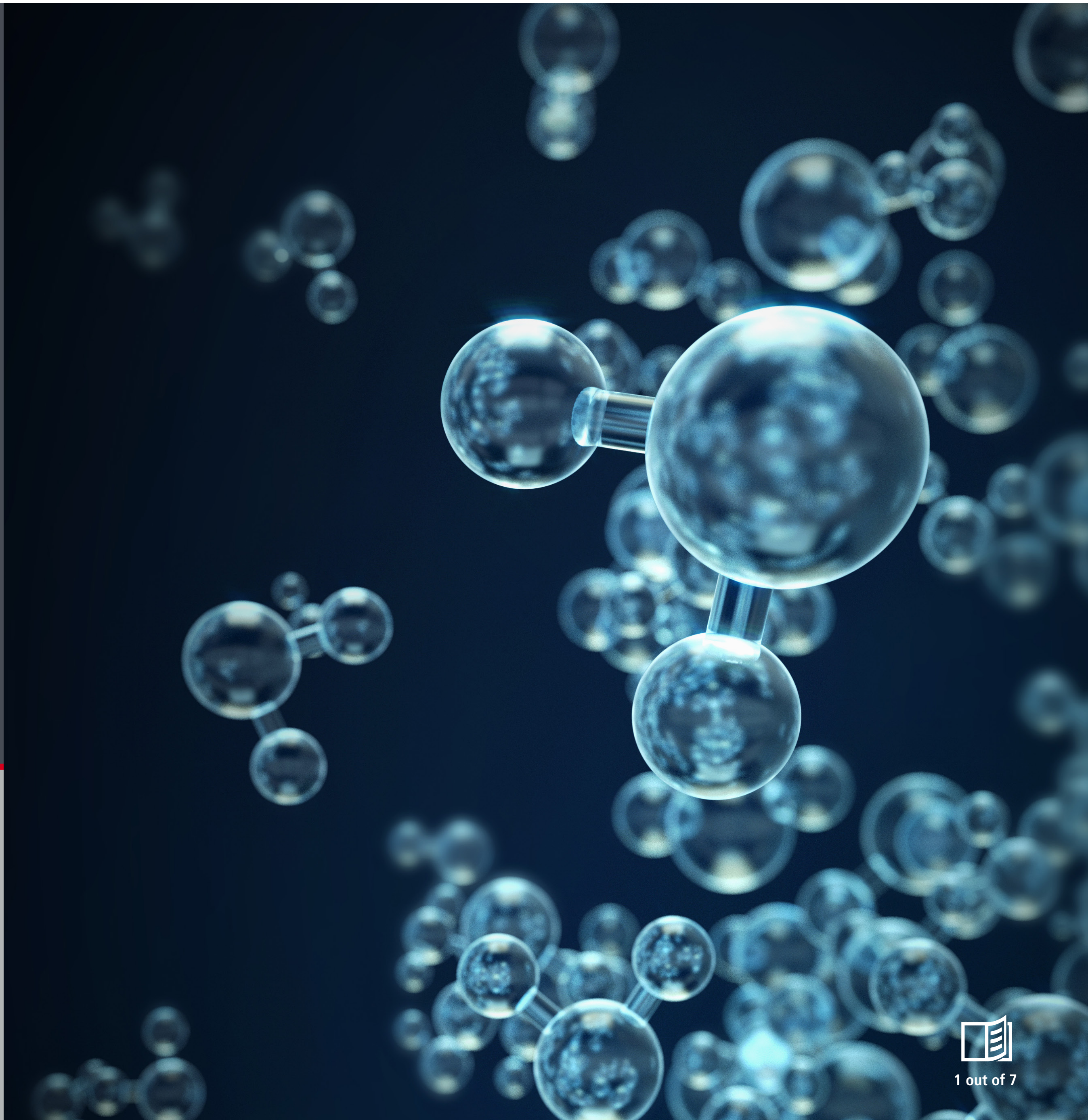
MHPS

Mitsubishi Hitachi Power Systems

Renewable Energy Storage

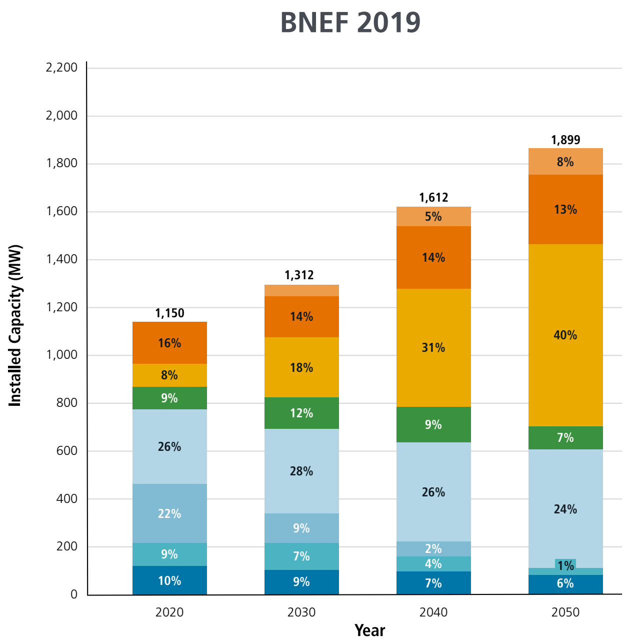
Combining Existing Dry Low NO_x Combustion Technology with Proven Hydrogen Storage and Production Approaches

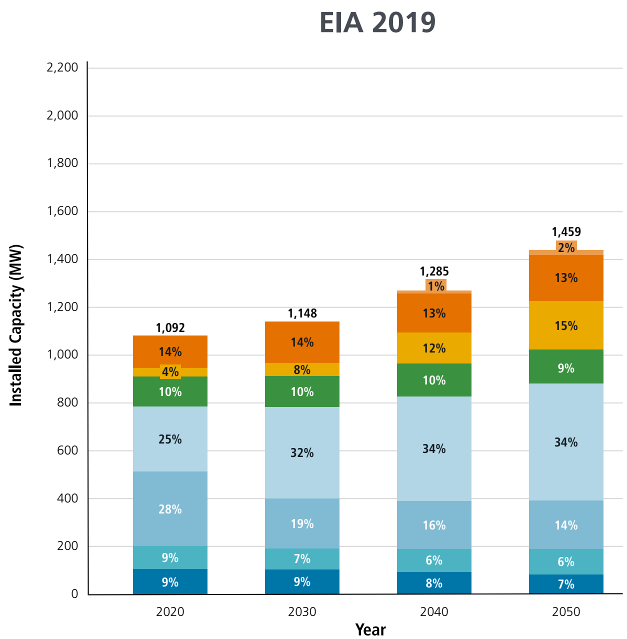


The Advanced Clean Energy Storage Project is a Required Investment to Enable a **100%** Renewables Future

According to the Carnegie Mellon US Power Sector Carbon Index [1], replacing coal-fired power plants with natural gas and renewable power has reduced carbon emissions from the U.S. power sector by 38% compared to 2005 levels. However, more change is necessary to achieve the 100% renewable power generation targets several states have set, and new technology is essential to reaching those ambitious clean energy targets. 2019 forecast models from the U.S. Energy Information Administration (EIA) and Bloomberg New Energy Finance (BNEF) show increased power generation from natural gas turbines through 2050. Two main drivers of this growth in natural gas power generation are the need to replace retiring coal-fired power generation and the need to balance an increasingly renewable-heavy grid that currently lacks sufficient energy storage.

Natural gas (baseload and peaking) is taking a leading role in the latest BNEF and EIA analyses





Energy Storage | Peaker | Solar | Wind | Combined Cycle | Steam | Nuclear | Hydro

Mitsubishi Hitachi Power Systems (MHPS) has a vision that new natural gas power plants can meet today's need for dispatchable and cleaner power, and also meet tomorrow's need to store vast quantities of renewable power for long periods of time. To help realize this vision, MHPS has partnered with Magnum Development to jointly develop the Advanced Clean Energy Storage (ACES) project in Delta, Utah.

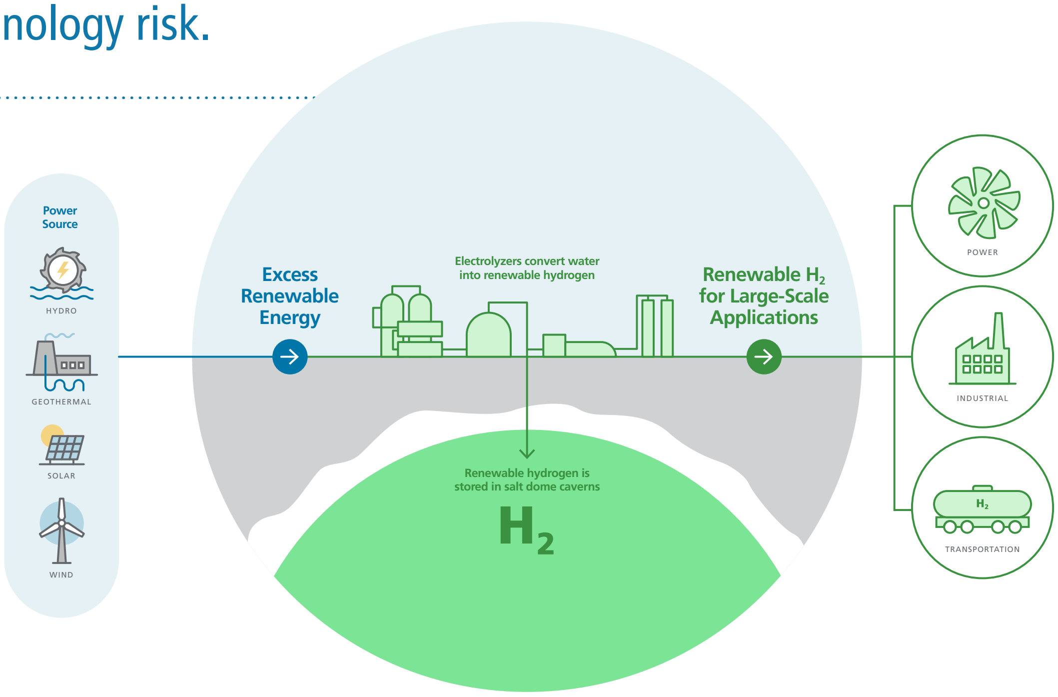
The project will enable utility-scale hydrogen production from renewable energy sources and store the hydrogen in underground salt dome caverns to provide a huge reservoir of renewable fuel for power generation when wind and solar power generation fall short of demand.

The ACES project combines three main technologies for renewable hydrogen production, storage, and gas-to-power that have been proven over the past 30 to 50 years to create a minimal technology risk project. MHPS and Magnum Development will be the first to combine these technologies into seasonal utility-scale storage that will lead the path toward a 100% renewables future.

The ACES project will

- Use excess electricity from the western United States region's renewable generation assets to produce renewable hydrogen
- Safely store renewable hydrogen
- Fuel combined-cycle gas turbines with a mixture of 30% renewable hydrogen and 70% natural gas at the Intermountain Power Agency's Intermountain Power Plant Renewal Project, which will enter commercial operation in 2025
- Convert gas turbines to use 100% renewable hydrogen according to IPA's schedule to meet California's ambitious clean energy standards
- Transport renewable hydrogen fuel to begin decarbonizing other verticals such as industry and transportation

ACES combines proven technologies for renewable hydrogen production, storage, and gas-to-power with minimal technology risk.



Producing Renewable Hydrogen Through Electrolysis

During times of renewable power oversupply, ACES will use electrolyzers to produce hydrogen from water using excess renewable power. Commercial electrolysis technology has benefited from decades of research to develop the two most commonly used technologies: Proton Exchange Membrane (PEM) and alkaline electrolyzer systems. The first large-scale electrolysis system was built in 1927, and pressurized industrialized alkaline electrolyzers were commissioned in 1948. [2]

Electrolysis is a proven technology used commercially for more than 50 years, and currently accounts for 4% of deliberate hydrogen production globally. [3] Although its cost has been a barrier to large-scale deployment, the recent move toward a carbon-free society has positioned electrolysis has a high growth industry. As was seen with PV solar panels, wind turbines, and Li-ion batteries, as global deployment scales up in the coming years, electrolysis costs are projected to "plummet." [4]

Electrolysis is a proven technology used commercially **50+** YEARS

Safely Storing Renewable Hydrogen Using Proven Technology

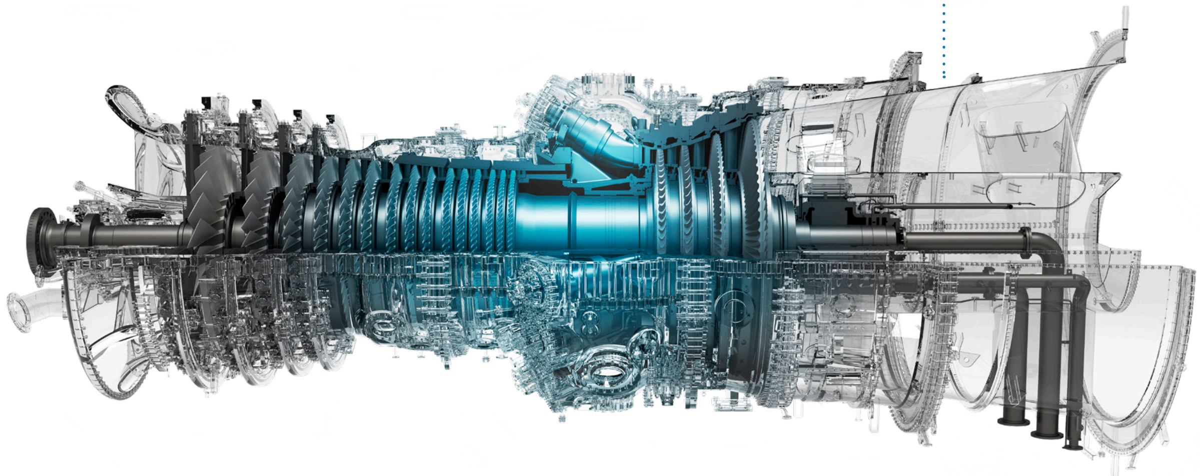
ACES will store renewable hydrogen in large underground salt dome storage caverns. Salt domes are unique geological features into which caverns are solution mined to provide economical bulk storage. Salt dome storage caverns have been used for many years to safely store a variety of hydrocarbon materials, such as refined petroleum products, crude oil, and propane. Three hydrogen salt dome storage caverns in the United States are in operation, with decades of experience: [5]

1. The Chevron Phillips Clemens Terminal in Texas has stored hydrogen since the 1980s in a solution-mined salt cavern. [6]
2. Praxair, Inc., a wholly owned subsidiary of Linde Plc, has a Liberty County, Texas, salt cavern storage system that supplies the 310-mile hydrogen supply line between Texas City, Texas, and Lake Charles, Louisiana, [7] with plans to extend to Phillips' Sweeney plant by 2021. [8]
3. Air Liquide's Spindletop cavern in Beaumont, Texas, supplies hydrogen throughout the Gulf Coast. [9]

The only "Gulf Coast quality" salt dome in the Western United States is located in Delta, Utah. Magnum Development has extensively characterized the properties of this salt dome, and has already placed several caverns in it to store petroleum products. The ACES project will use this salt dome to accomplish the same large-scale hydrogen storage that has been used for decades to supply hydrogen to the refineries of the U.S. Gulf Coast.

Fueling Gas Turbines with Renewable Hydrogen

Building on its decades of experience in hydrogen combustion technology, MHPS is developing two new generations of dry low NO_x high efficiency combustion systems for its largest and most advanced gas turbines.



MHPS is the world leader in hydrogen combustion technology with more than

3.5 million hours

of experience co-firing hydrogen at 29 facilities since the early 1970s.

The first generation combustion system is available today, using existing dry low NO_x natural gas combustion technology in MHPS's latest generation of G- and J-Class gas turbines. The first generation combustors are capable of using up to a 30% hydrogen / 70% natural gas mix. MHPS has demonstrated that this mixture of hydrogen and natural gas will produce NO_x and CO_2 emissions equivalent to those from modern natural gas power plants.

To achieve 100% hydrogen combustion, a second generation combustion system is in development. It uses a "multi-cluster" combustor technology that MHPS borrowed from the MHI heavy launch rocket division to achieve 100% hydrogen fueling with NO_x emissions consistent with modern 100% natural gas combustion systems. MHPS is currently validating this combustion system in its JAC gas turbines, with a proprietary technology roadmap to provide a commercial product in the coming years.

MHPS is a world leader in hydrogen combustion technology with more than 3.5 million hours of experience co-firing hydrogen at 29 facilities since the early 1970s. MHPS has demonstrated more than 400,000 hours co-firing 90% hydrogen in those facilities. In addition, MHPS benefits from MHI's heavy launch rocket division, which has many years of experience with 100% hydrogen combustion.

MHPS's experience with high-hydrogen fuels for power generation includes refinery off-gas, blast furnace gas, and syngas produced from gasification. MHPS began developing hydrogen-rich fuel capabilities in the late 1960s to deploy gas turbine technology fueled by coke oven gas. During the 1980s and 1990s, MHPS added both refinery off-gas and syngas utilization to its hydrogen fuel portfolio.

Conclusion

MHPS and Magnum Development share society's vision to rapidly advance carbon-free energy on a commercial scale. The ACES project provides a complete end-to-end solution to produce, store, and convert renewable hydrogen for carbon-free year-round power in the western United States.

This bold vision leverages technology that has been tested and proven over decades, along with new advances in dry low NO_x combustion technology. ACES is the first commercial-scale project to combine and advance these technologies toward a target of a 100% renewables future.

The ACES project provides a complete end-to-end solution to produce, store, and convert renewable hydrogen for carbon-free year-round power.

Works Cited

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