U.S. DEPARTMENT OF ENERGY

DOE Hydrogen Program Panel Discussion

Sunita Satyapal, HFTO; Robert Schrecengost, FECM; Jason Marcinkoski, NE; John Vetrano, SC; Todd Shrader, OCED

Hydrogen Annual Merit Review

June 6, 2022




The U.S. DOE Hydrogen Program Spans Multiple DOE Offices

Hydrogen is a key element of a portfolio of solutions to decarbonize the economy

Hydrogen Program

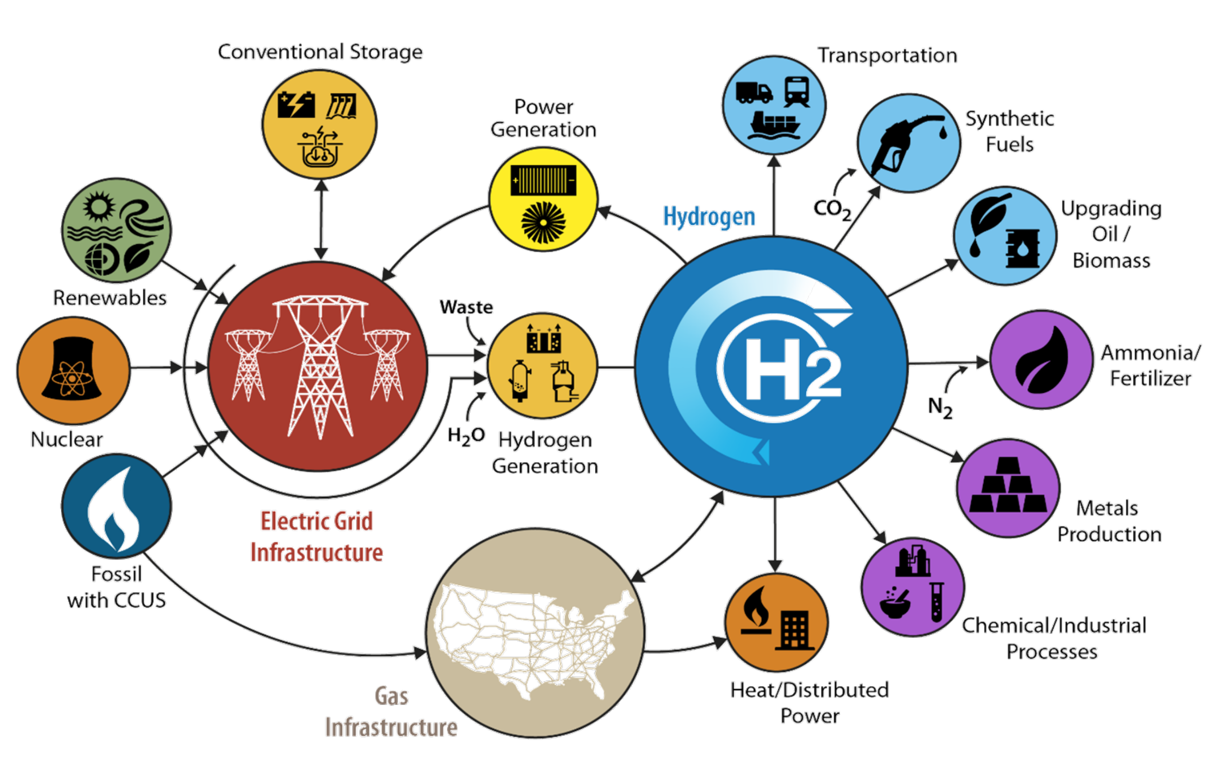
Coordinated across DOE

Focuses on research, development, demonstration, deployment (RDD&D) to address:

- **The entire H_2 value chain** from production through end use
- **H_2 production from all resources** (renewables, nuclear, and fossil + CCS)

www.hydrogen.energy.gov

H2@Scale vision to guide how hydrogen can enable clean-energy pathways across applications and sectors in an increasingly interconnected energy system

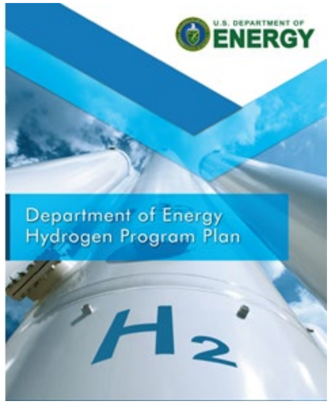


Priorities

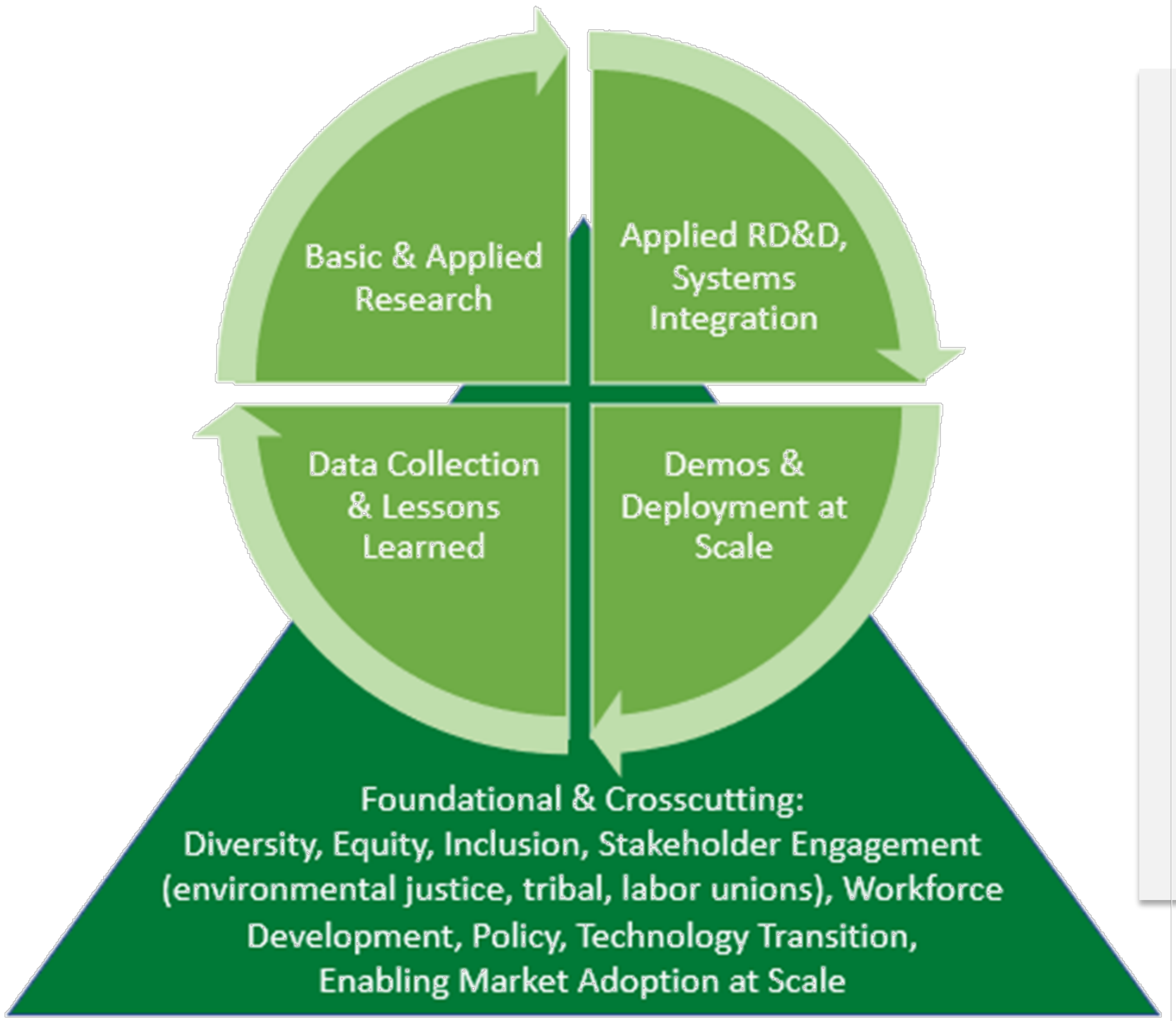
- Low cost, clean hydrogen
- Low cost, efficient, safe hydrogen delivery and storage
- Enabling end use applications at scale for impact

Includes workforce development, safety, codes, standards, and EJ priorities

DOE Hydrogen Program Plan (2020)



Coordinated Strategy Across RDD&D



DOE Hydrogen Program:

- Includes more than **400 projects**
- More than **200 companies & universities and 15 National Labs**
- **FY22 Appropriations: >$310M* across DOE**
- **FY23 Budget Request Hydrogen Crosscut*: $406M**
  - EERE: $217.5M
  - FECM: $116M
  - NE: $12M
  - SC: $60.4M

*Final to be updated pending SC, ARPA-E, and final allocations by end of year.

* https://www.energy.gov/sites/default/files/2022-05/doe-fy2023-budget-volume-2-crosscutting.pdf

EERE Hydrogen RDD&D Focus Areas and Progress

Focus RDD&D on H_2 from renewables, H_2 storage, delivery, infrastructure, fuel cells, and utilization

Examples of Hydrogen Activities Across EERE

- Coupling H_2 production with renewables (wind, solar, marine, geothermal) [HFTO, WETO, SETO, WPTO, GTO]
- Synfuels production with renewables [BETO, HFTO]
- SuperTruck for heavy duty vehicles [HFTO, VTO]
- Industrial (steel, chemicals) demonstrations and manufacturing RD&D of systems and components for electrolyzers and fuel cells [AMO, HFTO]

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Focus on $1.5B for Electrolysis, Manufacturing, Recycling
Collaboration with OCED on $8B for H2 Hubs

Impact Spans Cost Reductions, Innovation and World's "Firsts"

- **Reduced cost by 90% for electrolyzers , 70% for fuel cells, and 30% for hydrogen storage tanks** in the last several years and quadrupled durability of fuel cells; enabled commercially viable fuel cell vehicles
- **Enabled over 1,200 U.S. issued patents** and 30 technologies in the market
- **Enabled multiple "firsts" for H_2 and fuel cells-** trigen system, airport tugs, parcel delivery vans, backup power, marine application, data center; electrolyzer-grid response; and launch of the American-made hydrogen refueler, safety, codes, and standards, and workforce development

See AMR 2022 Opening Plenary talk at https://www.hydrogen.energy.gov/annual_review.html
EERE: Energy Efficiency and Renewable Energy; WETO: Wind Energy; SETO: Solar; WPTO: Water Power; GTO: Geothermal; BETO: Bioenergy; AMO: Advanced Manufacturing; VTO: Vehicle Technologies

Hydrogen Activities in Fossil Energy with Carbon Management (FECM)

Bob Schrecengost, Hydrogen with Carbon Management Division Director (Acting)

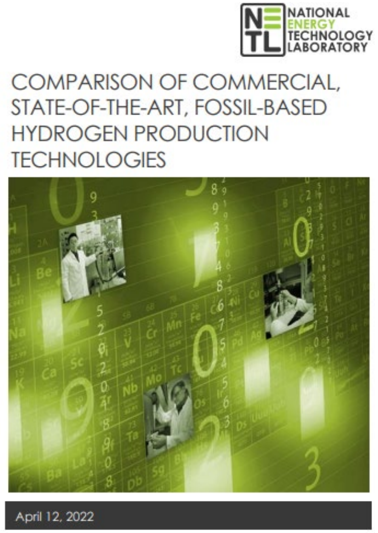
FECM - Hydrogen R&D Investments and Areas

Key Focus Areas:

- Low-cost, net-zero hydrogen production and utilization technologies, including Turbines, Reversible Solid Oxide Fuel Cells, and Point Source Carbon Capture integrated with Gasification and Reforming Technologies

Future RD&D:

- Carbon-Neutral Hydrogen Production Using Gasification & Reforming Technologies – planned awards on SMR/ATR + CCS FEEDs, gasification of mixed waste streams and biomass
- Hydrogen Use for Electricity Generation, Fuels, and Manufacturing
- Large Scale Hydrogen Transport Infrastructure
- Large Scale On-site and Geological Hydrogen Storage – SHASTA program continues



Recent Accomplishments:

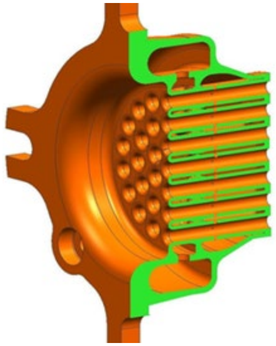
- Published NETL study "Comparison of Commercial State-of-the-Art Fossil-Based H_2 Production Technologies"
- Fossil Energy-based Production, Storage, Transport & Utilization of Hydrogen – made 4 gasification and 6 hydrogen turbine awards in FY21/22
- University Turbines Systems Research — Focus on Hydrogen Fuels – made 6 awards in late FY21
- FEED studies on repurposing existing facilities for clean hydrogen production – 21st Century Power Plants
- Started programs on Methane Mitigation and Repurposing Fossil Assets to lower carbon intensity and costs of clean hydrogen production with carbon-based feedstocks

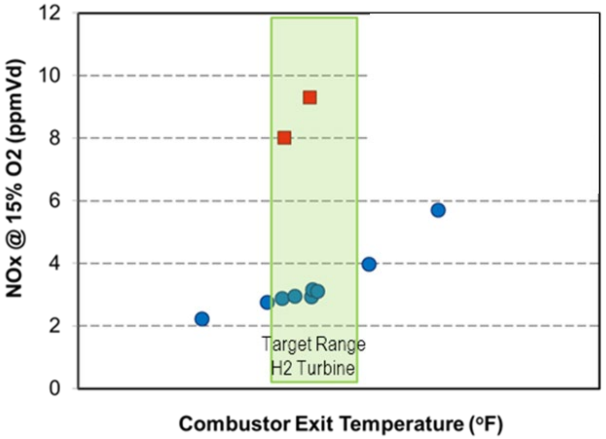
FECM Funding and Key Hydrogen Activities

Advanced Turbines Program

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 emissions that have been demonstrated for full scale combustor geometries.





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 *

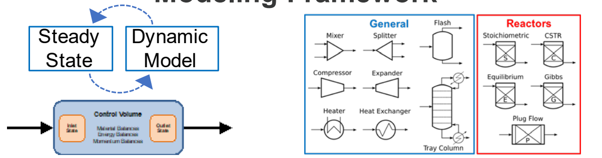
FY2022 Hydrogen Related R&D Investments

- **Hydrogen with Carbon Management:**
  - Solid Oxide Fuel Cells – materials, components, systems, reversible SOFC at utility scale;
  - Turbines – 100% H_2 firing, retrofit systems;
  - Gasification and reforming technologies
  - Materials for hydrogen turbines – CMCs
- **Point Source Carbon Capture:** Pre- and Post-combustion capture (gasification/reforming and industrial decarb.)
- **Crosscutting R&D:**
  - Energy Storage – large scale materials-based and H_2 storage, grid-scale energy storage;
  - Simulation Based Engineering /Integrated Energy Systems – Modeling and optimization tools for FE and FE-based and IES systems (IDAES)
- **21st Century Power Plants:** FEED studies for gasification-based carbon-negative power and hydrogen co-production

IDAES Integrated Platform

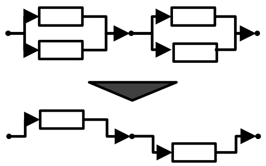
Institute for the Design of Advanced Energy Systems

Modeling Framework



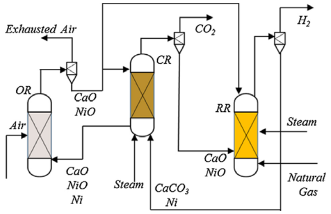
Hierarchical - Steady-State & Dynamic - Model Libraries

Conceptual Design



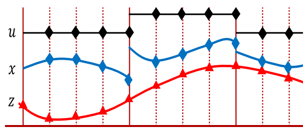
PYOMO GDP

Plant Design
Process Optimization

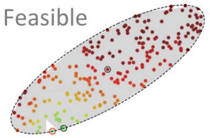


Process Operations
Dynamics & Control

caprese



Uncertainty Quantification
Robust Optimization

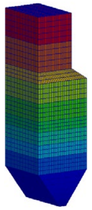


PyROS

AI/ML
Surrogate Modeling

ALAMO a black-box modeling tool

PySMO



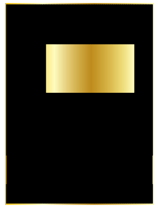
Enterprise Optimization
Grid & Planning

Materials
Optimization

MatOpt Nanomaterials optimization

Open Source: https://github.com/IDAES/idaes-pse

Lee, et al., *J. of Adv. Manufacturing and Processing* (2021)



NATIONAL ENERGY TECHNOLOGY LABORATORY | BERKELEY LAB | Sandia National Laboratories | Carnegie Mellon | West Virginia University | UNIVERSITY OF NOTRE DAME | Georgia Tech

PYOMO

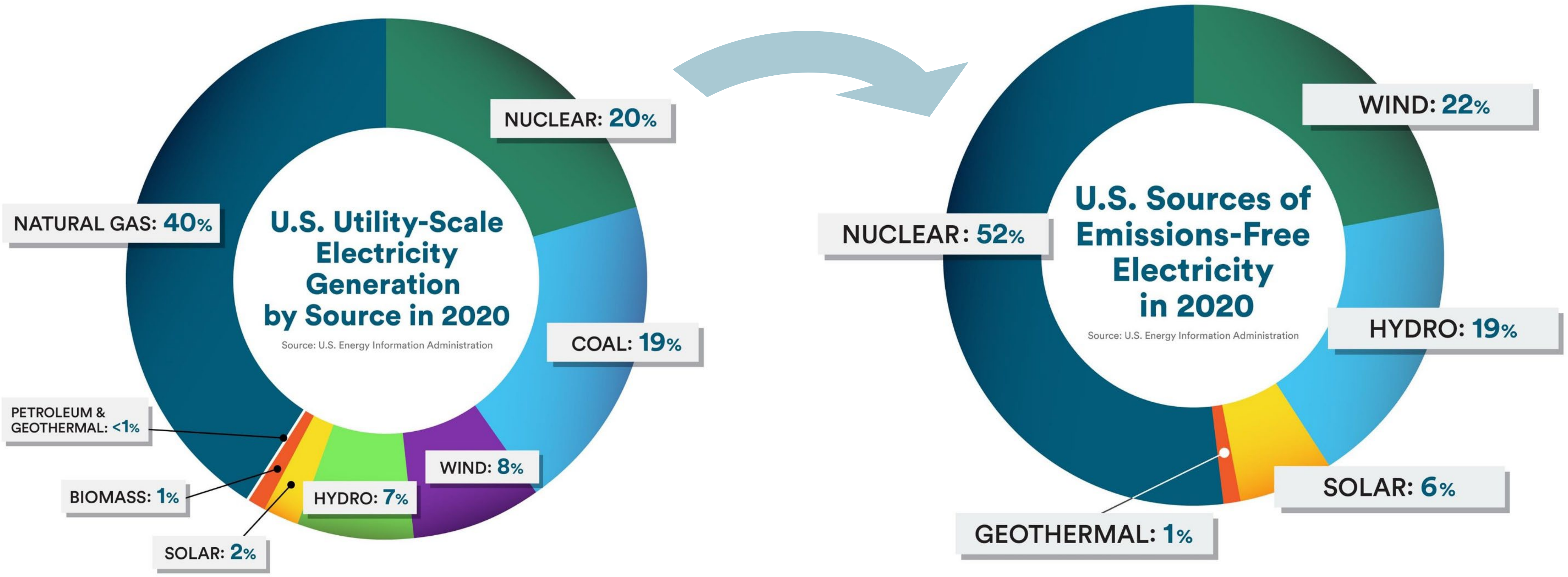
IDAES Institute for the Design of Advanced Energy Systems | python™

Gurobi	CPLEX	Xpress	CBC	Ipopt
GAMS	NEOS	Mosek	BARON	GLPK

Office of Nuclear Energy (NE)

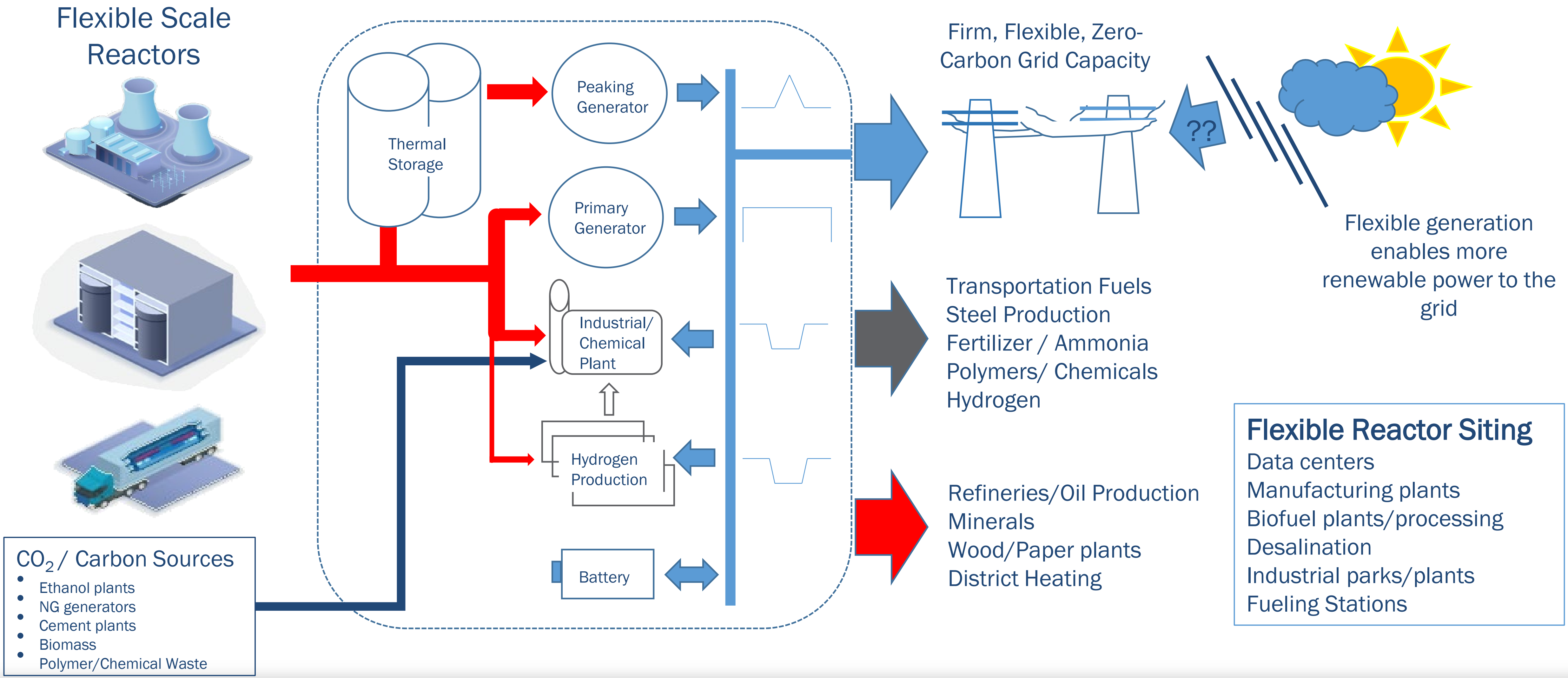
Jason Marcinkoski, Program Manager

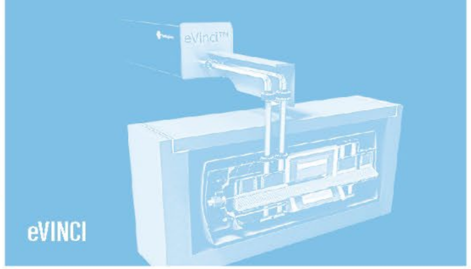
Nuclear: Crucial for Clean Energy Mix

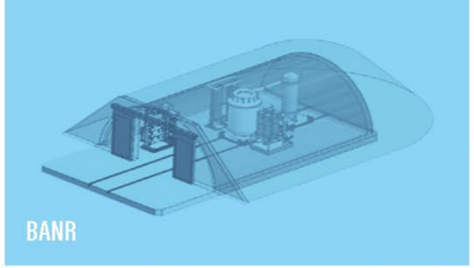


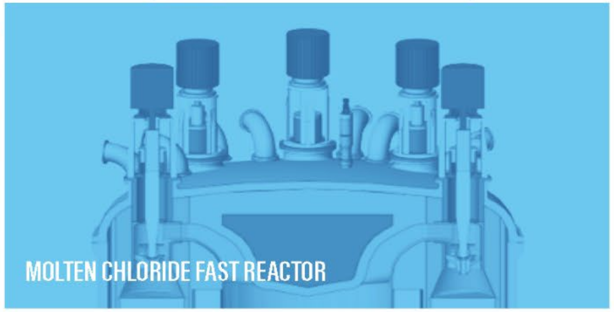
Source: U.S. Energy Information Administration

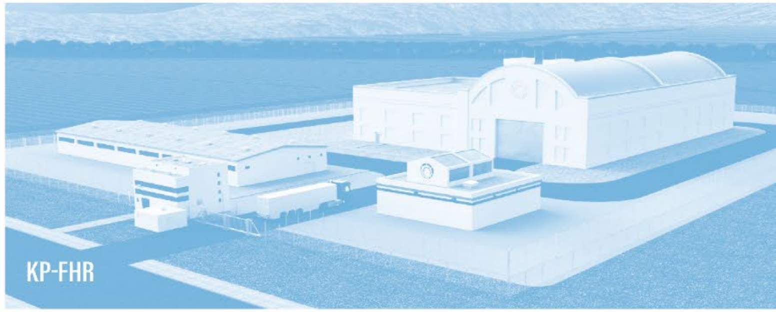
Nuclear Integrated Energy System Concept





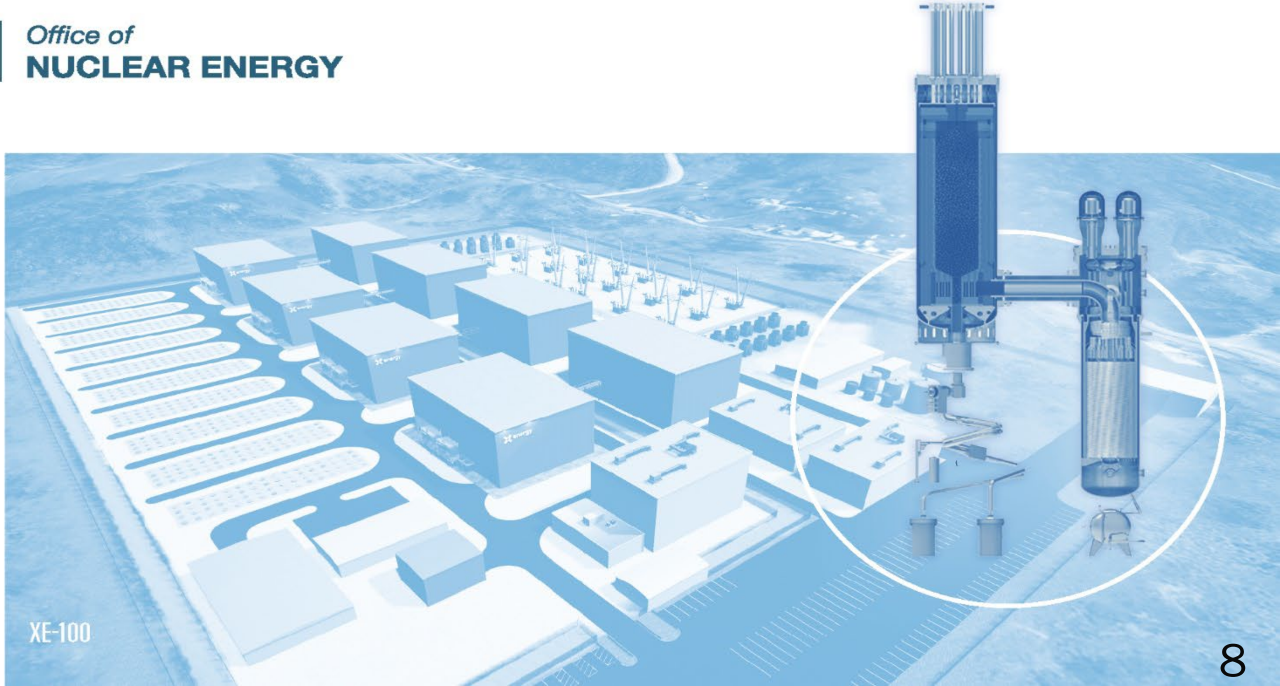






ADVANCED NUCLEAR TECHNOLOGY

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY



Nuclear-H_2 production demonstration projects

- **Constellation (Exelon): Nine-Mile Point NPP**
  - 1 MWe Low Temperature Electrolysis (LTE)
  - Using "house load" power
  - H_2 production beginning ~October 2022

- **Energy Harbor: Davis-Besse NPP**
  - 1-2 MWe LTE
  - Power provided by completing plant upgrade with new switch gear at the plant transmission station
  - H_2 production beginning ~2023/24

- **Xcel Energy: Prairie Island NPP**
  - 150 kWe High Temperature Electrolysis (HTE)
  - Engineering planned for tie into plant thermal line
  - H_2 production beginning ~Q1 2024

- **APS/PNW Hydrogen: Palo Verde Generating Station**
  - 15-20 MWe LTE H2 production, ~6-8 tons H2/day
  - H_2 storage + H_2 to gas peaking turbines (50%), syngas pilot
  - H_2 production expected 2024 (Award still under negotiation)

Nine Mile Point Nuclear Power Plant

Davis-Besse Nuclear Power Plant

Prairie Island Nuclear Power Plant

Palo Verde Generating Station

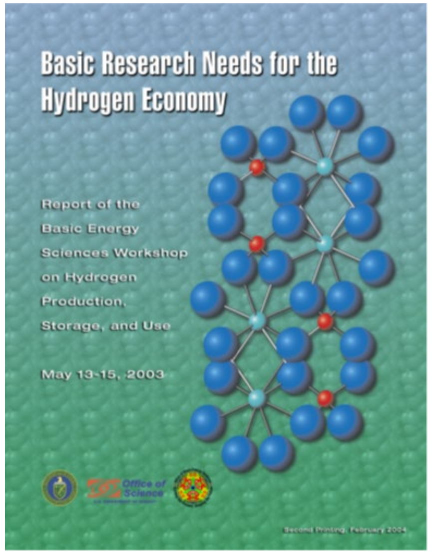
In collaboration with HFTO, EERE

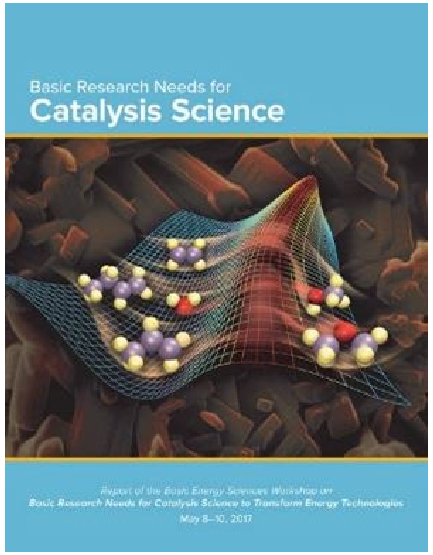
Hydrogen Research in Basic Energy Sciences (SC)

John Vetrano, Technology Coordination Program Manager

Hydrogen and Fuel Cell Underpinning Science in SC-BES

- Fundamental chemical and materials sciences research to advance understanding and transformative approaches for hydrogen generation and use
- Research topics include
  - **Discover, design, and synthesize advanced materials** including catalysts for chemical conversions, membranes for separation, purification and ion transport, photoelectrodes for solar hydrogen production, and novel materials for hydrogen storage.
  - **Understand chemical and biochemical mechanisms, leading to their design and control,** for efficient and selective chemical and biochemical processes such as reactions, separations, ion/molecular transport, molecular update/release.
  - **Advance experimental and computational tools, including AI/ML,** to accelerate discovery and increase understanding of fundamental chemical, materials, and biological processes.
- Annual solicitations applicable for basic research in these areas include the "open" annual SC FOA. FOAs focused on special topics (e.g., Energy Frontier Research Centers, etc.) can also be relevant to hydrogen research.
- At the core of SC-BES strategic planning are reports from "Basic Research Needs" workshops and roundtables (e.g., 2003 Hydrogen Economy; 2017 Catalysis Science; 2019 Liquid Solar Fuels). In 2021, SC-BES held a hydrogen-focused roundtable to explore new science opportunities to advance hydrogen technologies.
- Two BES-sponsored presentations Wednesday at 3:30 in the Interagency Session





Priority Research Opportunities to Advance Foundational Science for Carbon-Neutral Hydrogen Technologies

Discover and Control Materials and Chemical Processes to Revolutionize Electrolysis Systems

- How do we co-design multiple components that work together to enable stable, efficient electrolysis for the carbon-free production of hydrogen from water?

Manipulate Hydrogen Interactions to Harness the Full Potential of Hydrogen as an Energy Carrier

- How do we acquire fundamental insights across the entire range of energies to allow selective tuning of hydrogen interactions with molecules and materials?

Elucidate the Structure, Evolution, and Chemistry of Complex Interfaces for Energy and Atom Efficiency

- How can co-existing and evolving interfaces be tailored at multiple length scales to achieve energy-efficient, selective processes and enable carbon-neutral hydrogen technologies?

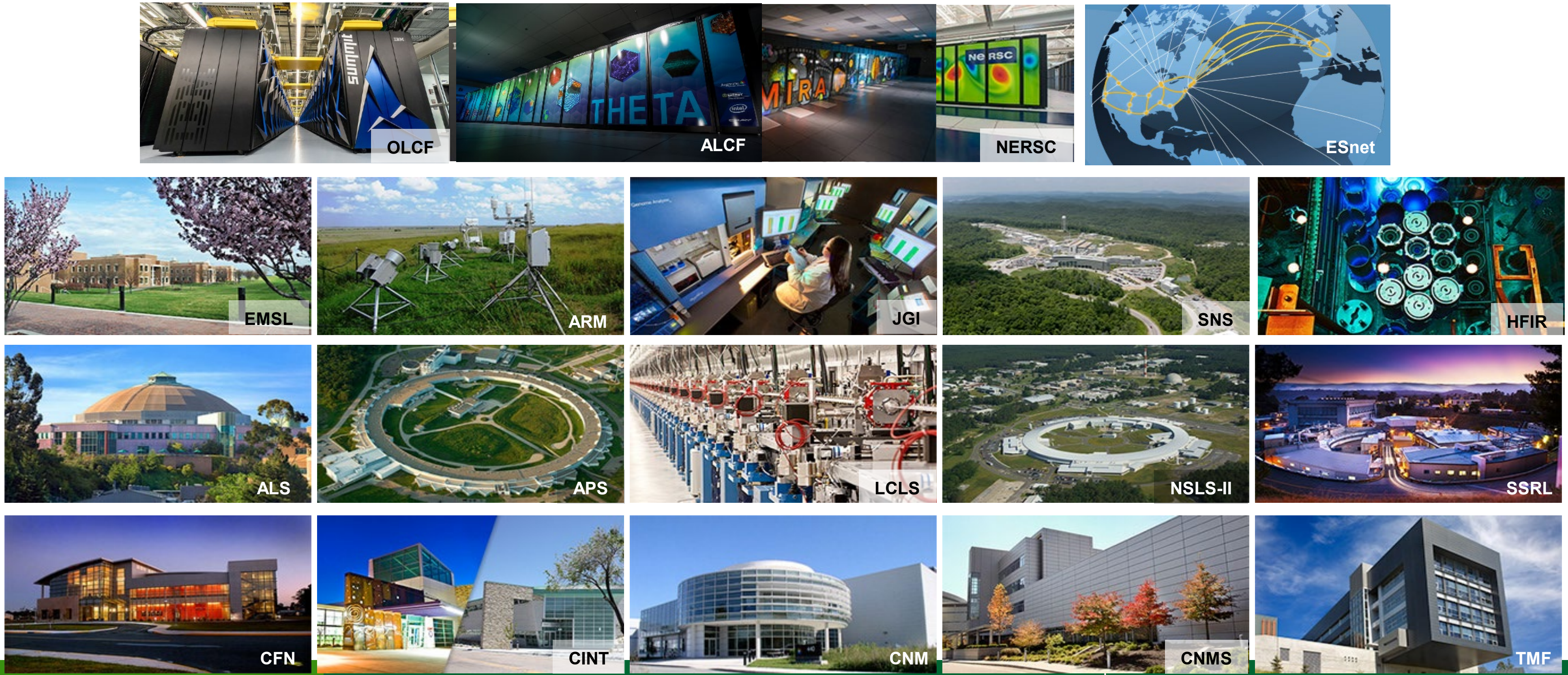
Understand and Limit Degradation Processes to Enhance the Durability of Hydrogen Systems

- How do we identify and understand the complex mechanisms of degradation to obtain foundational knowledge that enables the predictive design of robust hydrogen systems?

Roundtable Brochure published on BES website on Hydrogen Day (10-08-2021); Report, Brochure & Technology Status Document available at: https://science.osti.gov/bes/Community-Resources/Reports

SC User Facilities Have Important Roles in Hydrogen Research

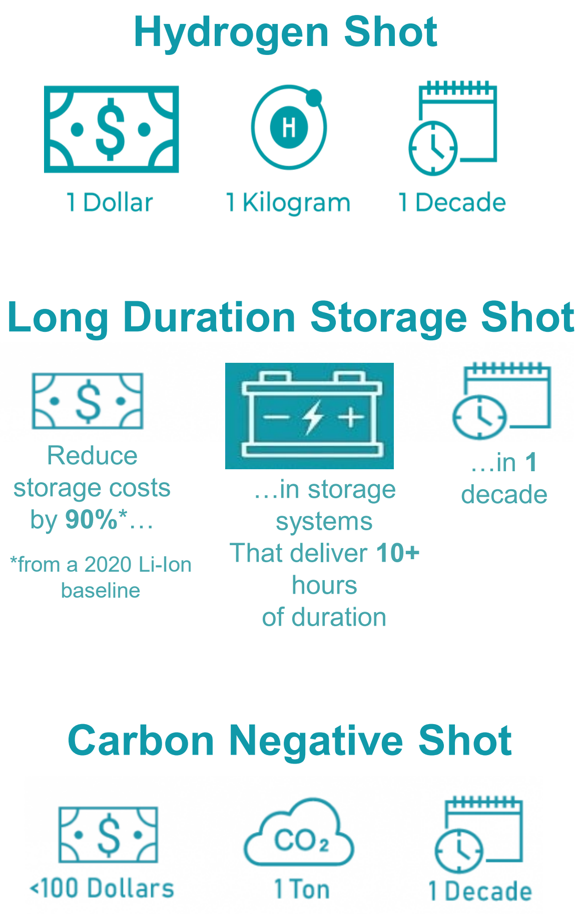
- Advanced Scientific Computing Research leadership class computers cross many disciplines to accelerate transformative progress
- Biological and Environmental Research user facilities bring bioanalytical instrumentation, genomic sequencing, and systems biology tools for innovative approaches for biological hydrogen generation
- Basic Energy Sciences light, neutron, and nanoscience facilities provide advanced synthesis and characterization to enable next-generation energy technologies



Strong collaboration between SC-BES User facilities and hydrogen-related consortia have resulted in joint publications in high-impact, peer reviewed journals.

FY 2023 SC Energy Earthshot Initiative (+$104M)

- Addresses key research challenges at the interface between basic research and applied research and development activities to bridge the R&D gap and realize the stretch goals of the DOE Energy Earthshots
- BES, with other SC Offices, will initiate a new research modality of Energy Earthshot Research Centers (EERCs)
  - Modeled on the Energy Frontier Research Centers, BES will support large teams that are multi-investigator, multi-disciplinary, and multi-institution (academic, national laboratory, industrial) to advance foundational knowledge and enabling capabilities in experimental and computational chemical and materials sciences **to address Energy Earthshot goals**
  - BES will coordinate closely with the Energy Technology Offices and existing research consortia/demonstration projects, to establish teams that span the R&D continuum and accelerate both science and technologies – providing a strong bridge between BES and technology research
- BES will complement EERCs with small group awards
  - Focus on use-inspired fundamental research to address knowledge gaps that limit achievement **of the Energy Earthshot goals**



Hydrogen Activities in Office of Clean Energy Demonstrations (OCED)

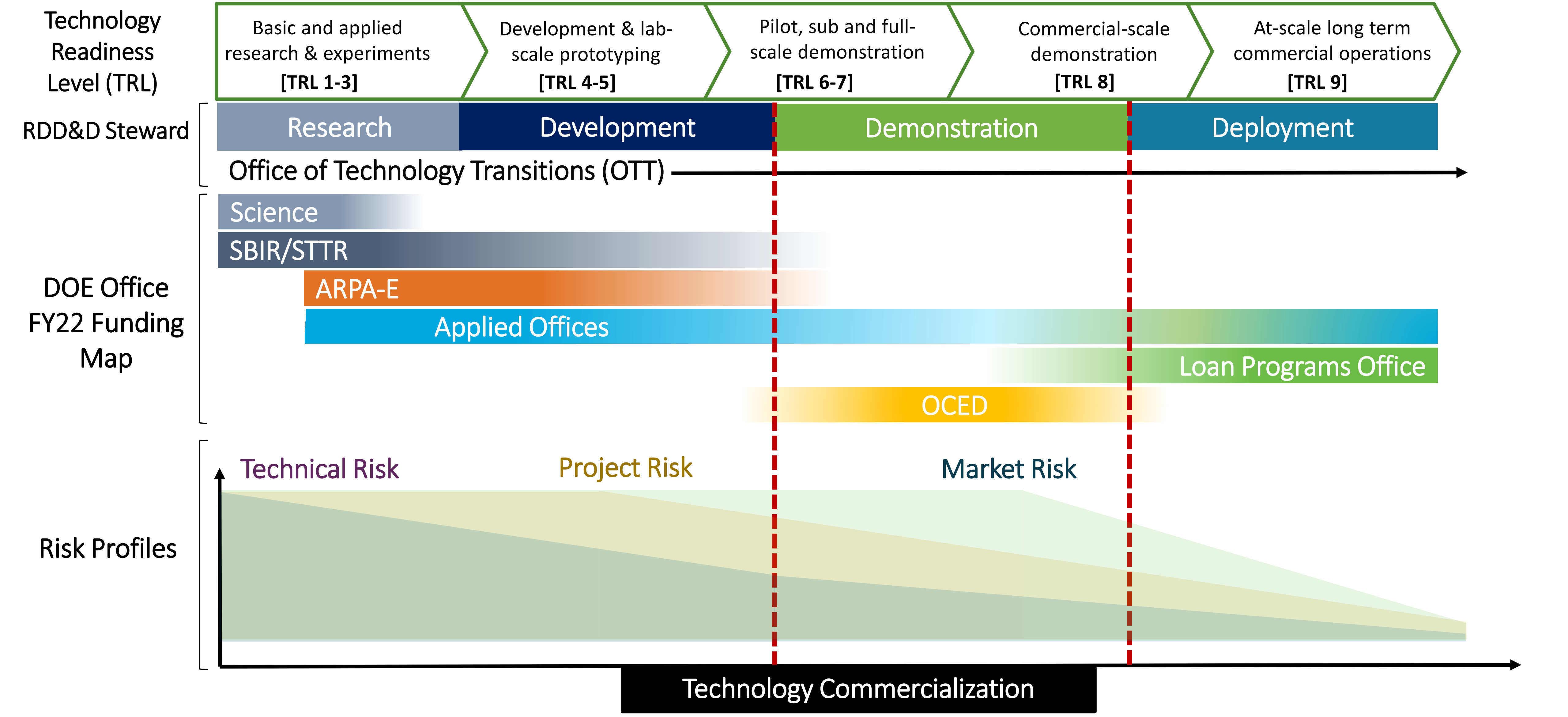
Todd Shrader, Deputy Director for Project Management

OCED Mission and Key Tenets

- **Mission:**
  - Deliver clean energy demonstration projects at scale in partnership with the private sector to launch or accelerate market adoption and deployment of technologies
  - Support the equitable transition to carbon-free electricity by 2035 and a net-zero economy by 2050

- **Key Tenets of Federally-Supported Demonstration Projects:**
  - Are a pathway to technical and commercial risk reduction and learning to make projects commercially viable by addressing technology challenges and driving down cost curves
  - Must target relevant operational environments, scales, and timeframes to validate the performance, cost, and value
  - Should enable downstream market adoption and deployment to accelerate scale-up leading to greenhouse gas reductions, job creation, and achieving environmental justice priorities
  - Involve substantial risk and the known and unknown risks factors will impact project outcomes

OCED Role Across Research, Development, Demonstration & Deployment (RDD&D) Continuum



Scope of OCED in the Bipartisan Infrastructure Law

- Regional Clean Hydrogen Hubs ($8 billion)
- Carbon Capture Demonstrations ($2.5 billion)
- Carbon Capture Large-Scale Pilot Projects ($937 million)
- Industrial Emissions Demonstrations ($500 million)
- Clean Energy Demonstrations on Mine Lands ($500 million)
- Energy Improvement in Rural and Remote Areas ($1 billion)
- Energy Storage Demonstration and Pilot Grants ($355 million)
- Long Duration Demonstration Initiative and Joint Program ($150 million)
- Upgrading Grids Demonstrations ($5 billion)
- Advanced Reactor Demonstrations ($2.5 billion)

For More Information

Website: https://www.energy.gov/office-clean-energy-demonstrations

Email: dl-oced-engagement@hq.doe.gov

Thank you!

More info on the DOE Hydrogen Program:

www.hydrogen.energy.gov

Additional Information

ARPA-E Hydrogen and Fuel Cells Activities

For more details see ARPA-E Summit, May 2022
https://www.arpae-summit.com/

How ARPA-E starts and manages programs