From Hydrogen Shot to Hydrogen Hubs

*Moderated by Eric L. Miller, HFTO Chief Scientist*

Hydrogen Program Annual Merit Review and Peer Evaluation Meeting, June 5, 2023, Arlington VA
Exciting Times for Hydrogen!
U.S. DOE Hydrogen Program – All-Hands-on-Deck!

Hydrogen is one part of a broad portfolio of activities. Includes multiple offices and the entire RDD&D value chain from production through end use.

Strategies:

1. Target strategic, high-impact end uses
   - Achieve 10 MMT/year of clean hydrogen by 2030

2. Reduce the cost of clean hydrogen
   - Enable $2/kg by electrolysis by 2026 and $1/kg H₂ by 2031

3. Focus on regional networks
   - Deploy regional clean hydrogen hubs and ramp up scale

Vision:
Affordable clean hydrogen for a net-zero carbon future and a sustainable, resilient, and equitable economy.

Benefits:
Emissions reduction; job growth; energy security and resilience.

Enablers:
- Good Jobs and Workforce Development
- Safety, codes and standards
- Policies and incentives
- Stimulating private sector investment
- Energy and environmental justice

www.hydrogen.energy.gov

Coordinated across Offices by DOE Hydrogen and Fuel Cell Technologies Office (HFTO)
Distinguished Panelists

Devinn Lambert
Deputy Director
Crosscuts & Energy Earthshots
Office of the Under Secretary of Science & Innovation

John Vetrano
Program Manager
Office of Basic Energy Sciences
SC

Katie Randolph
Operations Supervisor
Hydrogen & Fuel Cell Technologies Office
EERE

Mark Ackiewicz
Director
Office of Carbon Management Technologies
FECM

Alison Hahn
Director
Office of Nuclear Reactor Deployment
NE
Comprehensive Strategic Approach Spanning RDD&D

Foundational and crosscutting efforts support the entire lifecycle of activities at DOE, from basic research through large-scale deployment.
Hydrogen Energy Earthshot

“Hydrogen Shot”

“1 1 1”
$1 for 1 kg clean hydrogen in 1 decade

Launched June 7, 2021
Summit Aug 31-Sept 1, 2021
The Energy Earthshots are designed to drive integrated program development across the U.S. Department of Energy's science and applied energy offices and ARPA-E and take an all-hands-on-deck approach to leading science and technology innovations to address tough technological challenges and cost hurdles, and rapidly advance solutions to help achieve our climate and economic competitiveness goals.

- Make a major impact to reduce emissions
- Address the hardest technology barriers
- Set highly ambitious decadal targets
- Are compelling, bold, and inspirational
- Significantly engage stakeholders
Strategic Alignment: Feedback loop

1. An Energy Earthshot focuses “All-hands” attention on a singular target
2. Scientific and strategic learnings, guides “All-hands”

Office of Science  Applied Energy Offices  Infrastructure Offices

Resources aligned
Informed with strategic planning
Stakeholders engaged

1 Dollar  1 Kilogram  1 Decade
Strategic Alignment: What “All-Hands” looks like from the street

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<td>BES Roundtable Foundational Science for Carbon-Neutral Hydrogen Technologies</td>
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<td>PI Meetings</td>
<td>Hydrogen from Next-generation Electrolyzers of Water Workshop</td>
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Snapshot of work:
June 21 - March 23

Decisive & Creative: Hydrogen Shot Fellowship
SC Mission:

Delivery of scientific discoveries and major scientific tools to transform our understanding of nature and advance the energy, economic, and national security of the United States.

- More than 29,000 Researchers supported at more than 300 Institutions and 17 DOE Labs
- Steward 10 of the 17 DOE National labs
- More than 37,000 Users of 28 SC Scientific Facilities
- $8.1B (FY 23 enacted)
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.
Priority Research Opportunities:

• Discover and Control Materials and Chemical Processes to Revolutionize Electrolysis Systems

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

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

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

FY 2024 Request: SC Energy Earthshots Initiative

• Funding for the SC Energy Earthshots Initiative started in FY 2023 with $100M

• Joint initiative between BES, ASCR, and BER to address key research challenges at the interface between basic research and applied R&D to realize DOE Energy Earthshots stretch goals.

• Two complementary programs:
  
  – Energy Earthshot Research Centers (EERCs): Multi-disciplinary, multi-institutional teams led by DOE laboratories focused on key research challenges at the interface of basic and applied R&D.

  – Scientific Foundations for Energy Earthshots: Small group awards led by academic or private sector institutions focused on use-inspired foundational science addressing knowledge gaps limiting achievement of Earthshot goals.

https://www.energy.gov/policy/energy-earthshots-initiative
EERE’s MISSION is to accelerate the research, development, demonstration, and deployment of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions economy-wide by no later than 2050, and ensure the clean energy economy benefits all Americans, creating good paying jobs for the American people—especially workers and communities impacted by the energy transition and those historically underserved by the energy system and overburdened by pollution.
EERE Clean Hydrogen Mission & Portfolio

**Feedstocks:**
- Renewable Energy and Water

**Technologies**
- Electrolysis: Low- and High-Temperature
- Advanced Water Splitting: Photo-electrochemical, Solar/High-T Thermochemical
- Biological Approaches

**Production, Storage, Delivery, Conversion, and End-Use RD&D; Emphasis on Renewable Integration**

**Example Activities**
- Hydrogen & Fuel Cell Technology RD&D
- Wind Hybrid Systems
- Solar Fuels Production
- Bio-fuels and Products
- Offshore Energy Harvesting
- Geological Hydrogen
- Manufacturing & Industrial Decarbonization

**Today**
- $4-6/kg clean H₂ scenarios*

**2026**
- BIL target: $2/kg clean H₂

**2031**
- H₂ Shot target: $1/kg clean H₂

*across multiple renewable energy scenarios
Integrated Consortia Approach – Water-Splitting Example

H2NEW Consortium
- Addressing performance/durability barriers through components & integration
- Enabling high-volume production of MW-scale electrolyzers & components

HydroGEN Consortium
- Accelerating foundational R&D of innovative materials for AWS technologies
- Fosters cross-cutting innovation using theory-guided applied materials R&D
Focus on Renewable Integration - Examples

- Solar water splitting using liquid metal RedOx cycles promoted by electrochemistry – *with SETO*
  - SETO003

- Wind to hydrogen RD&D, including offshore wind – *with WETO, HFTO*
  - WETO001

- Hydropower-Based H₂ Production Analysis – *with WPTO*
  - WPTO001
FECM’s Strategic Vision will enable DOE to make strategic carbon management decisions to ensure that fossil fuel usage is put into proper context with climate change and is designed for a future that achieves and maintains net-zero greenhouse gas emissions.
Pre-Commercial... H₂ Generation (TRL 6+)

Advanced CCS Systems for SMR

- Svante VeloxoTherm™ solid adsorbent at Linde SMR H₂ plant
- ~1,100,000 tonnes/year net CO₂ capture
- 90% Capture Efficiency
- Production of lower carbon H₂ with 99.97% purity

Advanced CCUS + for ATR

- Separate & store ~190,000 tons/year net CO₂ from hydrogen production unit with >90% carbon capture efficiency
- Separate and store 1.66 million tonnes/year of 95% pure CO₂ with >97% carbon capture efficiency
- System combining carbon capture, H₂ production (220 MMSCFD at 99.97% purity), and H₂ combustion in auxiliary burners
Current Status

• Subsurface hydrogen storage is domestically limited to salt cavern storage facilities.
• Expanding the footprint for subsurface storage to different geologies and geographies.

Goals & Objectives

• Identify and address key technological hurdles
• Develop tools and technologies
• Subsurface geologic characterization efforts to demonstrate storage permanence and risk management.
• Determine viability, safety, and reliability
Nuclear Integrated Energy System Concept

Flexible Reactor Siting
Data Centers
Manufacturing Plants
Biofuel Plants / Processing
Desalination
Industrial Parks / Plants
Fueling Stations

CO2 / Carbon Sources
Ethanol Plants
Direct Air Capture
Power Generators
Cement Plants
Biomass
Polymer / Chemical Waste

IntraAg: Thurs. AM

Grid Capacity
Firm, Flexible, Zero Carbon

Transportation Fuels
Steel Production
Fertilizer / Ammonia
Polymers / Chemicals
Hydrogen

Refineries / Oil Production
Minerals
Wood / Paper Plants
District Heating
Joint NE - EERE path to Earthshot Goal of $1/kg-H₂

- **HFTO R&D improves electrolysis performance and durability**
- **NE reduces cost of power production**
- **Production Tax Credit incentivizes early adoption**
- **Early adoption helps reach achieve high volume manufacturing**
Pilot Plant Hydrogen Production Demonstration Projects

Constellation: Nine-Mile Point Plant
- H₂ production began March 2023
- NEL Hydrogen Proton Electrolyte Membrane electrolysis module

Energy Harbor: Davis-Besse Plant
- H₂ production beginning in 2024
- 2 MWₑDC Cummins Proton Electrolyte Membrane electrolysis module

Xcel Energy: Prairie Island Plant
- H₂ production beginning in 2024
- Bloom Energy high temperature solid-oxide electrolysis module
From your perspective, what are key challenges and RD&D opportunities for meeting the clean hydrogen cost targets of $2/kg (2026) and $1/kg (Hydrogen Shot)?
Advanced Research Projects Agency – Energy: Overview

Rising Above the Gathering Storm Published - warning policymakers that U.S. advantages in science and technology had begun to erode

America COMPETES Act Signed – authorizing the creation of ARPA-E

American Recovery & Reinvestment Act Signed – Providing ARPA-E its first appropriations of $400 million, which funded ARPA-E’s first projects

2007

Resilient energy infrastructure for the 21st century

2009

Affordable, sustainable energy for all

2023

U.S. economic development

American leadership in science and technology

1,468+ Awards
69+ Programs

Current Funding: $470M (FY23)
Creating New Learning Curves – High Risk, High Reward
ARPA-E Creates a Mountain Of Opportunity for Energy Technology

Supports previously funded ARPA-E technologies to commercial viability

- Enables further technology de-risking of pre-production prototypes
- Encourages small business, company, and industry participation

**SCALEUP 2019**
10 Awardees - $70+ million

**SCALEUP 2021**
8 Awardees - $100 million
CH$_4$ $\rightarrow$ 2 H$_2$ + C (s), lowering the cost of H$_2$ production while producing high value carbon

Methane Pyrolysis – Opportunity for Two Valuable Products

8 projects
$21M$ in federal funding
High Efficiency in Transportation

**Climate-Friendly Commercial Aviation**

**Energy Carrier**
- EVS4ALL
- ESS1K
- Power2Fuel
- BioCrops

**Efficiency**
- Electric Power
- Shaft Power

**Operations**
- NextCAR
- InterModal

REEACH: High efficiency aviation energy systems powered with carbon neutral fuel: SAF, NH₃, H₂
Geologic H₂ – Stimulating a New Primary Energy Source

The Opportunity is MASSIVE

150 trillion tonnes of hydrogen potential under our feet

1 trillion (0.7%)
Would power US economy for 1,000 years

Dr. Doug Wicks
Program Director

What's ARPA-E's involvement?:
Seeding a geologic H₂ technology ecosystem that enables low GHG H₂ at...

...<$1/kg

Everything Up to the Well Head
• Exploration
• Stimulation
• Subsurface Engineering
OTT OVERVIEW

OTT’s Mission
“to expand the commercial impact of the research investments of the Department” & to drive private sector uptake of clean energy technologies

Steward commercialization across the DOE
OTT HIGHLIGHTS

Liftoff Reports
- 4 reports live – including Clean Hydrogen
- 60+ external interviews
- 2000+ comments
- 30+ working group members across DOE + National Labs

Technology Commercialization Fund
- Base Annual Appropriated: OTT-led CLIMBR
- BIL: CACTI Lab Call (H2 topic), MAKE IT prize (soon), MRV lab call (selections announced!)

Lab Partnering Service

Adoption Readiness Levels
Secretary Jennifer Granholm: This effort will "help drive engagement between government and industry to unlock exciting new opportunities and ensure America is the global leader in the next generation of clean energy technologies."

Robinson Meyer: "The most detailed guide yet to how the Biden administration plans to conduct industrial policy for the most advanced — and the most fledgling — energy technologies in its arsenal."

From Politico’s EnergyWire: “Developed in part for private investors, the three reports lay out the chief barriers for the three technologies along with possible solutions and rough timelines for their emergence in the 2020s and beyond.”

We will continue a steady drumbeat of communications highlighting key insights from reports already released, announcing the release of new reports, and through industry events.
Currently released on liftoff.energy.gov:

- **Clean Hydrogen**
- Long Duration Energy Storage (LDES)
- Advanced Nuclear
- Carbon Management

What’s next:

- **Industrial decarbonization:**
  - Cross-cutting report (Pulp/Paper, Glass, Steel, Food/Bev)
  - Chemicals & Refining
  - Cement

- Grid (VPPs, other topics)

- Other topics TBC
Liftoff Reports Evaluate the Path to Near-term Deployment - Including How Entire Clean Energy Value Chains Will Emerge

2030 costs across the value chain if advances in distribution and storage technology are commercialized

Upstream: Hydrogen production

- Reformation-based production
  - w/ $0.75/kg PTC: LCOH = $0.4-0.85/kg

- CO2 transport/sequestration

Water electrolysis
  - w/ $3/kg PTC: LCOH < $0.4/kg

Midstream: Hydrogen distribution and storage assuming state-of-art technology at scale

- Commercialized, best-in-class gas compression
  - $0.2-0.4/kg at 500 bar, 10 tpd (tank storage, truck distribution)
  - $0.1/kg at 80-120 bar, 50+ tpd (pipeline, co-located electrolysis)

- Water electrolysis
  - $2.7/kg at 50 tpd

- Liquefaction

- Liquid hydrogen storage
  - $0.2/kg at 7 days, 50 tpd scale
  - $0.1/kg at 80 bar for 7 days, 600 tpd

- Compressed gas tank storage
  - $0.8/kg at 500 bar for 7 days

- Salt cavern storage

- Gas phase trucking

- Liquid hydrogen trucking

- H2 pipeline

- LCOH = $0.4-0.85/kg

Downstream: End use applications

End use willingness to pay

- Ammonia: $0.9-2.3/kg
- Refining: $1-1.3/kg
- Steel: $1.25-2.3/kg
- Chemicals: $0.9-2.3/kg
- NG blending: $0.4-0.5/kg
- Industrial heat: $0.7-1.5/kg
- Power gen. (high-capacity firm): $1.25-2.3/kg
- Aviation and maritime fuels: $0.4-0.5/kg
- HDMD road transport: $0.7-3/kg
- Next generation fuel dispensing at high utilization: $4-5/kg

1. See appendix for calculation details
2. Data based on cost-downs shared from leading-edge companies who have deployed at demonstration scale (or larger)
3. Range based on varying renewables costs and electrolyzer sizes/technologies
4. Defined as the price an off-taker will pay for clean hydrogen
5. Represents delivery of hydrogen to aviation and maritime fuel production facilities
6. Greater than or equal to 70% utilization, assumes line fill at high pressure

Sources: HDSAM, Argonne National Laboratory; DOE National Hydrogen Strategy and Roadmap, Hydrogen Council

Readers should sum (1) Upstream costs and (2) Midstream costs to arrive at a potential delivered cost of clean hydrogen, based on production pathway and storage/distribution method selected. Hydrogen production costs shown take an upper bound of production costs (~2MW (450 Nm3/h) PEM electrolyzer with 6/6.54 MW PTC credit applied) and the credit the PTC at point of use. A wider range of LCOH values, without the PTC credit applied, are described in Figures 11 and 12 in the Clean Hydrogen Liftoff Report.

U.S. DEPARTMENT OF ENERGY

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Building the Bridge to Bankability

Providing financing for technologies to go the last mile to reach full market acceptance
What LPO Offers Borrowers

The unique value of working with LPO for clean energy technology project financing

LPO loans and loan guarantees are differentiated in the clean energy debt capital marketplace in three primary ways:

- **Access to Patient Capital**
  that private lenders cannot or will not provide.

- **Flexible Financing**
  customized for the specific needs of individual borrowers.

- **Committed DOE Partnership**
  offering specialized expertise to borrowers for the lifetime of the project.
Innovative Clean Energy - 1703 ICE

Loan guarantees for the deployment of innovative energy projects at commercial scale

**Eligibility**

The Title 17 program can consider innovative clean energy projects that:

1. Use innovative technology.
2. Reduce, avoid, or sequester greenhouse gas emissions or air pollutants.
3. Are located in the U.S.
4. Provide reasonable prospect of repayment.

**Loan Guarantee Features**

- LPO can offer 100% guarantee of U.S. Treasury’s Federal Finance Bank (FFB) loans or partial guarantees of commercial loans.
- Senior secured debt priced competitively with commercial rates.
- DOE can serve as sole lender or as a co-lender.
- Structures may include project finance, structured corporate, corporate or warehousing lines.
Advanced Clean Energy Storage (ACES)

- Commercial scale-up of technology
- Bellwether project for the U.S. Hydrogen sector
- Reliable long duration (seasonal), grid-scale storage of excess renewable energy
Hydrogen Hubs

- Hydrogen Hubs funding will accelerate the U.S. clean hydrogen market through a focus on new sectors, increasing hydrogen production and reducing cost
- $8B allocated to the development of hubs
Vision: Hydrogen Hubs Liftoff

2023-2026
Focus on industrials/chemicals e.g., ammonia production and oil refining

2027-2034
Focus on economies of scale to reduce costs. Emphasis on adoption in new sectors, greater number of producers, offtakes, distribution and storage networks and support of Justice40.

2035+
Focus on a sustained commercial market of 10 MMTpa per year supporting 100% clean electricity goal

2050+
Successful transition to hydrogen demand of 50 MMTpa per year supporting net zero emissions goal
Hub’s Project Schedule

Phase 1:
Detailed Project Planning
Up to $20M
50% minimum cost share
12-18 months

Phase 2:
Project Development, Permitting and Financing
Up to 15% of total DOE funding
50% minimum cost share
2-3 years

Phase 3:
Installation Integration and Construction
50% minimum cost share
2-4 years

Phase 4:
Ramp Up and Sustained Operations
50% minimum cost share
2-4 years

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From your perspective, what are key challenges and priorities for achieving clean hydrogen commercial liftoff?
Special thanks to all our Panelists, & our Audience

- Have a Wonderful AMR!