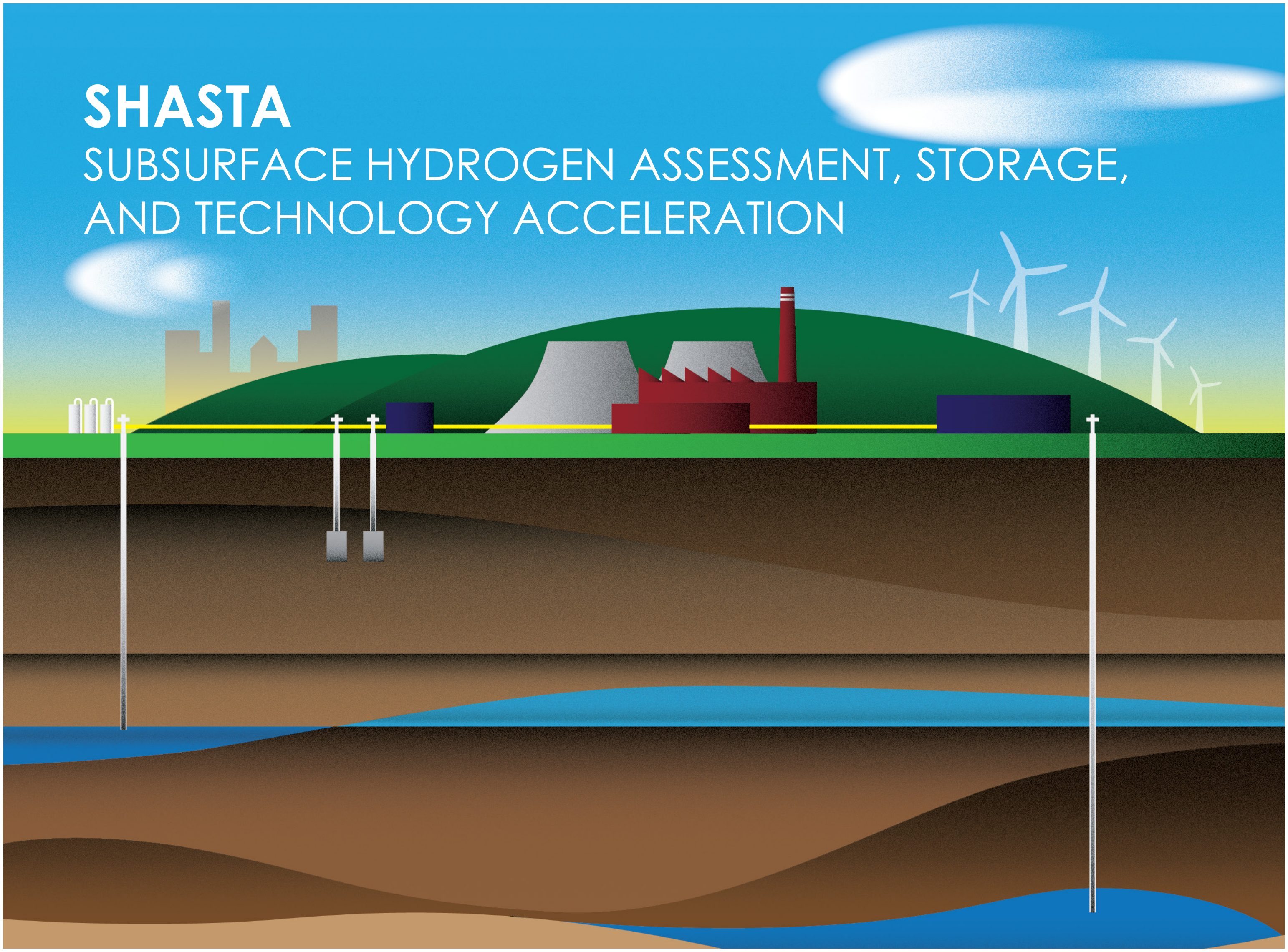
SHASTA
SUBSURFACE HYDROGEN ASSESSMENT, STORAGE, AND TECHNOLOGY ACCELERATION



NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

OVERVIEW

The DOE's Office of Fossil Energy and Carbon Management (FECM) is leveraging the unique capabilities and demonstrated expertise of four national laboratories — The National Energy Technology Laboratory (NETL), Pacific Northwest National Laboratory (PNNL), Lawrence Livermore National Laboratory (LLNL), and Sandia National Laboratories (SNL) — to determine the viability, safety, and reliability of storing pure hydrogen or hydrogen-natural gas blends in subsurface environments in a project named SHASTA or Subsurface Hydrogen Storage Assessment, and Technology Acceleration.

Hydrogen is emerging as a low-carbon fuel option for transportation, electricity generation, manufacturing applications, and clean energy technologies that will accelerate the United States' transition to a low-carbon economy. However, a key challenge is to ensure the safe and effective storage of hydrogen. Large-scale storage of H_2 can be achieved by utilizing underground resources similar to how natural gas (NG) has been stored for the past century. Underground hydrogen storage (UHS) has the potential to provide the storage capacity required for the future hydrogen energy market.

R&D232, February 2024

SHASTA-SUBSURFACE HYDROGEN ASSESMENT AND TECHNOLOGY ACCELERATION

Recent studies have concluded that UHS is less costly than storage in above-ground vessels. Although there is much experience in underground storage of natural gas, there are significant technical challenges that must be addressed to store H_2 economically and safely at the commercial scale. The SHASTA team is addressing the following challenges:

- Hydrogen storage efficacy for a variety of underground systems such as depleted hydrocarbon reservoirs, saline aquifers, and salt caverns.
- Effect of hydrogen's low density, energy density and viscosity on gas storage behavior.
- Hydrogen loss through biogeochemical reactions such as methanogenesis, sulfate reduction and iron reduction.
- Effect of hydrogen's small molecular size on risk of containment loss from the storage reservoir through caprock, faults or fractures, or leaky wells.
- Development of real-time monitoring technology to assess gas migration, potential leakage, microbial activity, and well integrity.
- Attaining support from key stakeholders as well as public acceptance.
- Supporting the emerging regulatory environment with strong scientific and technical basis.

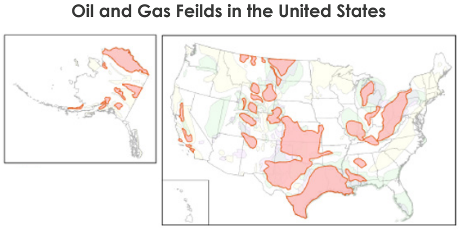
World-class facilities at the four labs, NETL, PNNL, LLNL, and SNL are currently being used to drive innovation in SHASTA. Research conducted at NETL builds on existing subsurface capabilities designed to enable high pressure, high temperature reactor studies that simulate wellbore subsurface reactions and diffusivity, assess the geochemistry and microbiology of reservoir types targeted for H_2/CH_4 storage, and develop optical fiber sensors capable of measuring H_2, CH_4, and pH. Specific capabilities includes: gas and ion chromatography, x-ray diffraction, scanning electron microscopy, mass spectrometry, qPCR and DNA sequencing, optical fiber sensor design, high temperature high pressure reactors, surface area and pore size analysis, and reservoir simulation. simulation. NETL researchers have access to world-class computing facilities, including the lab's latest supercomputer Joule 3.0.

Research conducted at PNNL will leverage expertise across the lab related to subsurface flow and transport, biogeochemistry, and technoeconomic analysis. Specific capabilities are housed within the biogeochemistry lab and subsurface science lab which hold the requisite equipment to conduct microbial analysis and flow through testing. The project can also leverage capabilities available at PNNL's Environmental Molecular Sciences Laboratory. For computer simulations, PNNL researchers have access to world-class computing facilities, including the lab's latest supercomputer Deception.

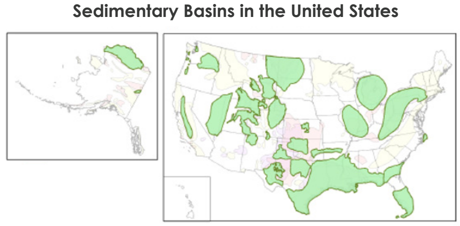
Research conducted at LLNL builds from expertise in rock-water-CO2 interactions in batch and flowing systems and application of a multiphase/multicomponent framework (GEOSX) to solve the H_2/CH_4 storage mass balance and thermodynamic equilibria equations. Additional LLNL capabilities co-located in these same buildings include gas and ion chromatography, various mass spectrometry techniques, nuclear magnetic resonance facilities, scanning electron microscopy, X-ray tomography, profilometry, and X-ray diffraction and fluorescence. For computer simulations, LLNL researchers have access to several TOP500 system through the Livermore Computing Center.

Laboratory work conducted at Sandia National Laboratories builds on existing capabilities for investigating geological formations for the potential subsurface storage of hydrogen, potential including permeability testing at high temperatures and pressures and geomechanical rock properties testing. Sandia's geochemistry laboratories are equipped to conduct hydrogen-induced reactions at in- situ conditions, with characterization of post-reaction processes, and assessment the of elemental and structural properties affecting hydrogen storage potential. Researchers use Sandia's high-performance computing for subsurface multiphase flow and reactive transport simulations for and modeling coupled processes. Sandia's microbiological researchers apply genomic DNA extraction and sequence the 16S rRNA gene for determination ofto determine metabolic potential with hydrogen.

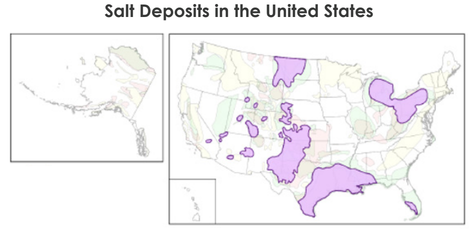
Oil and Gas Feilds in the United States



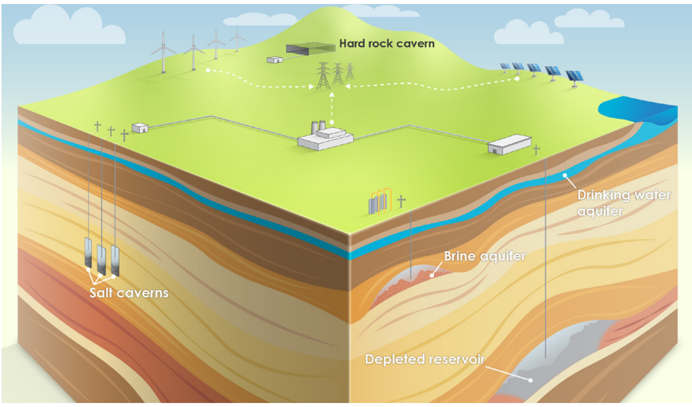
Sedimentary Basins in the United States



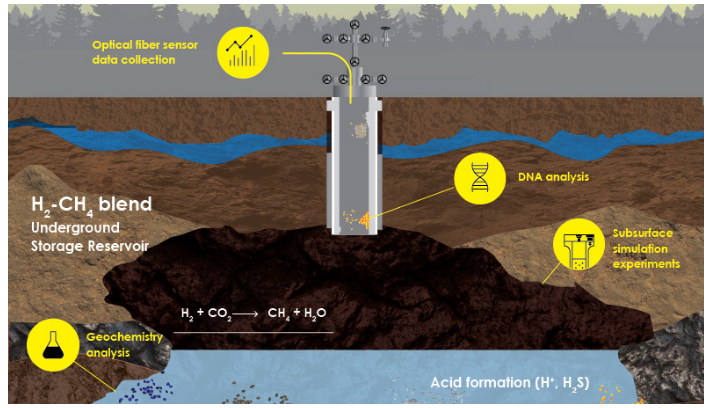
Salt Deposits in the United States



Shaded areas represent potential geologic storage units of each of the three types: oil and gas fields, sedimentary basins, and salts domes. Dots represent existing underground natural gas storage in each type of storage unit.



Underground storage of H_2 is less costly than storage in above-ground vessels but significant technical challenges must be addressed to store H_2 economically and safely at the commercial scale. SHASTA research focuses on quantifying materials compatibility, investigating core- and reservoir-scale performance and characterizing microbial interactions.



Research on the challenges of storing pure hydrogen or hydrogennatural gas blends in subsurface environments include securing data on DNA analysis, subsurface simulation experiments and geochemistry analysis. SHASTA uses analytic capabilities in combination with optical fiber sensors and modeling to collect data to advance research.

The National Energy Technology Laboratory is a U.S. Department of Energy national laboratory that drives innovation and delivers technological solutions for an environmentally sustainable and prosperous energy future. Through its world-class scientists, engineers and research facilities, NETL is ensuring affordable, abundant and reliable energy that drives a robust economy and national security, while developing technologies to manage carbon across the full life cycle, enabling environmental sustainability for all Americans, advancing environmental justice and revitalizing the economies of disadvantaged communities.

The Pacific Northwest National Laboratory advances the frontiers of knowledge, taking on some of the world's greatest science and technology challenges. Distinctive strengths in chemistry, Earth sciences, biology, and data science are central to our scientific discovery mission. PNNL's research lays a foundation for innovations that advance sustainable energy through decarbonization and energy storage and enhance national security through nuclear materials and threat analyses.

For more than 60 years, the Lawrence Livermore National Laboratory has applied science and technology to make the world a safer place. Livermore's defining responsibility is ensuring the safety, security and reliability of the nation's nuclear deterrent. Yet LLNL's mission is broader than stockpile stewardship, as dangers ranging from nuclear proliferation and terrorism to energy shortages and climate change threaten national security and global stability. LLNL responds with vision, quality, integrity, and technical excellence to the nation's most challenging security problems.

For more than 70 years, Sandia National Laboratories has kept the US nuclear stockpile safe, secure, and effective as part of our multidisciplinary national security engineering laboratory. Sandia's role has evolved to address the additional complex threats facing our country by carrying out research and development supporting US nuclear deterrence, national and global security, energy and homeland security, and advanced science and technology. We help the nation with core capabilities in systems engineering and integration, high performance computing, modeling and simulation, extreme environment testing, nanotechnologies, and microsystems.

The Department of Energy's Office of Fossil Energy and Carbon Management (FECM) is made up of about 750 federal employees—scientists, engineers, technicians, and administrative staff. Its headquarters offices are in downtown Washington, DC, and in Germantown, Maryland. The organization also includes the National Energy Technology Laboratory with offices in Morgantown, W. Va., Pittsburgh, PA, Sugar Land, TX, Albany, OR, and Anchorage, AK; and the Strategic Petroleum Reserve based in New Orleans, LA. FECM is responsible for Federal research, development, and demonstration efforts on advancing technologies to meet our climate goals and minimize the environmental impacts of fossil fuel use, including low carbon power generation and low carbon supply chains; carbon capture and storage (CCS) technologies; methane emissions reductions; critical mineral productions; and carbon dioxide removal. The Office is committed to improving the conditions of communities impacted by the legacy of fossil fuel use and to supporting a healthy economic transition that accelerates the growth of good-paying jobs.

U.S. DEPARTMENT OF ENERGY Fossil Energy and Carbon Management | NATIONAL ENERGY TECHNOLOGY LABORATORY | Pacific Northwest NATIONAL LABORATORY | Lawrence Livermore National Laboratory | Sandia National Laboratories www.NETL.DOE.gov

NATIONAL ENERGY TECHNOLOGY LABORATORY

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