Hydrogen Technology Guidebook for Elected Officials

United States Hydrogen Alliance

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United States Hydrogen Alliance

The United States Hydrogen Alliance is a 501 (c)(6) non-profit association of members advocating for the development, deployment and utilization of clean hydrogen in all 50 states.

We serve the hydrogen industry through state and federal policy advocacy, market development, and community building. Our mission is to leverage the unique attributes of hydrogen to reduce emissions across traditional sectors, increase energy resiliency and diversity, enhance local economies and workforces, and protect the nation domestically and abroad.

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Hydrogen- Fueling the Future

Hydrogen is *fundamentally different* from traditional combustible fuels.

When combusted, hydrogen does not emit carbon dioxide— its only direct emission is water vapor. This clean profile is reflected in its very name: “hydrogen,” derived from the Latin meaning “to produce water.”

Moreover, hydrogen is most often used in fuel cells or for power generation without combustion, producing electricity with zero emissions at the point of use.

Hydrogen fuel cell vehicles represent an exciting advancement in transportation that supports cleaner communities, technological progress, and long-term energy solutions.

They operate quietly and emit only water vapor, offering a sustainable alternative without sacrificing performance or convenience.

With refueling times similar to gasoline vehicles and the ability to cover significant distances, hydrogen cars are well-suited for a variety of driving needs.

As infrastructure continues to grow, hydrogen mobility can help diversify the nation’s energy portfolio, support local economies through innovation, and contribute to a more sustainable future across industries and regions.

Hydrogen-based energy generation contributes to a well-rounded and adaptable energy system.

Its ability to produce electricity without relying on combustion offers a pathway to reduce impacts on air quality while maintaining dependable power supply.”
“Hydrogen can be stored and transported, making it useful for meeting energy demands across seasons and regions.

Integrating this resource into the energy mix encourages the development of advanced technologies and infrastructure, creating opportunities across a range of industries.

As energy needs evolve, hydrogen offers a versatile option to support continued growth and resilience.

1. Introduction

Executive Summary

Historically, hydrogen has primarily been used in chemical, industrial and commercial applications. Therefore, the general public's lack of awareness of hydrogen's integral part in their lives is no surprise.

Hydrogen usage is much more than just a theory; hydrogen is used to produce fertilizer to grow our food, remove sulfur from crude oil and natural gas, and even assists us in stopping acid rain to protect the efficacy of catalytic converters. We use hydrogen to propel our shuttles to space, and is a key component of the screen you are reading off of at this time. Hydrogen even plays a part in the production of many household cleaning products. Despite these applications, most of the population is unfamiliar with the multi-faceted molecule.

By comparison, electricity visibly plays a role in our daily lives. Therein lies the secret; visibility allows for acceptance by mainstream consumers. Regardless of these challenges, the hydrogen industry has forged forward, through hard work, education, and persistence. Hydrogen power has begun to emerge as the principle solution to several significant energy, environmental, and national security challenges.

Still, a question remains. ***Why?***

After centuries of background hydrogen use, why are leaders suddenly investing in this seemingly unknown molecule on unprecedented levels? Why are large companies and conglomerates investing millions into hydrogen?

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Executive Summary

Hydrogen and fuel cells can be deployed **now** to decarbonize transportation, industrial, and power generation sectors. In addition, the technology can serve as an advantageous strategy to manage and improve energy storage, grid resiliency, space exploration, national security, and environmental conservation. As a result, U.S. and international leaders across the world are investing in hydrogen now. To date, major investments ($9.5 billion) have been made by the federal government, in addition to California's $100 million. China has invested $20 billion, Germany $8 billion, France $7 billion, Spain $1.5 billion, and at least $76 billion has been invested globally. It is critical for each policymaker, from local to congressional, to seriously consider how hydrogen can and will play a role in their districts.

Transport

Trucks, vessels, locomotives, airplanes, off-road equipment like tractors and mining excavators require large amounts of energy within a limited space. Altering these vehicle types to batteries is not feasible, especially for long distance usage. Instead, a fuel cell is the only suitable zero emission technology for heavy-duty transport. The fuel cell, which operates almost identically to a battery, provides electricity for propulsion. In other words, a fuel cell electric vehicle is more or less a battery electric vehicle that provides the advantages of significant range and power without compromising the air quality benefits of zero emission transportation.

Industrial Processes

The fertilizer and oil industries are among the largest consumers of hydrogen globally today. Hydrogen is a key chemical in the production of ammonia. It is estimated that half of the food produced across the globe comes from industrial fertilizers derived from ammonia. The oil industry uses hydrogen in its final stages of processing crude oil to remove contaminants like sulfur. In the future, some industries are looking to combust hydrogen in processes that cannot be electrified. For instance, steel, iron, cement, glass manufacturing employ chemical processes that require fossil fuels and hydrogen is proving to be a promising alternative in the coming decade.

Long-duration Energy Storage & Renewable Energy Curtailment (Maximizing Renewables)

Hydrogen can play multiple supporting roles in improving the reliability and resiliency of the electrical grid. Intermittent renewable power generation, like solar and wind, can supply more electricity than is needed at certain times of the day, which in turn creates grid management issues. Hydrogen can serve as a daily to seasonal energy storage solution to avoid curtailment of renewable electricity. That hydrogen can be used to generate electricity when needed, as well as provide fuel to industrial, commercial, and transportation applications.

National Security

For over 70 years, the U.S. Department of Defense (DOD) has been investing in hydrogen and fuel cell technology. Many advances in fuel cells and fuel cell electric vehicles is a direct result of DOD funding, which has helped propel the technology to its full potential. The U.S. Army deems hydrogen fuel as the next tactical fuel, and the U.S. will need to produce the fuel domestically or rely on its allies for access to hydrogen. The U.S. Air Force has been demonstrating hydrogen production and infrastructure, military fuel cell electric vehicles and equipment, and off-grid power generation at Joint Base Pearl Harbor-Hickam, Hawaii for over a decade. It is likely that hydrogen and fuel cells will be important assets on the mainland, islands, and abroad.

Space Exploration

Since 1958, the National Aeronautics and Space Administration (NASA) has utilized hydrogen and fuel cells to conduct missions. Apollo 11 was powered by three fuel cells and hydrogen as rocket fuel. The fuel cells even provided drinking water for the astronauts. Today, OxEon's solid oxide electrolyzer (a fuel cell that operates in reverse) is producing oxygen from carbon dioxide from Mars' atmosphere as a part of NASA's Mars Curiosity Mission. There is no doubt that fuel cells, electrolyzers, and hydrogen will remain key technologies for space exploration.

Environmental Benefits

According to a report conducted by the Energy Futures Initiative led by former DOE Secretary Moniz, there is an "unprecedented and urgent need for emission reductions at very significant scale to meet mid-century targets [and hydrogen] is uniquely suited to both lower the carbon intensity of the existing energy system and become a pillar of the future low-carbon economy." Leaders are pressed to cut emissions from all sectors as quickly as possible. However, the decarbonization of commercial transport and industrial processes, in addition to newfound problems with higher penetrations of renewables on the electrical grid are challenges that cannot be solved with more electricity, our go-to tool. These challenges can actually be solved with hydrogen.

Abbreviations

ARCH2	Appalachian Regional Clean Hydrogen Hub
ARCHES	Alliance for Renewable Clean Hydrogen Energy Systems
ASF	Abfallwirtschaft und Stadtreinigung Freiburg
CNG	Compressed Natural Gas
CCUS	Carbon Capture, Utilization, and Storage
CCS	Carbon Capture and Sequestration
DNA	Decarbonization Network of Appalachia
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
FCEV	Fuel Cell Electric Vehicle
FLIRT	Fast Light Intercity Regional Train
FTA	Federal Transit Administration
GHG	Greenhouse Gas Emissions
GLCH	Great Lakes Clean Hydrogen Hub
H-CNG	Hydrogen Compressed Natural Gas

IIJA	Infrastructure Investment and Jobs Act
LIGH2T	Leading in Gulf Coast Hydrogen Transition
MACH2	Mid-Atlantic Clean Hydrogen Hub
NASA	National Aeronautics and Space Administration
NFL	National Football League
NOx	Nitrogen Oxides
PNW H2	Pacific Northwest Hydrogen Hub
RNG	Renewable Natural Gas
SAF	Sustainable Aviation Fuel
SHINe	Southwest Clean Hydrogen Innovation Network
SMR	Steam-Methane Reforming
VOC	Volatile Organic Compounds

2. Hydrogen Feedstocks

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Hydrogen feedstocks are the raw materials or energy sources used to produce hydrogen, forming the basis of its role as a versatile energy carrier.

There are 22 recognized feedstocks, ranging from renewable resources such as solar and wind to traditional fossil fuels such as coal, natural gas, and oil.[2] Each feedstock has unique characteristics and plays a crucial role in shaping the sustainability and efficiency of hydrogen production.

Recognized feedstocks include those seen in Figure 1. By exploring these diverse sources, we can better understand their contributions to the hydrogen economy, their potential to drive innovation in energy systems, and their role in transitioning to a cleaner, more diverse energy landscape.

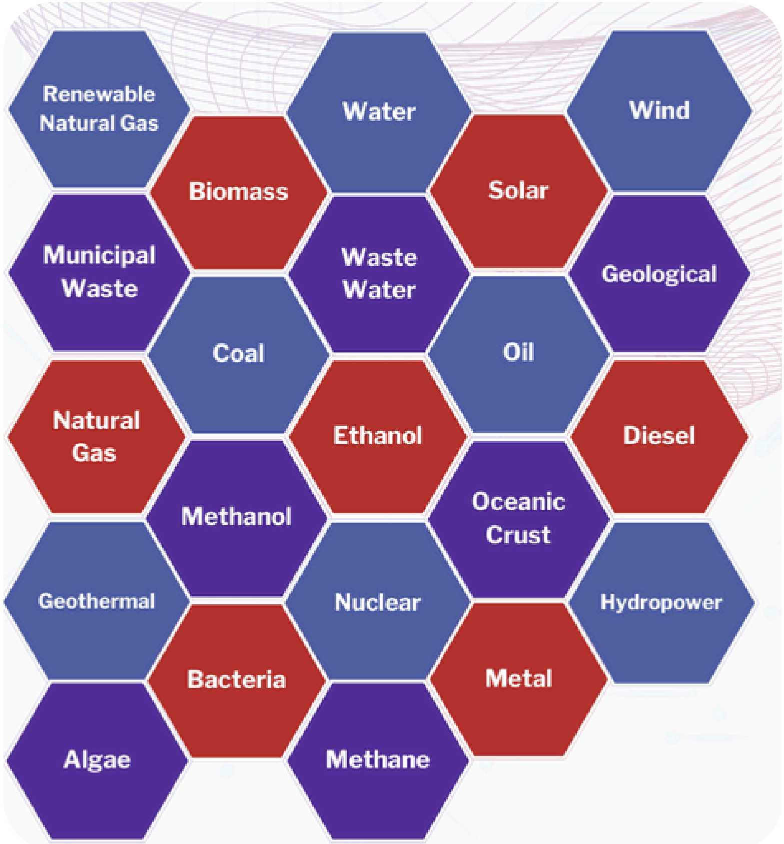

Fig. 1: Recognized Feedstocks

Fig. 2: Hydrogen Production Plant[1]

Facts on Feedstocks

SOLAR: Two processes can use solar energy to produce hydrogen: water electrolysis using electricity generated from photovoltaic, a nonmechanical device that converts sunlight directly into electricity,[3] solar panels, and direct solar water splitting.

Electrolysis of water powered by photovoltaics was first presented at the Florida Solar Energy Center in 1983, funded by the NASA Kennedy Space Center.[4] Direct solar splitting refers to any procedure in which solar energy is directly used to produce hydrogen from water without going through the intermediate electrolysis step.

Fig. 3: Solar Panel Farm

HYDROPOWER: Hydropower is a cost-effective and renewable electricity source suitable for hydrogen production via water electrolysis. As of 2023, hydropower accounted for approximately 15% of global electricity generation, making it the largest single source of renewable energy.[5] In 2022, the global weighted average cost of electricity from hydropower projects was $0.061 per kilowatt-hour, positioning it as the lowest-cost source of electricity in many markets.[6]

DIESEL: Diesel-fueled vehicles are a significant source of harmful pollutants, including ground-level ozone and particulate matter. Researchers at the Fraunhofer Institute for Solar Energy Systems in Germany have developed a patented process that transforms liquid diesel fuel into vapor and converts it into hydrogen gas in a reformer- without producing residues such as soot.[7]

Facts on Feedstocks Continued

WIND: Wind-generated electricity can be used to power water electrolysis, producing hydrogen that can fuel vehicles or be stored for later use. This stored hydrogen can then generate electricity through fuel cells when wind power is unavailable, making wind farms an effective resource for hydrogen fuel production.

COAL: Hydrogen production from coal is achieved through a process called gasification. This method starts with partial oxidation, where a limited amount of air is introduced to the coal. Instead of burning the coal entirely, only a small amount of oxygen is added to initiate combustion, generating just enough heat to sustain the gasification reaction.[8] This controlled heating is crucial, as complete combustion would convert all the carbon in the coal to carbon dioxide, eliminating the potential to extract valuable hydrogen.[8] The goal is to decompose the coal into its chemical components, maximizing hydrogen yield while minimizing energy loss and unwanted emissions.[8]

Fig. 4: Natural Gas Fired Power Plant

NATURAL GAS: Natural gas is one of the primary feedstocks for hydrogen production. RNG is biogas- the gaseous product of organic matter decomposition- that has been refined to high purity standards. RNG is converted to hydrogen through SMR, the same process used to produce hydrogen from conventional natural gas. In this process, biomethane—the main component of biogas—reacts with steam to generate hydrogen-rich syngas—a mixture of hydrogen and carbon dioxide—ultimately yielding carbon-negative hydrogen.[9] SMR remains the most common method of hydrogen production in the U.S., serving both commercial and industrial applications. With natural gas primarily composed of methane, it emits fewer air pollutants—such as carbon dioxide, carbon monoxide, nitrogen oxides, and particulate matter—than petrol or diesel. H-CNG is a blend of hydrogen and CNG, with an ideal hydrogen concentration of 18%.[10] Research conducted by the Automotive Research Association of India and Indian Oil Corporation Ltd indicates that using H-CNG can reduce carbon monoxide emissions by up to 70% compared to traditional CNG, while also achieving fuel savings of up to 5%.[11]

3. Hydrogen Production Pathways

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Hydrogen production pathways consist of the different methods used to produce hydrogen from various feedstocks. These pathways differ in terms of technology, energy requirements, emissions, and overall sustainability, making them critical to understanding the role of hydrogen in a clean energy future. Each pathway offers unique advantages and faces distinct challenges, reflecting the diversity of approaches needed to meet global hydrogen demand.

Among the most widely used pathways, SMR stands out for its high efficiency and relatively low costs, although it necessitates carbon capture technologies to mitigate its greenhouse gas emissions. Other established pathways include gasification and biomass conversion, which can utilize both fossil fuels and renewable materials to produce hydrogen. Electrolysis, powered by renewable electricity, has emerged as a key sustainable method by splitting water into hydrogen and oxygen without producing direct emissions. Additionally, emerging technologies such as photobiological splitting and methane pyrolysis offer promising advancements in low-emission hydrogen production, highlighting ongoing innovation in the field.

Biomass-Derived Liquid Reforming

Hydrogen Sources: Ethanol, Mathanol

Renewable liquid fuels are reacted with high-temperature steam to produce hydrogen near the point of end use.

Biomass-derived liquids, such as ethanol and bio-oils, can be produced at large, central facilities located near the biomass source to take advantage of economies of scale and reduce the cost of transporting the solid biomass feedstock.[12] The liquids have a high energy density and with some upgrading can be transported with a minimally new delivery infrastructure and at relatively low cost to distributed refueling stations, semi-central production facilities, or stationary power sites for reforming to hydrogen.[13]

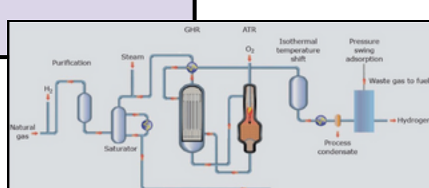

Fig. 5: Steam Methane Reforming

Steam Methane Reforming

Hydrogen Sources: Renewable Natural Gas, Natural Gas, Municipal Waste, Methane

SMR is the most common method for producing hydrogen due to its low cost and high efficiency. By reacting natural gas with high-temperature steam, hydrogen is separated from the carbon atoms in methane.

The steam reforming reaction typically achieves an efficiency of around 70%, which is relatively high compared to other commercially available hydrogen production methods.[14] The output streams of the SMR process consist of hydrogen gas which is the desired product for a multitude of industrial applications, including ammonia production, refineries, fuel cells, hydrogenation reactions, and energy storage.[15] However, the process also generates carbon dioxide, a byproduct that needs to be effectively separated and captured to mitigate environmental impact, and carbon monoxide, which must be minimized to ensure high-purity hydrogen.[16] Some applications can also deliver graphite, which is defined as a critical raw material. At this moment, the United States relies on China as a supplier of this critical mineral.

Electrolysis

Hydrogen Sources: Solar, Wind, Geothermal, Hydropower, or Nuclear combined with Water, Methane

When electricity is generated from renewable sources like solar or wind, the hydrogen produced through this process is also classified as renewable, offering significant emissions reduction benefits.[18] Power-to-hydrogen initiatives are gaining momentum, utilizing renewable electricity to produce hydrogen via electrolysis.

In several areas across the country, the current power grid is not well-suited for supplying electricity for electrolysis due to its reliance on fossil fuels, which results in greenhouse gas emissions and low efficiency in electricity generation.[19] Efforts to produce hydrogen through electrolysis are focused on integrating renewable energy sources such as wind, solar, hydro, and geothermal, as well as nuclear energy; these pathways for hydrogen production generate minimal greenhouse gas emissions and air pollutants.[19] However, to compete with established carbon-based methods like natural gas reforming, production costs for electrolysis need to be significantly reduced.[20]

Fig. 6: Methane Pyrolysis Pilot Project[17]

Methane Pyrolysis

Hydrogen Sources: Methane

The thermal breakdown of methane into hydrogen gas and solid carbon.

Methane pyrolysis is a thermal process that separates methane into hydrogen and solid carbon. Unlike traditional hydrogen production methods, this approach generates hydrogen without emitting carbon dioxide.[20] The resulting solid carbon has diverse applications, including use in tire manufacturing, as a reinforcement material in concrete, in battery anodes for energy storage, and in advanced materials such as carbon composites for lightweight structural components, among others.[21]

Photobiological Water Splitting

Hydrogen Sources: Bacteria, Algae

Microbes, such as green algae, consume water in the presence of sunlight and produce hydrogen as a byproduct.

In the future, photobiological production technologies have the potential to offer cost-effective hydrogen production powered by sunlight, with minimal to zero carbon emissions.[22] Algae and bacteria used in this process could be cultivated in non-potable water, unsuitable for drinking or agriculture, and may even make use of wastewater.[22]

Microbial Biomass Conversion

Hydrogen Sources: Biomass

Biomass is converted into sugar-rich feedstocks that can be fermented to produce hydrogen. Biomass is a plentiful domestic resource, and various microbes have naturally adapted to efficiently decompose it, generating hydrogen and other byproducts.[23] Fermentation, already established as an industrial method for producing biofuels and other goods, has addressed many challenges related to scaling up production systems.[24] This progress enables hydrogen researchers to concentrate on overcoming the specific challenges associated with hydrogen production.[25]

Geologic Hydrogen

Hydrogen Sources: Earth, Oceanic Crust

Hydrogen that is naturally occurring within the earth's crust.

Geologists know that many natural processes generate hydrogen, but to understand hydrogen's resource potential, it's crucial to identify which processes produce it in large quantities. One widely recognized process occurs when groundwater interacts with iron-rich minerals like olivine, resulting in hydrogen formation as the water's oxygen bonds with the iron.[26] However, various natural processes, such as microbial activity and petroleum formation, consume this hydrogen, which is why hydrogen is rarely found alongside hydrocarbon gasses like methane or propane.[17]

Exploring geologic hydrogen resources will likely use similar strategies and technologies as petroleum exploration, with some adaptations from mineral and geothermal exploration.[26] Because hydrogen can make steel brittle, slightly different materials will be needed for production, but existing natural gas drilling equipment can be used.[26] Unlike natural gas fields, hydrogen fields might be renewable due to the fast rate of hydrogen generation through water reduction.[26] Some researchers believe that instead of needing traditional reservoirs, we could tap into rocks generating hydrogen or stimulate production by injecting hot water into iron-rich rocks, similar to enhanced geothermal energy methods.[26]

Gasification

Hydrogen Sources: Biomass, Municipal Waste, Coal

Synthesis gas can be produced by reacting coal or biomass with high-temperature steam and oxygen in a pressurized gasifier, a process known as gasification.[27] This method transforms coal or biomass into gaseous components, generating a mixture that includes hydrogen and carbon monoxide; the carbon monoxide is then reacted with steam in a secondary process to extract and separate the hydrogen.[28]

With carbon capture and storage, hydrogen can be produced directly from coal with near-zero greenhouse gas emissions.[29] Since growing biomass consumes carbon dioxide from the atmosphere, producing hydrogen through biomass gasification results in near-zero net greenhouse gas emissions without carbon capture and storage.[30]

Photoelectrochemical Water Splitting

Hydrogen Sources: Solar, Water

Photoelectrochemical systems produce hydrogen from water using special semiconductors and energy from sunlight.

Photoelectrochemical water splitting generates hydrogen by utilizing sunlight and specialized semiconductors known as photoelectrochemical materials; these materials harness light energy to break water molecules into hydrogen and oxygen.[31] This method is a promising solar-to-hydrogen technology, offering the potential for efficient energy conversion at low operating temperatures through the use of affordable thin-film or particle-based semiconductor materials.[31] However, further advancements in efficiency, durability, and cost reduction are necessary to make this technology commercially viable.[31]

Partial Oxidation

Hydrogen Sources: Oil

The fuel-air mixture undergoes partial combustion in a reformer, it produces a gas rich in hydrogen, known as syngas. The syngas can be utilized in various applications, such as powering a fuel cell.

Partial oxidation is a method used to produce hydrogen from natural gas. Instead of using a lot of oxygen to fully burn the gas into carbon dioxide and water, partial oxidation uses a limited amount of oxygen; this partial reaction creates a mixture of hydrogen and carbon monoxide.[29] To get more hydrogen, the carbon monoxide is then treated in a second step called a water-gas shift reaction, where it reacts with water to produce additional hydrogen and carbon dioxide.[29] Key advantages to partial oxidation include speed, reduced size, and heat generation.[32]

4. Hydrogen Distribution

4. Hydrogen Distribution

Hydrogen distribution employs a variety of methods, each tailored to meet specific logistical and operational requirements. Trucks play a critical role, utilizing tankers to efficiently transport both liquid and gaseous hydrogen to diverse locations. For large-scale distribution, pipelines are indispensable, especially for meeting the demands of heavy hydrogen consumers such as industrial hubs and seaports. In the maritime sector, innovative hydrogen-powered bunker barges are transforming the shipping industry by facilitating mid-route refueling, significantly reducing emissions. These vessels also hold the potential to produce hydrogen onboard through ocean water electrolysis, showcasing a forward-thinking approach to sustainable maritime operations.

TRUCKS: Trucks are an important method of distributing hydrogen, both gaseous and liquid. Cryogenic tankers that hold liquid hydrogen, and tube trailers that hold highly pressurized hydrogen gas, are essential for hydrogen distribution for areas that do not have hydrogen pipeline distribution systems nor other methods of production, distribution, or storage.[33]

Transporting gaseous hydrogen is more economical over short distances, but transporting liquid hydrogen is more economical over long distances (typically over 150 miles), as the tankers can hold a much higher mass of hydrogen.[34]

Fig. 6: Long distance tanker

PIPELINES: Pipelines used for hydrogen distribution operate much like those used to transport natural gas.[35] Importantly, existing natural gas pipelines can be converted for hydrogen use, which can transport large amounts of hydrogen throughout the pipeline system, and the pipelines can transport hydrogen and natural gas at the same time.

While existing pipelines would need to be adapted, or new pipelines would need to be constructed for the express purpose of carrying hydrogen, these offer the best solution to large-scale hydrogen distribution.[36] Hydrogen pipelines become non-negotiable once heavy hydrogen consumers become more commonplace (e.g., seaports, airports, distribution centers, industrial applications, etc.).

Fig. 7: Pipelines

5. Conclusion

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Hydrogen is ***fundamentally different*** from traditional combustible fuels. When combusted, hydrogen does not emit carbon dioxide—its only direct emission is water vapor. This clean profile is reflected in its very name: “hydrogen,” derived from the Latin meaning “to produce water.

Rather than acting simply as an energy carrier; it is a symbolic, practical, and structural bond across sectors, geographies, and generations. Interconnectedness with other clean energy sources like nuclear, solar, natural gas, and coal position it as a frontrunner in the clean energy race.

Hydrogen has maintained a foundational role in modern societies’ past, present, and future, re-centering it as a synergistic and versatile force that connects people, powers systems, and anchors a cleaner, more sustainable world.

Investing in hydrogen is not just a practical next step— it is a matter of national security. With regions such as East Asia and Europe going full-speed ahead, the US must act now. The hydrogen industry has the ability to not just bring in millions of jobs for American workers, but also supply American-made solutions.

The time to idle is over; the time to act is now.

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