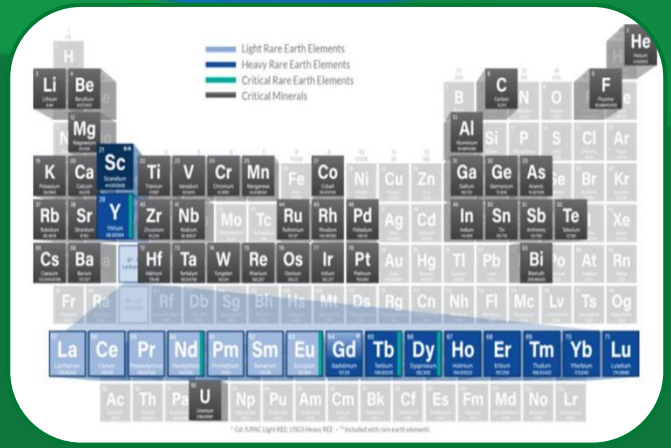
U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

10th International Gas Turbine Conference

Gas Turbines in a Carbon-Neutral Society
Gas turbine opportunities and challenges towards a U.S. hydrogen economy
DOE Office of Fossil Energy and Carbon Management

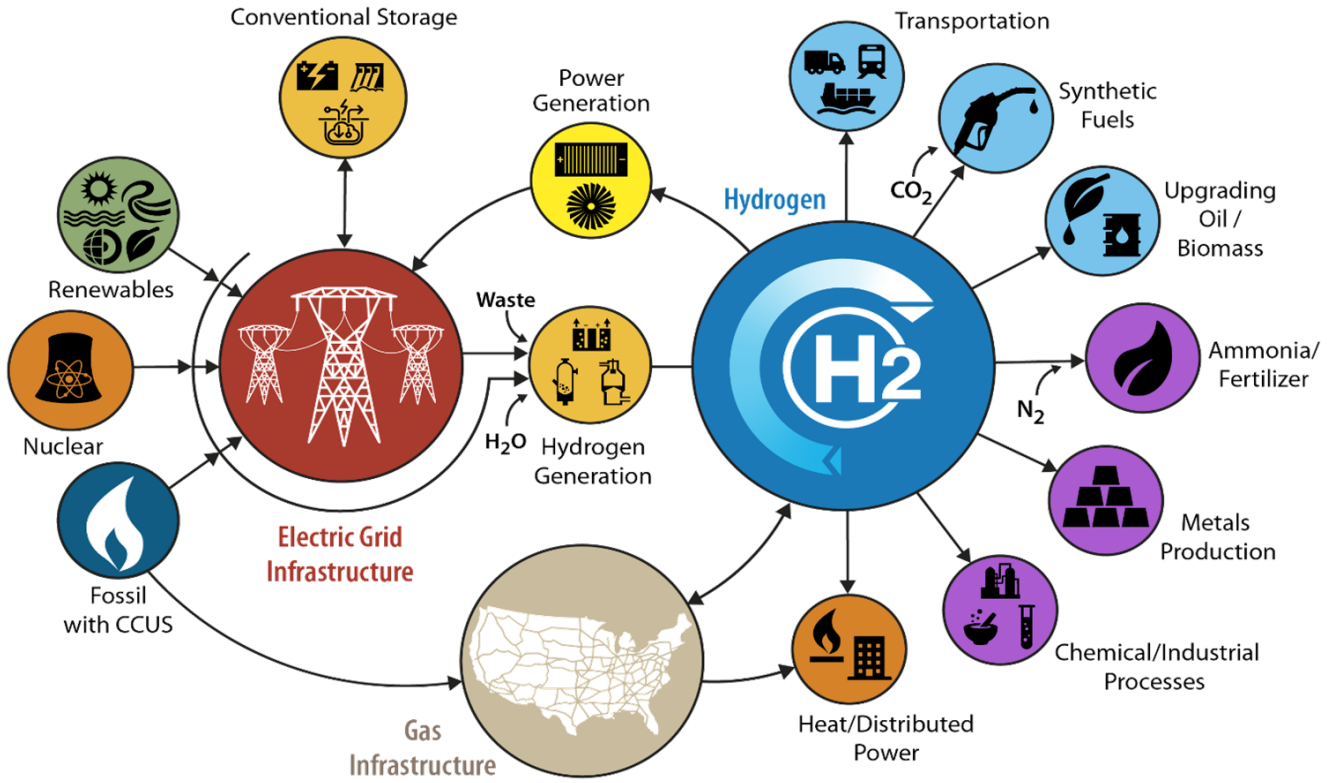
October 13, 2021





DOE-Wide Priority: Hydrogen at Scale (H_2@Scale)

DOE's H2@Scale initiative provides an overarching vision for how hydrogen can enable energy pathways across applications and sectors in an increasingly interconnected energy system.



Priorities

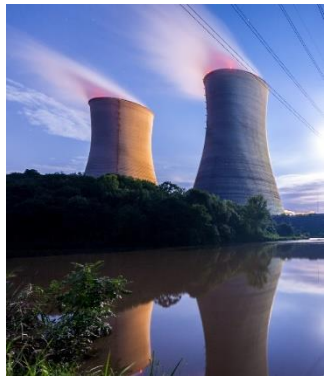
1. **Low cost, clean hydrogen generation $1/kg by 2030**
2. **Low cost, efficient, safe hydrogen delivery and storage**
3. **End use applications to achieve scale and sustainability, enable emissions reduction and address Justice40 priorities**

Global potential estimated by H_2 Council: $2.5 trillion, 30 million jobs, 6 GT CO_2 reduction.

RD&D, Demonstration Project Examples

Different regions, hydrogen sources, & end uses across sectors

H_2 from Nuclear Energy



New York

Demonstrates a MW electrolyzer with a nuclear plant (collaboration with Nuclear Office)

H_2 from Renewables

Texas

Integrates wind, solar, RNG from waste with onsite electrolysis and multiple end-uses

H_2 for Data Center

Washington

Integrates a 1.5MW fuel cell with a data center to provide reliable and resilient power

Clean Ammonia

Minnesota

Distributed production of NH_3 using wind- driven electrolysis

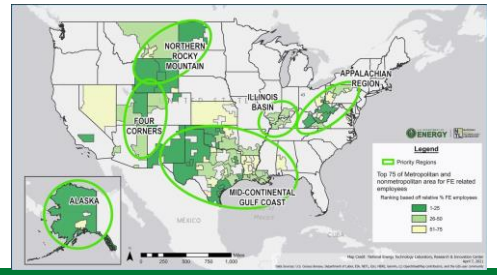
H_2 for Steel Production

Missouri

Reduction of 30% in energy and 40% emissions vs. conventional processes

H_2 Regional Deployments

Potential to site in regions vulnerable to impacts from fossil energy job losses



Assessment of regional hydrogen/CCUS **infrastructure buildout** and **job impacts**

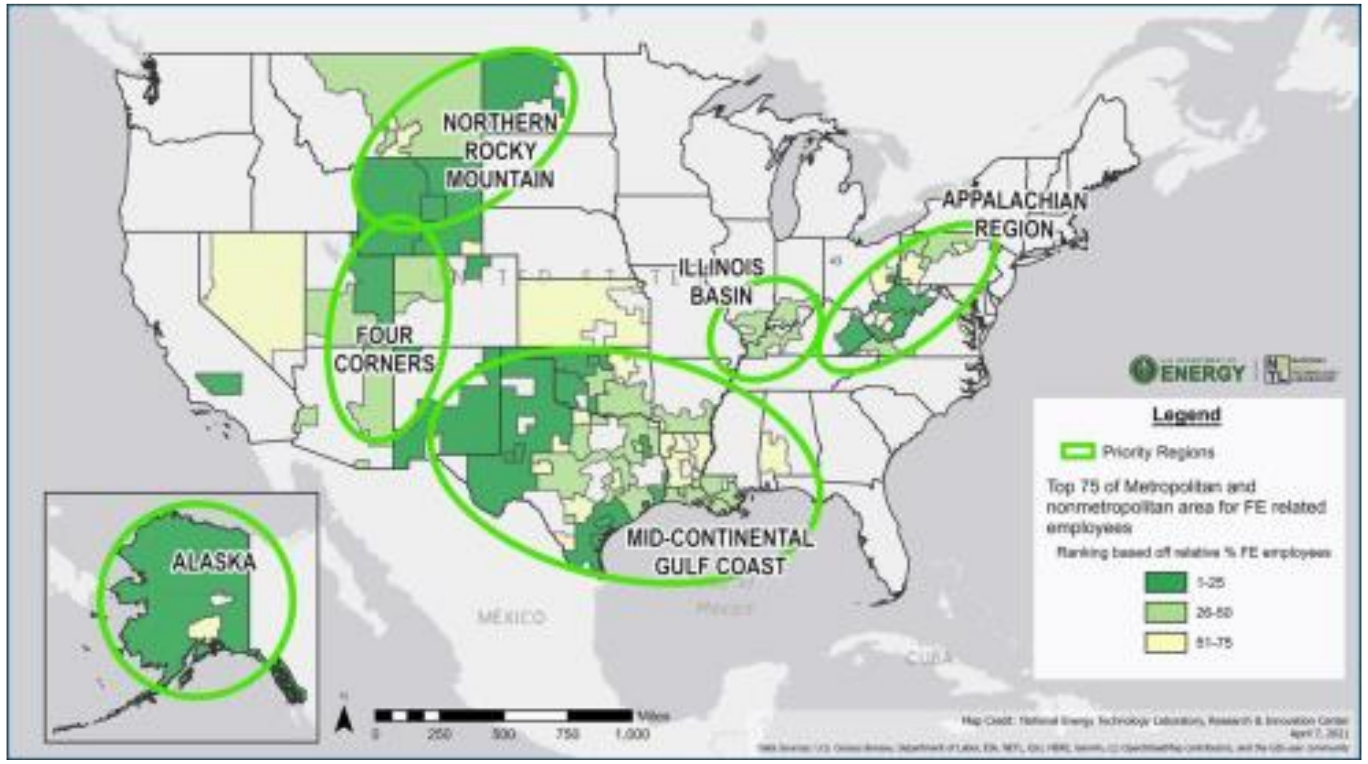
H_2 for Marine Application

California

1st-of-its-kind maritime H_2 refueling on floating barge - up to ½ ton H_2 /day

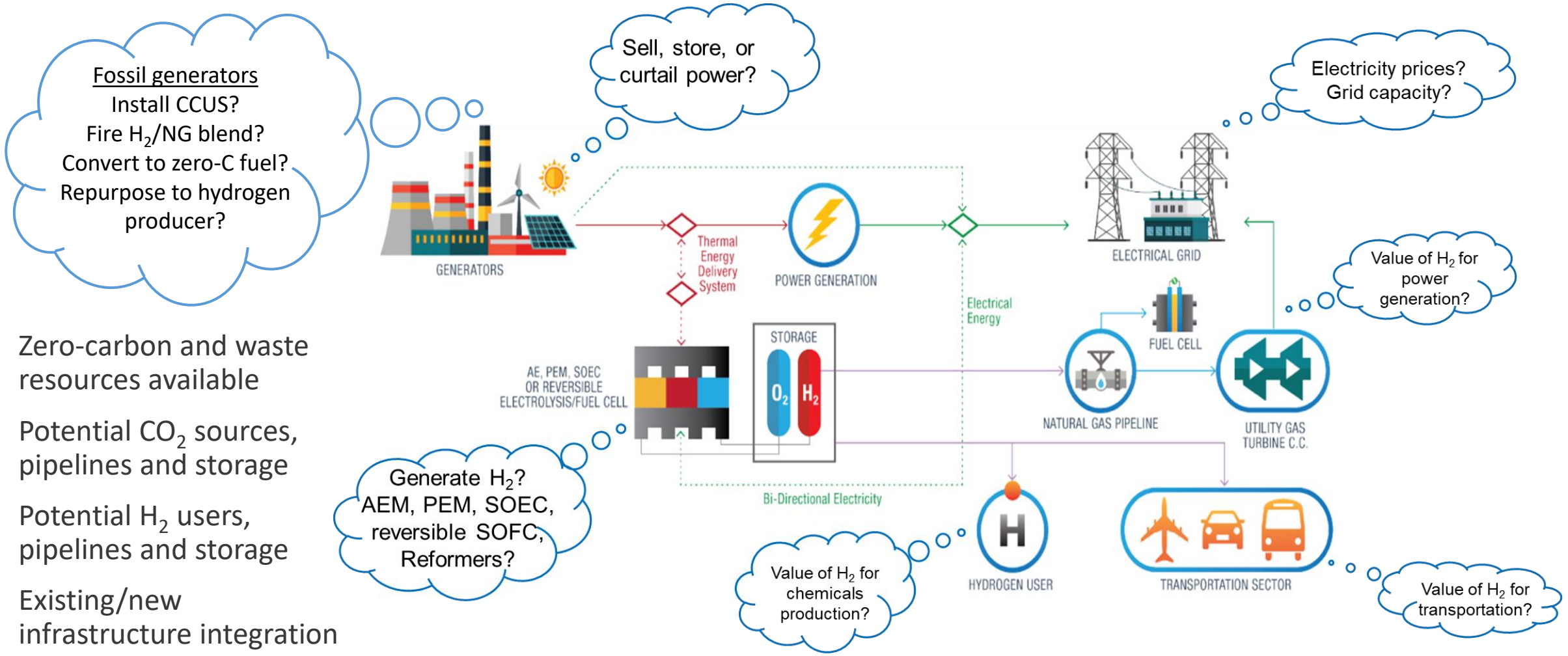
Regional Hydrogen Deployment Analyses

H_2 Regional Deployments have the potential to site in regions vulnerable to impacts from fossil energy job losses



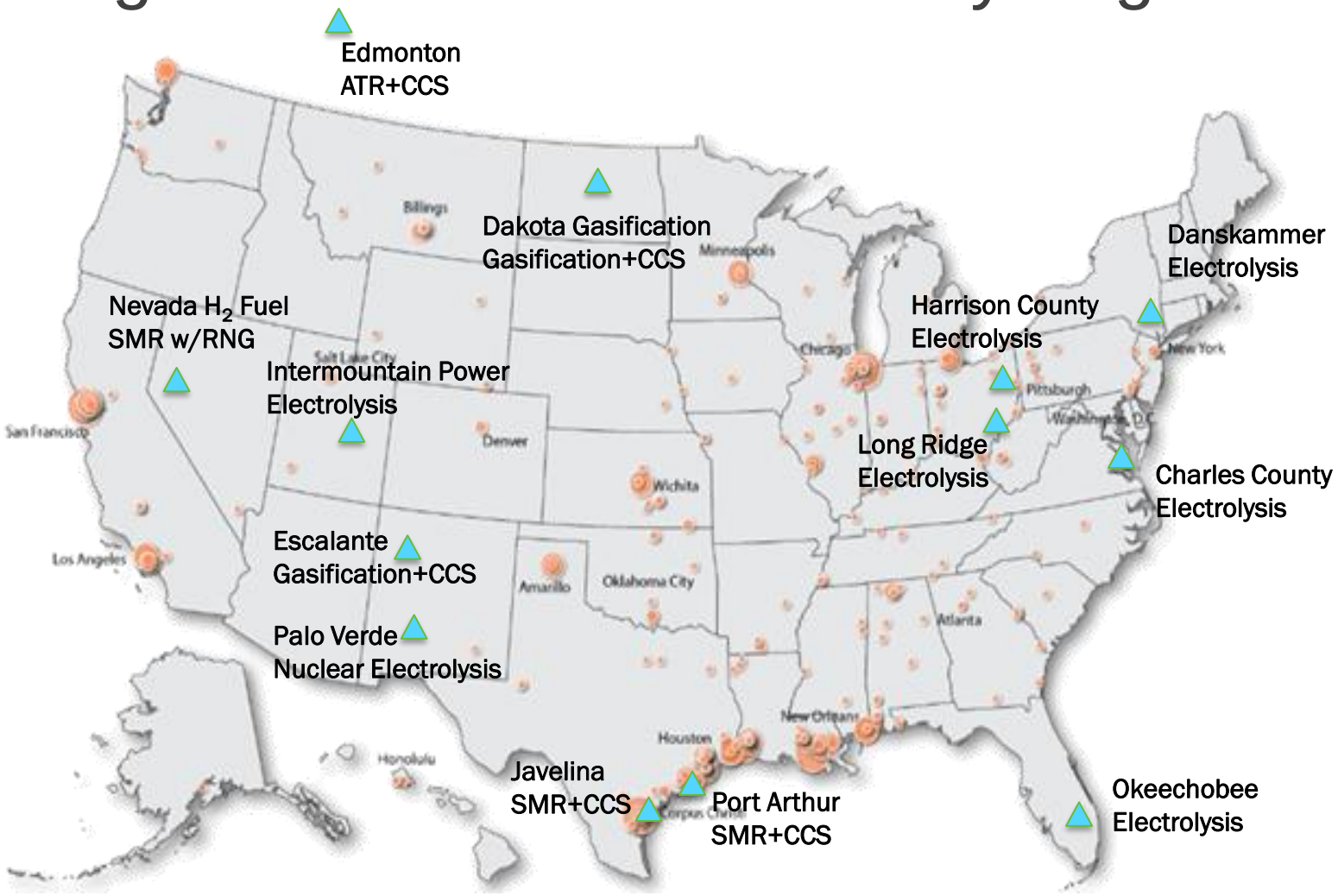
Assessment of regional hydrogen/CCUS **infrastructure buildout** and **job impacts**

Elements of Regional Analysis of Hydrogen Economy



- Zero-carbon and waste resources available
- Potential CO_2 sources, pipelines and storage
- Potential H_2 users, pipelines and storage
- Existing/new infrastructure integration

Existing and Announced Clean Hydrogen Projects in U.S.



Hydrogen Production Projects

Announced Hydrogen Turbine Projects in U.S.

Hydrogen Production Projects

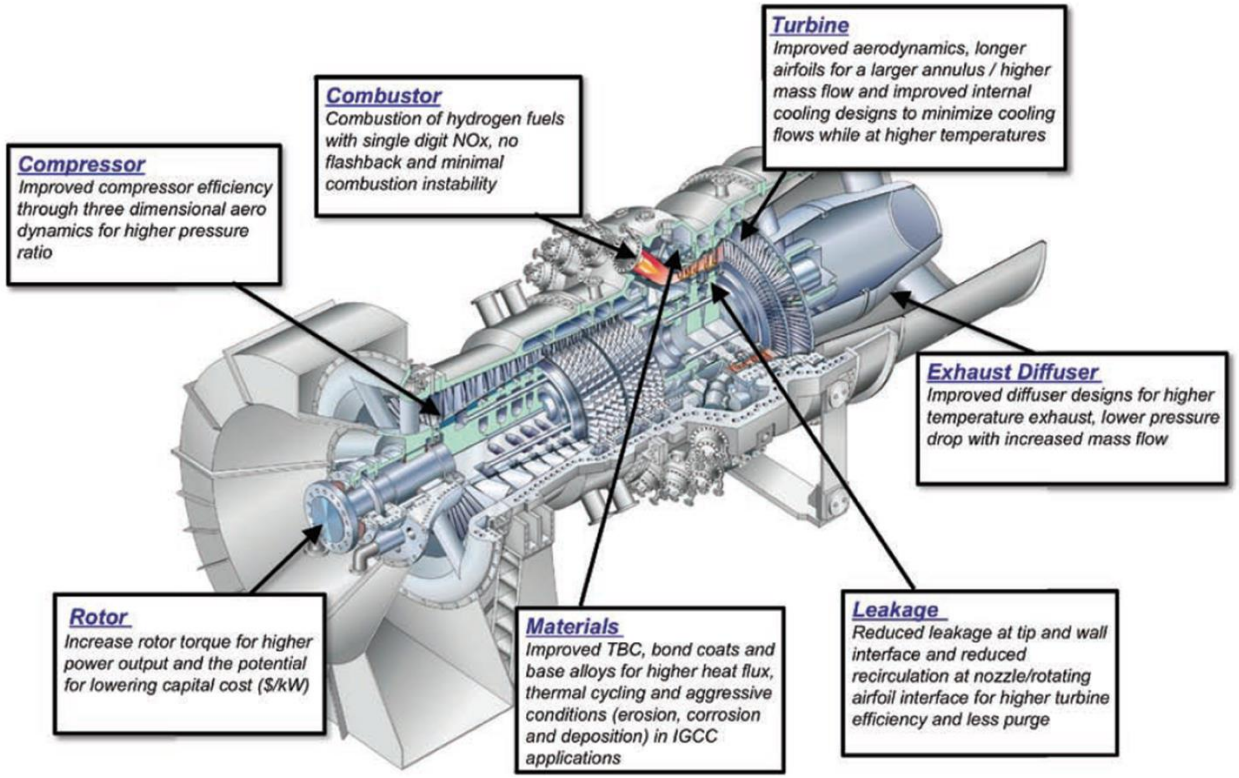
Hydrogen Turbine Projects

High H_2 Turbines for Power Generation

Apply science and engineering knowledge of stable high temperature, low NO_x hydrogen combustion.

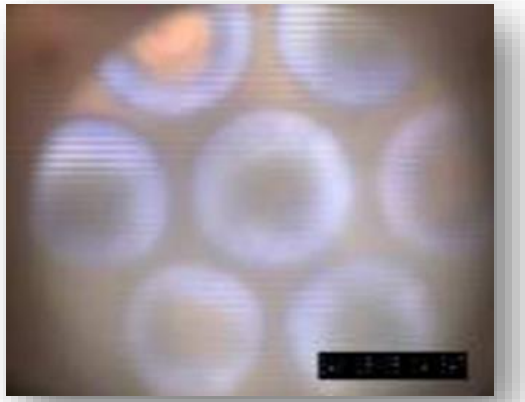
- Apply H_2 combustion engineering to utility scale and aero derivative machines – new and retrofit
- Development of CFD models that can handle complex chemistry, flashback at part load, moisture effects on heat transfer and TBCs
- Develop and test hydrogen combustion retrofit packages
- Apply advanced manufacturing for hydrogen combustors
- Develop control strategies and instrumentation

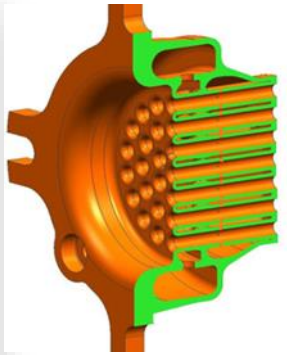
Aim for 100% zero-carbon machine to meet the demand for flexible, low-carbon power.



Representative-Scale H_2 Combustion Testing

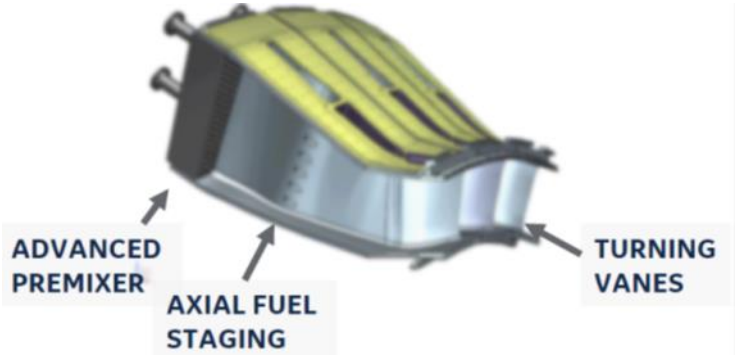
- Tested at full F-class & advanced gas turbine conditions.
- 100+ hours full can combustor operation with > 90% H_2.
- 20 hrs operation with 100% H_2
- < 3 ppm NOx @15% O_2 at target temp. with N_2 diluent.
- NOx emissions for H_2 fuels likely similar to natural gas that have been demonstrated for full scale combustor geometries.



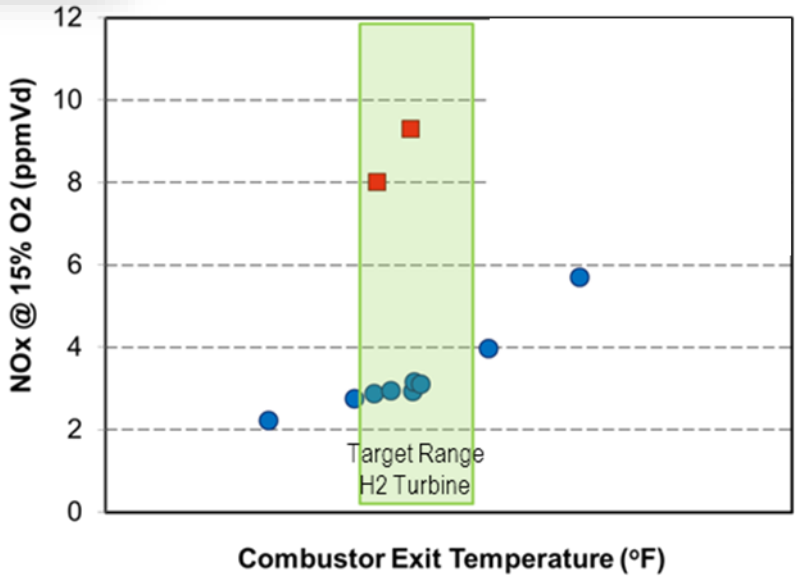


High-Hydrogen

Directly led to full scale combustion system development



Full-scale tests will advance technology readiness level to TRL6 to support future commercialization efforts



Ref: Proceedings of ASME Turbo Expo 2012, June 11-15, 2012, Copenhagen, Denmark, GT2012-69913; DEVELOPMENT AND TESTING OF A LOW NOX HYDROGEN COMBUSTION SYSTEM FOR HEAVY DUTY GAS TURBINES, W. York, W. Ziminsky, E. Yilmaz *

Hydrogen Awards Under Funding Opportunity Announcements

FOA 2400 Solid Oxide Fuel Cells (SOFCs)

- FY21 - Solid Oxide Electrolysis Cell (SOEC) Technology Development for Hydrogen Production ($8M over 2 years, 8 awards)

FOA 2400 Advanced Turbines

- FY21 - Hydrogen Combustion Systems for Gas Turbines – Industrial Class ($4.5M over 4 years, 1 award)

FOA 2397 Advanced Turbines

- FY21 - University Turbine Systems Research (UTSR) – Focus on Hydrogen Fuel – ($6.2M over 3 years, 8 awards)

FOA 2376 Gasification

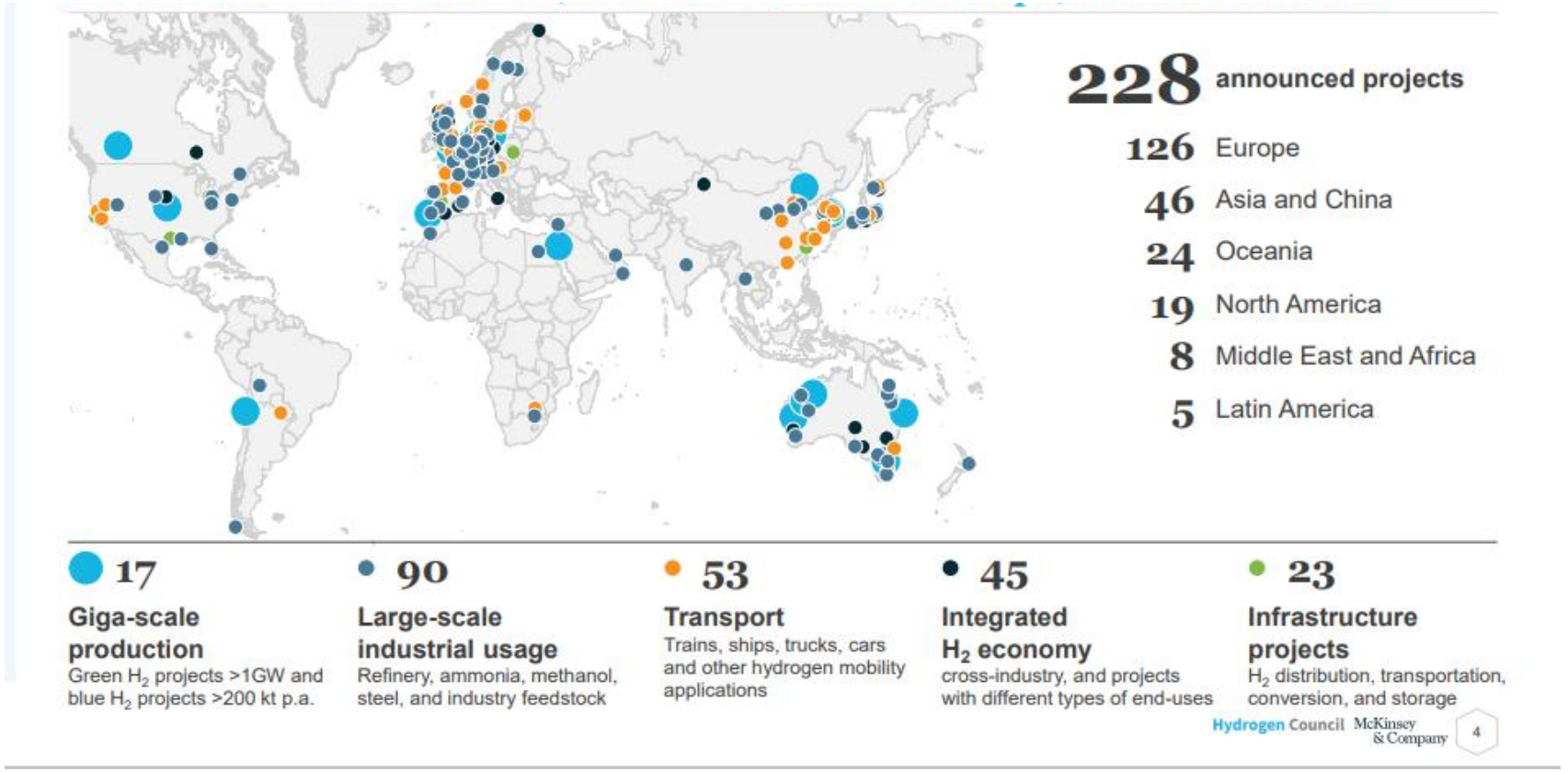
- FY20 - Enabling Gasification of Blended Coal, Biomass and Plastic Wastes to Produce Hydrogen with Potential for Net Negative Carbon Dioxide Emissions – ($2M over 2 years, 4 awards)

FOA 2300 SOFCs

- FY20 - Solid Oxide Fuel Cell (SOFC), Electrolyzer, and Hybrid Technology Development – ($34M over 3 years, 12 awards)

Global Interest in Hydrogen

Around the world hydrogen projects of unprecedented scale are being announced across the entire value chain, with 85% location in Europe, Asia and Australia



~10X growth in non-US deployments and manufacturing in the last few years

Source- H2 Council- to be published

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Questions?

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