughout Wyoming as corridors for potential new pipelines. Another 900 miles of corridors have also been identified on private and state lands.

- ✓ Studies and planning are underway to create regional hydrogen energy hubs, such as the current projects being led by The Williams Companies and Tallgrass Energy.

- ✓ With major investments being made by national and international companies, the growing wind energy sector is poised to be a player in green hydrogen,

- ✓ Affiliations and collaborative agreements have been made with entities on the cutting edge of hydrogen development such as the Idaho National Laboratory.

- ✓ The University of Wyoming School of Energy Resources (SER) research and development has the talent and capacity to address challenges and introduce innovation and new technology. The new Hydrogen Energy Research Center (H_2ERC) has a focus on all forms of clean hydrogen.

- ✓ Billions in proposed and/or planned investments in Wyoming hydrogen related projects have been made for expanded infrastructure and production.

- ✓ Wyoming is home to national leaders with a stake in hydrogen such as ExxonMobil, The Williams Companies, EOG Energy Resources, Tallgrass Energy, Holly Frontier Renewables, Ramaco Carbon, Jonah Energy, Chesapeake, Oxy, Anschutz North America, Rocky Mountain Power and Nordex U.S.

- ✓ There is an experienced workforce across the energy sector, and ongoing commitment and capacity among Wyoming's higher education institutions to train the workforce for jobs in Wyoming's Hydrogen Economy.

Wyoming: A Regional Leader

In February 2022, Wyoming joined the states of Colorado, New Mexico and Utah to sign a Memorandum of Understanding to coordinate and develop a regional clean hydrogen hub. Together, the states will work to compete for a portion of the $8 billion allocated in the 2021 Infrastructure Investment and Jobs Act toward four or more regional hydrogen hubs. The Signatory States will work together in developing a Western Inter-State Hydrogen Hub with supporting facilities in each state in response to the US DOE Request for Proposal.

Economic Development Opportunities in Wyoming

Wyoming: Where Renewable Energy Resources, Innovation and Industry Converge

For over 100 years, the State of Wyoming has been an energy leader, and once again it has the opportunity to build on its expertise, natural resources, diverse renewable energy sources, experienced workforce and infrastructure in the energy sector to accelerate low-carbon solutions that could position Wyoming as a leading hub of Net Zero innovation. And with its supportive tax structure, comprehensive legislation, and geologic potential, Wyoming is expected to continue as a leader in carbon capture policy development and project deployment, as well as renewable energy.

Build a Comprehensive Business Infrastructure to Support Wyoming's "All of the Above" Energy Strategy

Wyoming has the unique opportunity to attract companies in established yet rapidly growing "New Energy" industries, as well as advancing the hydrogen production and energy storage value chains by actively attracting and retaining project developers, asset owners, financial traders, and professional support businesses. This will require a comprehensive and targeted economic development strategy to attract businesses from across all energy value chains and create a supportive atmosphere for business development.

Wyoming also is well positioned to establish regional hydrogen hubs due to its:

- ✓ High concentration of large industrial facilities with significant emissions.
- ✓ High quantities of fossil fuel use for on-site industrial energy production.
- ✓ Presence of facilities qualifying for the federal 45Q tax credit for carbon capture retrofit, as well identified feasible near- and medium-term capture opportunities.
- ✓ Current reported production of hydrogen and ammonia.
- ✓ Large saline and fossil geologic formations for permanent carbon dioxide (CO_2) storage.
- ✓ Existing multimodal commodity distribution infrastructure, such as freight railroads, barge waterways and ports, and interstate highway routes for freight trucking.
- ✓ Existing conventional energy distribution infrastructure for hydrogen blending and established rights-of-way for low-impact CO_2 and hydrogen transport infrastructure.

Where Might Wyoming Play in the National Hydrogen Economy?

Be a Recognized Leader in Moving the Needle Toward the Federal Goal to Reduce CO_2

Wyoming has the ability to impact the national goal by using its strong R&D capacity at the University of Wyoming and industry partners to advance CCUS technology and processes to safely capture and store millions of metric tons of CO_2 each year. Wyoming also is slated to become a leader in the application of nuclear power with the Natrium Project and production of green hydrogen with the Chokecherry and Sierra Madre Wind Energy Project and its planned initiative called the Wyoming Clean Power Center.

Create Demand for Hydrogen as a Product

The strongest argument for growth in Wyoming's future leadership role in the country may be to increase demand for the kind of hydrogen the state can produce rather than its production capabilities.

Storage

Wyoming has the benefit of having several options for storage; and the political, regulatory, and legal atmosphere in Wyoming gives it the opportunity to meet storage capacity demand with the greatest chance of success.

Transportation
Wyoming has an extensive rail network, in addition to two major interstate highways, I80 and I25, that connect it to neighboring states. This is complimented by the Pipeline Corridor Initiative underway.

Build on the Growing and Diverse Energy Industry to Meet Domestic and Global Market Demand
Attract companies in industries such as wind, solar and biofuels, along with advancing the renewable natural gas and low-carbon value chains. Simultaneously, engage the energy industry "decision-makers" including those in oil and gas, power and renewables, and investment firms to enter the hydrogen market.

Provide Feedstock for Industry and Long-distance Transport
About 95% of the hydrogen currently consumed in the U.S. serves as a feedstock or reactant in industrial processes, for example within refining, ammonia, and methanol plants. Wyoming and its energy businesses are positioned to support this switch to low carbon hydrogen and be a significant national player is the goals to reduce in domestic carbon emissions.

Commercialize Cutting-Edge R&D
Commercialization of emerging industrial decarbonization technologies generated from the R&D being undertaken at the University of Wyoming School of Energy Resources has the potential for a large impact on targeted industries including iron and steel, chemicals, cement, and food and beverages.

Decarbonize the Power System
Hydrogen could help decarbonize the power system, particularly as it provides strategic opportunities for storing large amounts of energy over longer durations, for example, when seasonal storage of energy is needed. In doing so, it can offer long duration discharge cycles that other technologies currently lack.

Be a Leader in Carbon Capture Deployment
Wyoming is positioned to be a leader in carbon capture deployment (CCUS), along with estimated capturable emissions in million metric tons and estimated range of capture costs for facilities in each industry.

Attract Large Demonstration-scale Projects
Continue to aggressively seek out and support demonstration projects, such as those currently underway with support from the Wyoming Energy Authority, with the potential to gain national attention.

Attract National and International Investments by Global Companies
Wyoming is attracting investment by companies that operate and/or produce for a global market. They are positioning hydrogen production projects potentially worth billions of dollars in the state.

Private Sector Investment Challenges

Businesses with interest in making investments in Wyoming's energy sectors have identified these challenges.

- ✓ The lack of hydrogen storage and transportation infrastructure in the U.S. western states is among the largest obstacles to the widespread use of hydrogen. Demand for hydrogen will quickly out-grow the capacity and range of transport systems such as trucks, so pipelines will be the optimal choice to transport the hydrogen.
- ✓ Second to infrastructure (primarily pipelines) is water as a top issue -- including rights, volume and quality necessary to execute electrolysis to scale; the anticipated closing of coal facilities over the next several years may provide an option for water resources
- ✓ There are additional barriers to green hydrogen developed from renewables, including the cost of investment vs ROI, financing, lag time to secure regional approvals to connect to the grid (up to 3 years), interconnect costs and the large number of authorities (49) involved among the Western states.
- ✓ There is need for clear, consistent and supportive policies and regulations at both the state and federal levels.
- ✓ Optimal locations for producing hydrogen may not be near the main energy demand centers, which means hydrogen production will need to be paired with some means of storing hydrogen and transporting it to consumers. And hydrogen production from renewables will require seasonal storage due to the temporal mismatch between periods of greatest low-carbon electricity availability and periods of highest heat demand.

- ✓ Federal financial incentives are not adequate to support infrastructure build-out or to incentivize the private sector as it works to overcome lack of equity financing need for investment in production, storage and transport. The PTC credit as proposed in the Build Back Better plan would have made a difference.
- ✓ Federal investment in infrastructure development is essential; however, current federal initiatives are focused on production. There are not dollars allocated to states or incentives to developers/producers to build the infrastructure necessary to develop an efficient transport and delivery system to markets; yet it will be essential to reach major destinations/ports such as the Baha California area for international exports.
- ✓ There is a need to have well established domestic and foreign major markets to receive Wyoming's hydrogen production. Banks and tax equity providers are not interested in financing projects unless they can demonstrate the hydrogen will get to end markets.
- ✓ Outreach and education efforts will be needed to educate the public, elected officials, and economic development professionals about hydrogen and its benefits to the State of Wyoming and their individual locals. The private sector should be a partner in the outreach efforts.
- ✓ Social and cultural acceptance of blue vs. green hydrogen– particularly the west coast -- will be a challenge and potential barrier to development of infrastructure for blue hydrogen.
- ✓ Trained workforce will be essential: although companies acknowledge Wyoming has a workforce well positioned to be retrained.
- ✓ There will be an ongoing need for the valuable assistance of cutting-edge R&D provided by the University of Wyoming and support for pilot projects from the Wyoming Energy Authority.

Conclusions and Recommendations

1. The Wyoming Energy Authority should continue its leadership role in defining the scope and content of the future of Wyoming's Hydrogen Economy and also develop a detailed roadmap to provide the support and policy necessary to address challenges and stimulate Wyoming's Hydrogen Economy.

2. Demonstrate commitment and demand by considering adoption of state-wide measures to reduce carbon emissions and commitment to hydrogen; particularly in support of the significant private investment required for different deployment and scalability of different types of technology.

3. Continue to develop, support and deploy the Wyoming Energy Authority's overall strategy to leverage Wyoming's abundant feedstock for hydrogen including low-cost coal, natural gas, wind, solar and uranium.

4. Aggressively pursue opportunities to be an anchor in collaborations with surrounding states and a valuable partner with projects being undertaken with the regional National Laboratories.

5. Bring together a diverse group of stakeholders to form an alliance focused on increasing Wyoming's competitiveness in the emerging hydrogen economy, proactively seeking supportive regulatory environment, and attracting investment for scaling-up of production, efficient and safe storage, and transport of hydrogen.

6. Prepare an infrastructure development plan with appropriate government, industry and community participation to create "value" for the production/storage/transport, while also meeting the growing market demand. Leverage the existing transport infrastructure including road, rail and network of natural gas pipelines.

7. It will be important for Wyoming to continue to develop policies and regulations aimed at safety, while being supportive of businesses that are making investments, reducing costs, creating new products and accelerating large-scale deployment as technology and markets evolve in the new hydrogen economy. And it will be critical to continue to streamline the permitting processes to support hydrogen production, storage and transport.

8. Develop a strategy for a significant amount of electricity at a reasonable cost needed to produce green hydrogen on a larger scale.

9. Continue to support demonstration projects, research, and innovation needed to prove and scale up emerging clean hydrogen technologies.

10. Actively pursue financial assistance via Federal dollars, direct loans, loan guarantees, and private investment for workforce training, R&D, facilities, and to build/retrofit the necessary shared infrastructure such as pipelines.

11. Continue with studies such as the evaluation of water resources and demand, and work with the University of Wyoming and private sector to develop a plan to address these challenges.

12. Develop a parallel strategy for hydrogen produced via CCUS and renewable energy sources.

13. Develop and provide technical support at the county and local community level as they deal with proposed private sector projects.

14. Continue to invest in pilot projects and seek out opportunities for interconnected hydrogen supply chain and infrastructure development projects that involve production, storage and delivery.

15. Continue to build on the momentum and national visibility of planned projects such as the Chokecherry and Sierra Madre Wind Energy Project, the Wyoming Clean Hydrogen Center being developed by Nordex Acciona, and Terra Power's nuclear project.

16. Continue to focus on R&D via input from the private sector and the University of Wyoming School of Energy Resources and its several Centers of Excellence.

17. "Make Wyoming Hydrogen Energy Ready" by continuing to support development of state-wide policies and scope of regulatory requirements for businesses to guide and facilitate hydrogen projects and encourage investments, i.e., codes and standards, permitting requirements, regulations for injecting CO_2 below the ground for safe and secure storage, CO_2 transport, tax credits and other financial incentives for CCUS and CO_2 injection, optimization of state taxes to incentivize transport and storage, etc. Build on cornerstone legislation such as Reliable and Dispatchable Low-Carbon Energy Standards made into law in 2020.

18. Actively seek out partnerships with the private sector and economic development agencies to create a "business case" for private investment in Wyoming's Hydrogen Economy; promoting Wyoming's distinct advantages including geology, strategic geographic location, abundance of available renewable energy from the sun and wind, and collaborative business environment.

19. Develop a state-wide and comprehensive economic development action plan that leverages the growing and diverse energy industry to meet domestic and global market demand. For example:

- Engage the broader business community (energy companies, banks, asset managers, private investors and venture capitalists) in public-private collaborative arrangements to support hydrogen development in Wyoming's economic development strategy
- Develop "Energy Development Zones" designated to support the development of a concentration of research/technology facilities and businesses. Such a zone might involve policies and programs such as zoning, infrastructure, provision of economic development incentives, and marketing targeted at the attraction of high-tech and/or renewable facilities and businesses.
- Develop "Energy Parks" at the county or regional level, with a focus on critical factors such a cyber security; and consider a hub strategically located in hydrogen production areas along the I80 and I25 corridors.
- Focus on attracting and supporting primary and supply chain companies in targeted industries including wind energy, solar power and biofuels, along with advancing the renewable natural gas and low-carbon LNG value chains.
- Develop a strategy that leverages the opportunity to develop an interconnected hydrogen supply chain based on established and proposed market access, potential markets in-state and exports.
- Develop and execute a market deployment strategy, including a branding strategy and messaging campaign targeted at both industry and talent recruitment.

20. Strengthen the Workforce Development Training available through Wyoming's community colleges and technical schools important to supporting a labor force capable of working in the hydrogen economy.