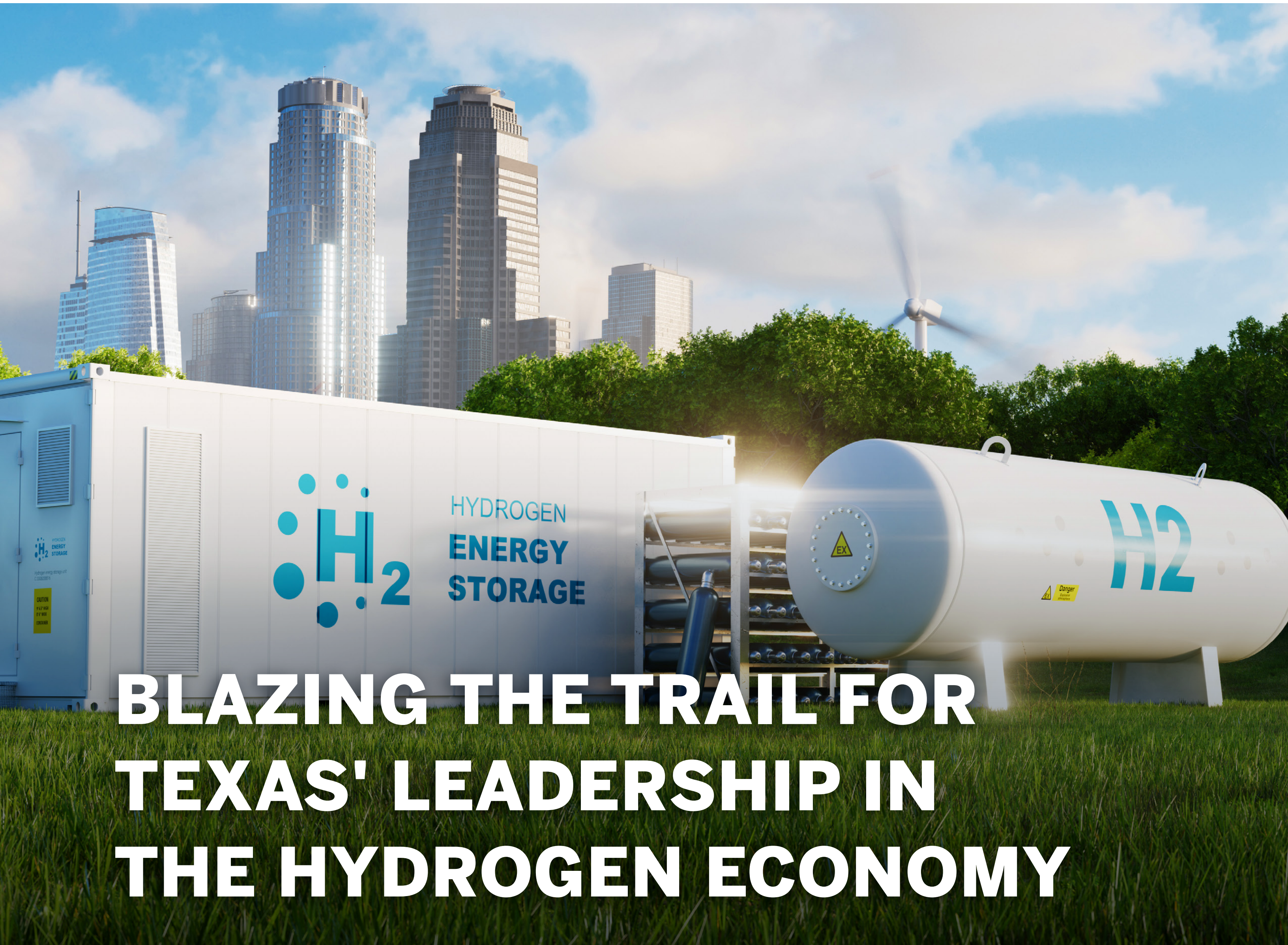
The University of Texas at Austin
Energy Institute



BLAZING THE TRAIL FOR TEXAS' LEADERSHIP IN THE HYDROGEN ECONOMY

The University of Texas at Austin (UT) Energy Institute connects the resources of the university's top-ranked programs to lead high-impact research aimed at transforming the nation's energy future.

350 Faculty and Staff
supporting energy innovation

$736 Million
in research expenditures (FY 2021)

805 Patents
issued in the U.S. since 2012

energy.utexas.edu

INTRODUCTION TO HYDROGEN

Globally, billions of dollars are being invested in hydrogen projects by both private industry and governments. This is because of the many benefits offered by a clean hydrogen future, including:

ECONOMIC DEVELOPMENT

Hydrogen production, storage, fueling, and distribution infrastructure throughout the state would boost the local economy and drive workforce development.

ENERGY RESILIENCY

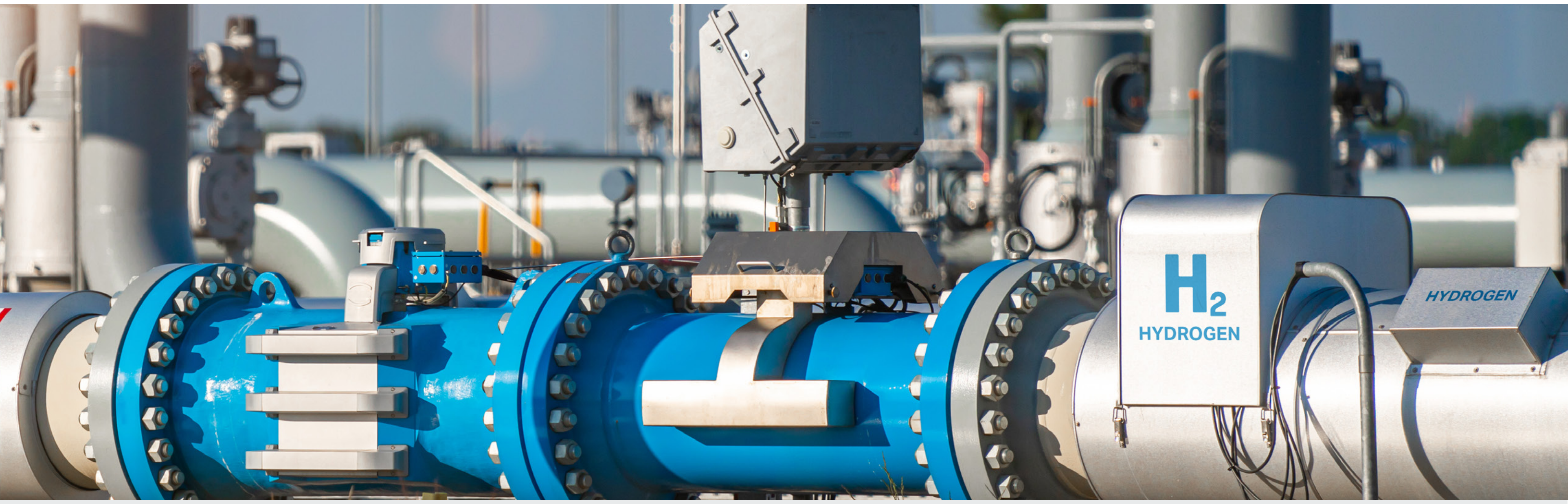
Hydrogen could enable Texas to store large volumes of renewable energy that can be tapped during times of high demand or severe weather, helping to bolster grid resiliency and reliability.

ONGOING ENERGY LEADERSHIP

Hydrogen development empowers Texas, with its favorable geology and vast natural gas reserves, to remain the nation's leading energy producer.

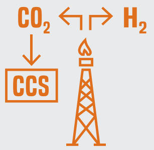
IMPROVED AIR QUALITY

When hydrogen is used in industrial, transportation or power generation, emissions of air and climate pollutants are dramatically reduced.



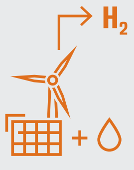
HYDROGEN PRODUCTION SOURCES

Hydrogen can be derived from a variety of sources and production processes abundant in Texas, including:



NATURAL GAS

Most hydrogen is obtained through the steam reformation of natural gas. Greenhouse gases created by this process can be captured and stored while simultaneously enhancing oil and gas production.



RENEWABLE ELECTRICITY

Hydrogen can be produced via electrolysis using surplus renewable electricity generated by Texas' vast wind and solar resources. Storing "extra" renewable electricity that is wasted today could help the state avoid energy shortages.

Texas is uniquely positioned to lead the development of the nation's clean hydrogen economy and become a hydrogen export superhub.

According to the Houston Energy Transition Initiative, by 2050 Texas could realize:

$100 BILLION
hydrogen economy

180,000
new jobs created

KEY TEXAS ADVANTAGES INCLUDE:

UNMATCHED ENERGY EXPERTISE
State oil and gas sector has technical and business expertise to succeed in hydrogen production, storage, and distribution

AMPLE ENERGY RESOURCES
Leads the nation in the production of both electricity and natural gas

ESTABLISHED PRODUCTION CAPACITY
Texas hosts a third of current U.S. hydrogen production with an experienced in-state workforce

EASY EXPORT OPTIONS
Gulf coast access with deep-draft ports for large ships

ESTABLISHED INFRASTRUCTURE
The nation's largest hydrogen pipeline network and well-established natural gas infrastructure

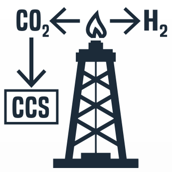
ABUNDANT STORAGE CAPABILITIES
Very large-scale geological storage options (salt domes, depleted oil and gas fields, saline aquifers)

INNOVATION HUB
Home to leading hydrogen research institutes and industry stakeholders driving product commercialization

Source: McKinsey & Company. (2022, June 8). Houston as the epicenter of a global clean-hydrogen hub. McKinsey & Company. Retrieved September 8, 2022, from: https://www.mckinsey.com/capabilities/sustainability/our-insights/houston-as-the-epicenter-of-a-global-clean-hydrogen-hub

UT researchers are coordinating an array of research and development initiatives to safely and cost-effectively scale up hydrogen production, storage, distribution, and end-use.

With effective leadership, supportive state and federal policies, and ample research and development funding, Texas can drive the development of a clean hydrogen economy and further cement its role as a world-leading low-carbon energy producer – spurring economic development, job growth, and pollution reduction throughout the state and beyond.

	Why is Additional Hydrogen Research Needed?	Sample UT Research Areas
 **PRODUCTION**	**Some hydrogen production processes emit significant CO2 emissions.** When hydrogen is derived by steam methane reforming of natural gas, the process emits large amounts of carbon dioxide. Carbon capture and storage is vital to maximize the well-to-wheels emissions benefits. **Clean hydrogen production is currently too costly to replace existing large- scale energy sources.** For the market to flourish, research and development is vital to achieve a cost-effective, scalable, clean, and efficient production of green hydrogen.	• Steam reforming with CO2 capture and storage • Design of efficient electrodes and water electrolysis reactors • Conversion of natural gas to hydrogen and solid carbon • Water electrolysis for hydrogen • Electrochemical reforming of natural gas • Multiscale methods for hydrogen generation
 **STORAGE**	**Resiliency is a critical factor to successfully scale the use of clean energy.** Commercial underground hydrogen is available in Texas today. Due to the potential volume and duration of storage, hydrogen looks to be a resiliency game changer for a legacy grid with battery storage. **Hydrogen and CO2 can be stored in large volumes to scale production and use.** Subsurface storage provides vast capacity, but needs to be evaluated for potential to interact with existing elements, risk of leaks, whether operating cost are viable, and more.	• Hydrogen storage in dissolution caverns in salt domes • Hydrogen storage in depleted oil and gas wells • Hydrogen storage in saline aquifers • Materials for low pressure ambient temperature, reversible, rapid hydrogen storage (e.g., hydrides, Metal-organic frameworks, hydrates, formic acid etc.)

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DISTRIBUTION	**Hydrogen must be properly handled to avoid resource loss and ensure safety.** Hydrogen is the lightest element with high mobility, and can be lost into the atmosphere or degrade pipelines and tanks during storage and transport. **Existing natural gas infrastructure could support hydrogen distribution.** Realization of a large-scale hydrogen economy is critically dependent upon cost-effective and safe transport of hydrogen via pipelines (both existing natural gas ones and new ones).	• New pipeline materials/coating development • Mechanistic understandings of pipeline degradation • H2-CH4 blend leakage detection and simulation • Pipeline network simulation and optimization • Economic assessment of H2-CH4 pipeline blending • Utilizing existing natural gas infrastructure for potential hydrogen use cases
END-USE	**Hydrogen performs differently than natural gas in stationary equipment.** Hydrogen blended into natural gas pipelines can help decarbonize and leverage existing infrastructure. But hydrogen blends change the combustion characteristics of the natural gas and can impact the performance and reliability of equipment, from generators to stoves and water heaters. **More hydrogen-powered vehicle options are needed for mobile applications.** Some of the most promising uses for hydrogen-powered vehicles are in high fuel use, heavy- duty vehicles. Developing more options for on- road and off-road vehicles (e.g. refuse trucks, terminal tractors, and locomotives) is key to enabling zero-emission strategies for some of the most demanding mobile applications.	• Emissions, performance and safety impacts of increasing blends of hydrogen on combustion equipment • Demonstration projects with data collection and analysis • Fuel cell system improvements to maximize performance capabilities, improve efficiency, and reduce costs • Fueling strategies for equipment that cannot practically rely on fixed fueling stations (i.e., need for mobile H2 fueling systems)

KEY BENEFITS OF UT'S RESEARCH

INDUSTRY INNOVATION
Helping organizations commercialize products and services by providing the R&D needed to drive down costs

RESOURCE PROTECTION
Evaluating hydrogen production's impact on water usage and emission addition/reduction

WORKFORCE DEVELOPMENT
Educating the next generation of leaders in the hydrogen economy

JUSTICE40 INITIATIVES
Assessing impacts and benefits of a hydrogen economy for disadvantaged communities

Visit energy.utexas.edu to learn more about The University of Texas at Austin's world-leading science and business programs and research centers working to build a successful hydrogen economy.

- **Cockrell School of Engineering** is the #1 engineering program in Texas, #6 engineering graduate program in the U.S., and #10 best program globally.
- **Jackson School of Geosciences** houses one of the oldest geoscience departments in the nation.
- **College of Natural Sciences** is one of the largest colleges of science in the nation.
- **McCombs Business School** is one of the country's top ranked business schools, focusing on holistic business education.
- **LBJ School of Public Affairs** is consistently ranked as one of the best public policy schools in the country, with a special focus on environmental policy and management.
- **Texas Law** is ranked as the #1 law school for return on investment among the top 15 law schools in the nation.
- **Bureau of Economic Geology** is focused on subsurface hydrogen storage, leakage detection, and fracture growth in rocks and techno-economics and value chain analysis.
- **Center for Electrochemistry** is developing new electrocatalysts and materials for electrochemical devices, such as fuel cells and water electrolyzers.
- **Center for Electromechanics** teams with industry on R&D that makes the production, storage, transmission, and use of hydrogen at scale affordable.
- **Center for Subsurface Energy and the Environment** is evaluating energy security solutions that balance environmental impact and affordable resources.
- **Electron Microscopy Facility** is achieving atomic scale characterization of new materials for hydrogen generation and utilization.
- **Oden Institute for Computational Engineering and Sciences** is using computational methodology to create new materials for energy applications, including hydrogen production and utilization.
- **Texas Materials Institute** is developing clean energy materials for fuel cells and water electrolysis.
- **Kay Bailey Hutchison Energy Center** focuses on the intersection of energy business, law and policy. This center leverages the resources of McCombs Business and Texas Law.

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