

Systems Development & Integration Overview

Jesse Adams, HFTO – Systems Development & Integration Program Manager



2023 Annual Merit Review & Peer Evaluation Meeting

June 6, 2023 – Arlington, VA



The Hydrogen and Fuel Cell Technologies Office (HFTO)

Mission	<p>Support research, development and demonstration (RD&D) of hydrogen and fuel cell technologies to advance:</p> <ul style="list-style-type: none"> • Clean Energy and Emissions Reduction Across Sectors • Job Creation and a Sustainable and Equitable Energy Future
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Office Sub-Programs		
Hydrogen Technologies	Fuel Cell Technologies	Systems Development & Integration
<div style="background-color: #006633; color: white; padding: 5px; margin-bottom: 10px; text-align: center;">Hydrogen Production</div> <div style="background-color: #006633; color: white; padding: 5px; text-align: center;">Hydrogen Infrastructure</div> <div style="text-align: center; margin-top: 20px;">  </div>	<div style="text-align: center; margin-top: 20px;">  </div>	<p>Transportation</p> <p>Industrial and Chemical Applications</p> <p>Grid Energy Storage and Power Generation</p>
Data, Modeling, Analysis, Safety, Codes and Standards		

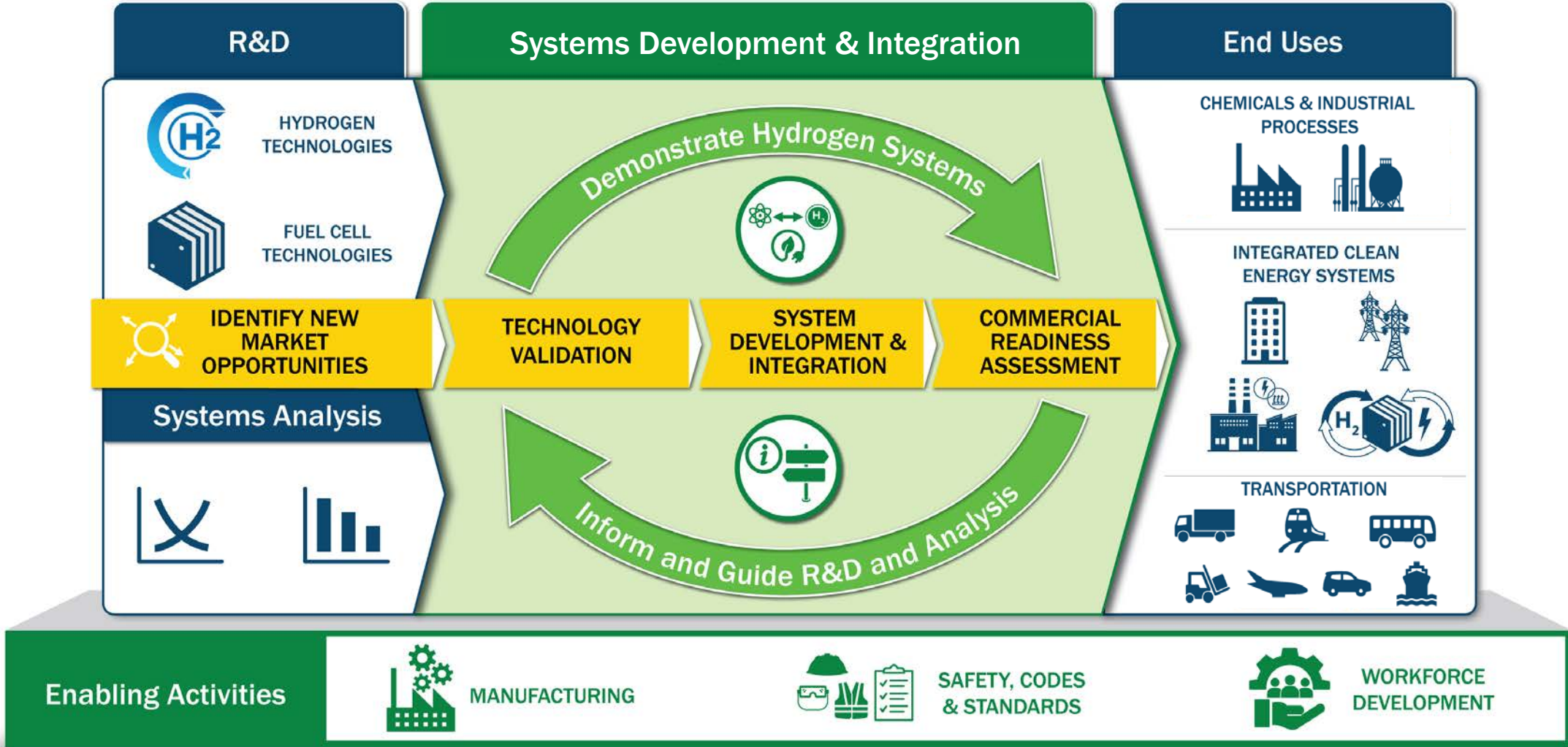






Enabling

Systems Development & Integration Overview



Bridging the Gap Between R&D and Deployments with First-of-a-Kind Integrated H₂ Demonstrations

Systems Development & Integration (SDI): Priorities

Current Focus Areas



- **Grid Energy Storage & Power Generation** including hybrid approaches

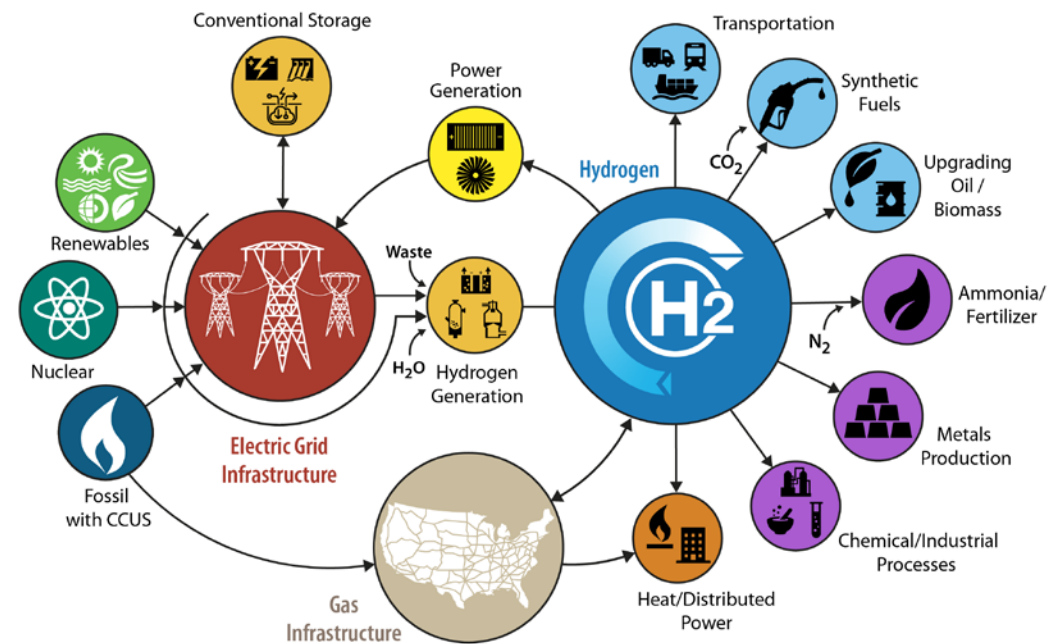


- **Chemical and Industrial Processes** integrating H₂ technologies focusing on decarbonization



- **Transportation & H₂** fueling demonstrations

Demonstrate H₂ & fuel cell integration to accelerate market adoption & reduce GHG emissions to enable H₂@Scale vision

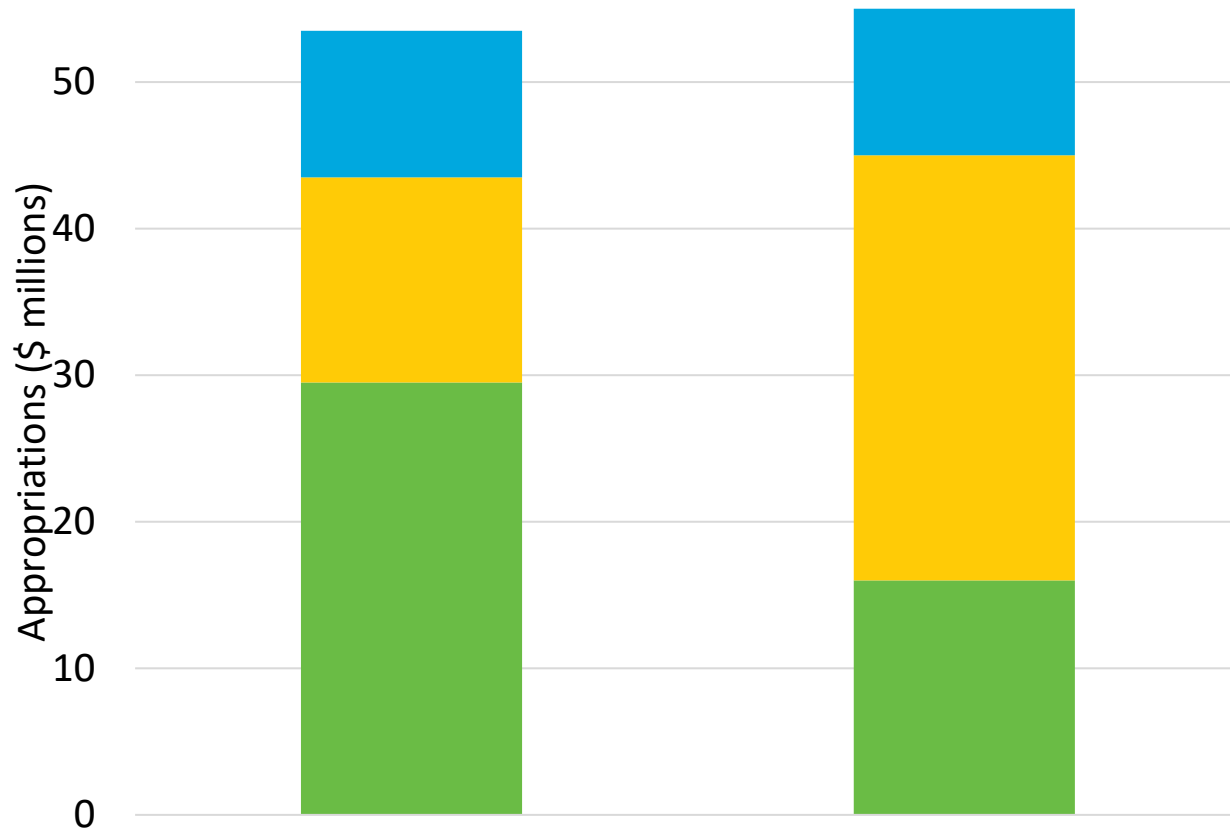


HFTO-SDI (TRL ~4-6) serves as **proving grounds for future deployments** (TRL ~6-8+) (i.e., OCED H2Hubs)

Systems Development & Integration: Budget

**FY22 Appropriations
\$53.5 million***

**FY23 Appropriations
\$55 million***



■ Industrial and Chemical Applications
■ Grid Energy Storage & Power Generation

■ Transportation

Program Direction

Systems Development & Integration Funding:

- Industrial & Chemical Applications
 - Steel (Iron ore reduction via H₂)
- Transportation
 - SuperTruck III & HD fueling
 - Fuel Cell System Testing
 - Fuel Cell Coach Bus
- Grid Energy Storage & Power Generation
 - Renewables / Nuclear to H₂
 - High Temperature Electrolyzer Validation
 - Micro-grids

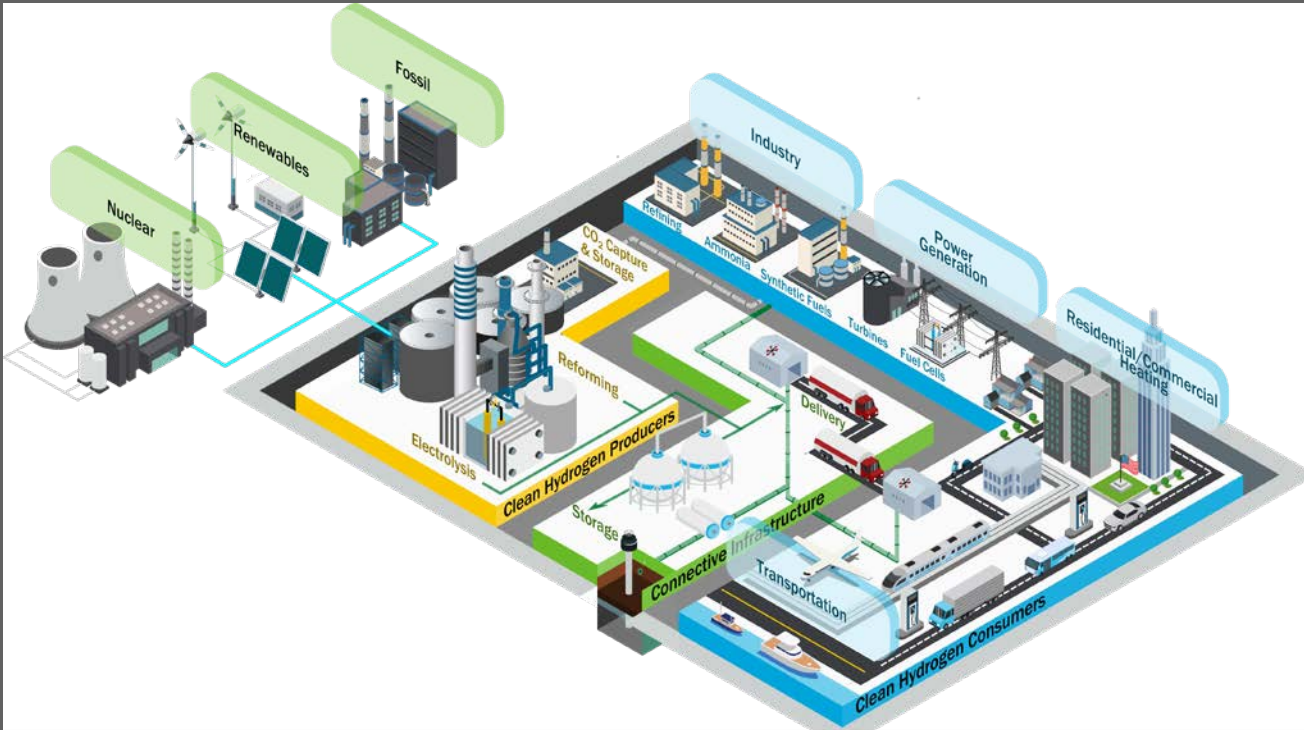
**FY24 Request
\$64 million**

Clean H2Hubs
\$8 billion over 5 years**

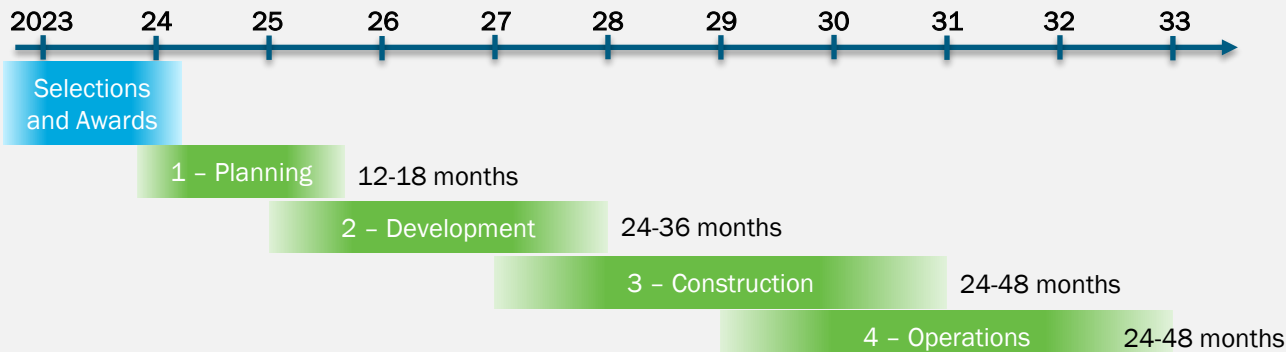
**Safety, Codes, & Standards Budget appropriations not shown here, but is included in SDI budget appropriations (\$10M FY22 & \$15M in FY23)*

***Funding through OCED, in collab with HFTO & all H2 programs*

Regional Clean Hydrogen Hubs – In Collaboration with OCED



H2Hubs Notional Timeline

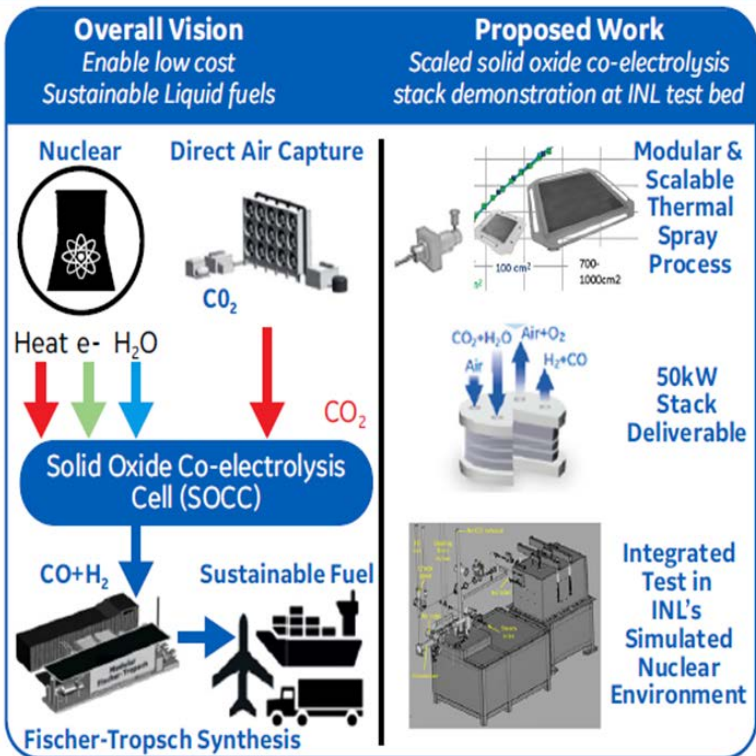


- Led by DOE’s Office of Clean Energy Demonstrations (OCED) in collaboration with HFTO & the DOE H₂ Program
- \$6-7B available under current FOA to develop 6-10 regional clean H₂Hubs across the country to create networks of H₂ producers, consumers, & local connective infrastructure to accelerate use of clean H₂
 - Feedstock diversity
 - End use diversity
 - Geographic diversity
 - Employment and training
- **Current Status**
 - FOA released in September 2022
 - Applicant Webinar held in January 2023
 - Full Applications submitted April 7, 2023
 - Merit Review in process
 - H₂Hub Selections in Fall 2023

SDI: Grid Energy Storage & Power Generation

New Nuclear-H2 Integration Projects – In Collaboration with NE

GE Research – Scaled Solid Oxide Co-Electrolysis for Low-Cost Syngas Synthesis from Nuclear Energy



Goals:

Complete engineering design/testing for production of synthetic jet fuel using nuclear energy from existing light water reactors & Solid Oxide Co-Electrolysis

- Complete TEA
- Manufacture of scaled solid oxide cells
- Integration & testing of 50kW stack at INL

Westinghouse – FEEDs for Integrating Commercial Electrolysis H₂ Production with Selected LWRs

Goals:

Complete Front-End Engineering Designs (FEEDs) development for nuclear-coupled SOEC H₂ production at specific U.S. LWR plants

- Designs will be developed for both pressurized water reactor (PWR) & boiling water reactor (BWR)
- Licensing impact assessments will be completed
- TEA & LCA for markets under consideration



Sub-Recipient/FFRDC



Utility Support



Industry Support



Academia Support



Potential Impact: Higher system efficiencies / lower cost through thermal integration of SOEC with nuclear plant

Expansion to Multi-MW Electrolyzer Stack and System Test Capabilities

Low-Temperature Electrolyzers – NREL (P207)

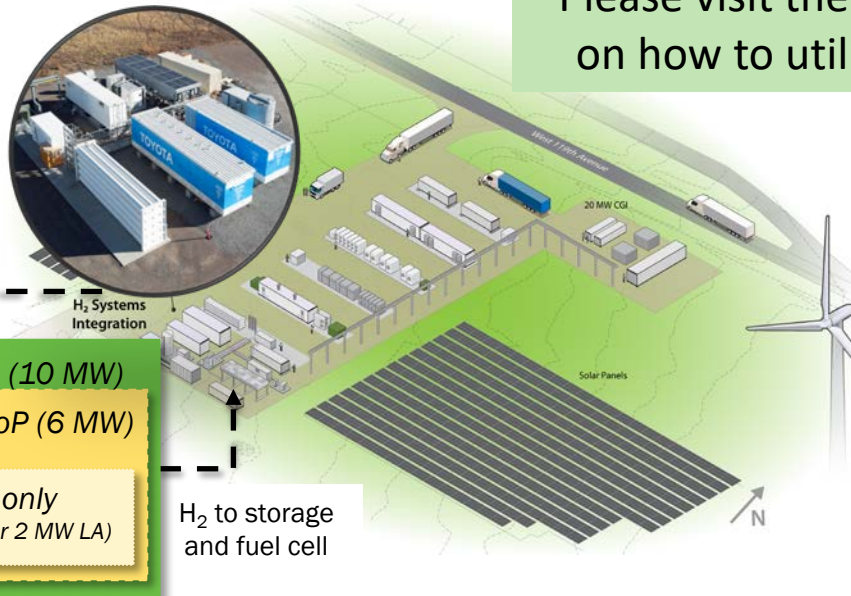
- Expansion of NREL’s Flatirons Campus ARIES capability to support industry
- Full LTE system testing up to 10 MW
- Parallel stack testing up to 6 MW in aggregate for PEM and/or LA
- Grid integration with renewable energy production and other ARIES assets

High-Temperature Electrolyzers – INL (SDI006)

- Development at INL’s Energy Technology Proving Ground
- Full, simultaneous HTE systems testing up to 10 MW in aggregate
- Simulated nuclear integration / future physical integration with advanced nuclear reactors

Please visit the posters for details on how to utilize these facilities

Coming online in 2026!



Coming online in 2024!

More than 10 Acres of Initial Testing Space Available



- 10 MW System Test Power
- Low and High Compression H2 Tanks
- H2 Multi-Stage Compression
- H2 Processing
- Multi-MWe Electrolyzers (10MW Total)
- DI Water Supply and MWe Boiler
- 5 MW Balance of Plant Power

Preliminary Set of Ultra Heavy-Duty Targets (Ferries, Rail, Mining, etc.)

Characteristic	Units	Interim Target	Ultimate Target
Fuel Cell System Lifetime	Hours	25,000	30,000
Fuel Cell System Cost	\$/kW	80	60
BOL FCS Efficiency at Rated Power	%	55	55
EOL FCS Efficiency at Rated Power	%	50	50
Hydrogen Storage System Cost	\$/kWh	9	8
H ₂ Storage System Life	Cycles	5,000	5,000
LH ₂ Bunkered Cost	\$/kg	7	4

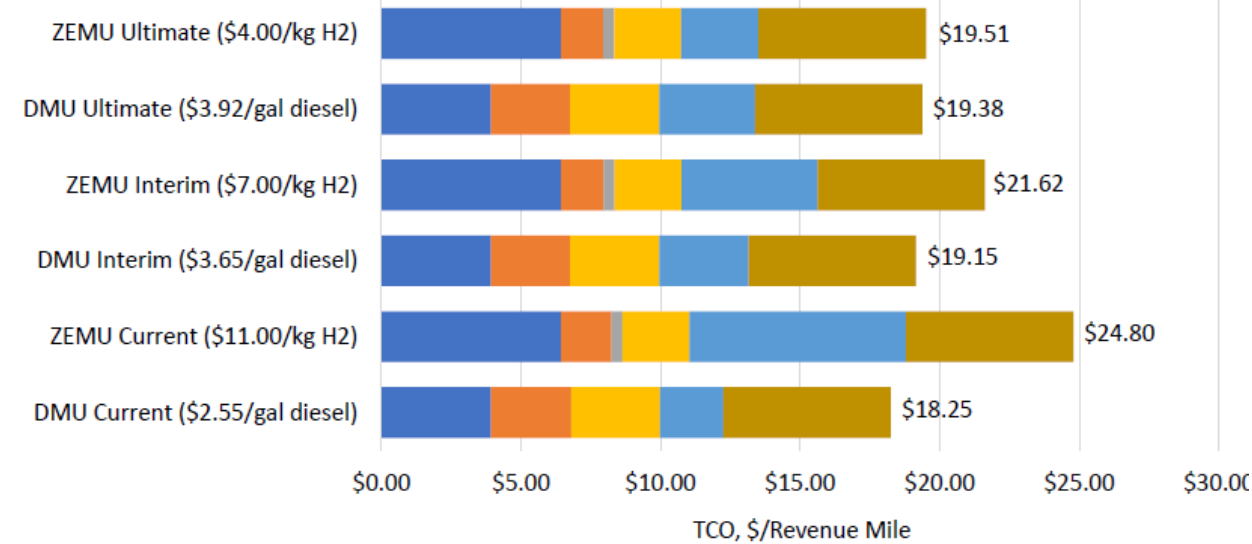
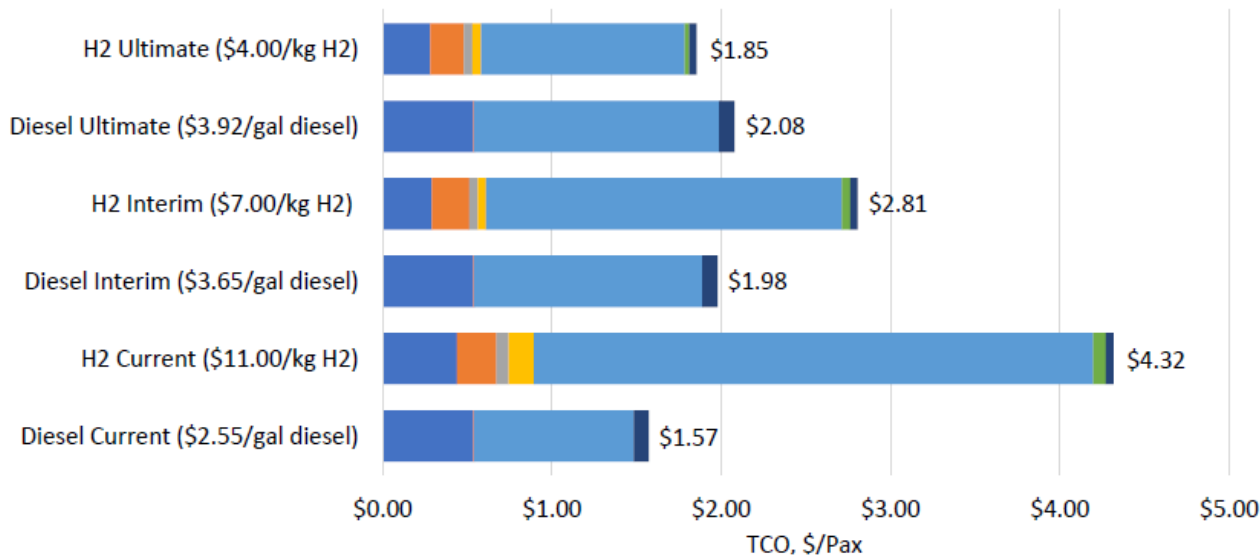
- High-level Targets are converging, so common set of "Ultra" HD Targets in development
- FC Multiple Unit Rail & Passenger Ferries are cost competitive with diesel @ \$4/kg H₂* (Ultimate Target)
- Mine Haul Trucks TCO in progress

*Cost of H₂ produced, delivered & dispensed

TCO Comparison for Passenger Ferries

Courtesy of ANL

TCO Comparison for Rail Multiple Units



■ CAPEX - Propulsion
■ CAPEX - Storage
■ CAPEX - Ship Upgrade

■ CAPEX - Stack Replacement
■ OPEX - Fuel
■ OPEX - Boiloff

■ OPEX - O&M

■ CAPEX - MU Purchase
■ CAPEX - Lifetime Overhaul
■ CAPEX - Infrastructure

■ OPEX - Maintenance - Vehicle
■ OPEX - Fuel
■ OPEX - Maintenance - Infrastructure

SDI: Outreach

Transportation

- SAE COMVEC Conference – September 2022
- Clean Buses in the U.S. Conference – November 2022
- SAE Government/Industry Meeting – January 2023
- Mission Innovation: Clean Hydrogen Mission Workshop, Hydrogen for Cargo Handling at Ports – January 2023 (with METI of Japan)

Grid Energy Storage & Power Generation

- Energy Exchange Clean Energy Campuses – October 2022
- BOEM Gulf of Mexico Roundtable Meeting – December 2022
- Floating Offshore Wind Shot Summit – February 2023
- International Partnering Forum for Offshore Wind – March 2023

Industrial & Chemical Processes

- Industrial Process Emissions Reduction (IPER) Workshop – March 2023
- Global Clean Energy Action Forum (Steel & Industrial Round Tables) – September 2022

Crosscutting

- Mission Innovation: Global Clean Energy Action Forum - 13th Clean Energy & 7th Mission Innovation Ministerials – September 2022
- Mission Innovation: Clean Hydrogen Mission Workshop, Hydrogen Detection Technologies for Safety – March 2023 (with METI of Japan)

SDI: International Collaboration



CLEAN HYDROGEN
MISSION

Clean H₂ collaboration with European Union, UK, Australia, & Chile on H₂ production, storage, distribution & end uses

Established Off-Road Working Group

Conducted capital equipment & fuel TCO analysis

Held workshop with Japan & other MI member countries on safety detection processes & sensor equipment



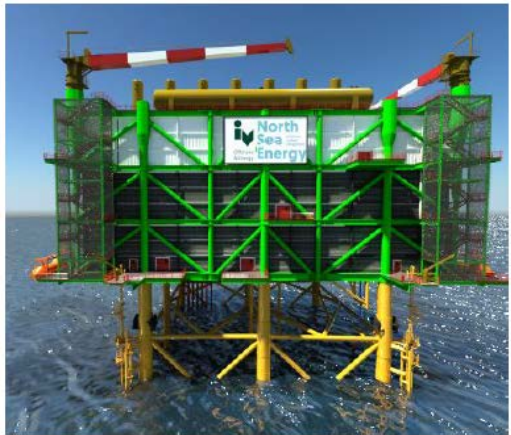
ZERO-EMISSION SHIPPING
MISSION

Maritime collaboration with Denmark, Norway & the UK on ships, fuel production & port infrastructure

Held workshop with Norway, Denmark & other MI member countries on life cycle costs for e-Ammonia fuel

Initiated study on bunkering e-Ammonia fuel at ports

International Working Group for Offshore Wind (OSW) to H2



- Partnership formed in 2021 between U.S. & Netherlands
 - (DOE, NREL, TNO & Hygro)
- FY23 collaboration includes OSW to H₂ TEA & assessment of knowledge gaps for multiple OSW to H₂ pathways
- Capital cost assessment for US & Netherlands completed
- Results show a lot of similarities in US-NL assessments, differences stem from supply chain and R&D cost reduction expectations

SDI: Collaboration Network

Fostering technical excellence, economic growth and environmental justice

Industry Engagement

21st Century Truck Partnership / U.S. DRIVE

Center for Hydrogen Safety

FCHEA

Participated in Numerous Conferences, Workshops & Working Groups

DOE H₂ Program Collaborations

Collaboration across H₂ through Joint Strategy Team (JST)

DOE IEDO

DOE VTO

DOE WETO

DOE OCED

DOE NE

DOE FECM

DOE Cross-Cutting Initiatives

Industrial Decarbonization, Long Duration Storage, Floating Offshore Wind, Clean Fuels & Products, Industrial Heat, Grid Modernization

Cross-Agency Collaborations

DOT (NHTSA, FRA, FHWA, MARAD, PHMSA)

DOD (Army, Navy, USMC, Air Force)

DHS (Border Patrol, Coast Guard)

IAA (Army-GVSC, Navy-NRL)

IWG (~15 government agencies)

U.S. Regional and International Collaborations

Project Coordination across ~20 U.S. States

Mission Innovation – Zero Emission Shipping

Mission Innovation – Clean H₂

International Offshore Wind to H₂ Working Group

IEA Wind and H₂ Tasks: Renewable Hybrid System Collaboration

Center for Hydrogen Safety

National Research Council-Canada

SDI: Highlights and Milestones

FY2022	FY2023	FY2024
Regional Clean H2 Hubs: Perform Stakeholder Engagement & Issue FOA (in collaboration w/ OCED)	Regional Clean H2Hubs: Concept Paper reviews complete; Full Applications received 4/7/23 & reviews in process (in collaboration w/ OCED)	Regional Clean H2Hubs: Select & Negotiate 6-10 H2Hubs (in collaboration w/ OCED)
Utilize ARIES Capabilities to Advance Integration of H ₂ Technologies in Energy Systems (NREL)	Demonstrated Integrated (behind-the-meter) 1.25 MW Electrolyzer Installation at Nuclear Plant (Constellation)	Develop 10MW Low & High Temperature Electrolysis Validation Facilities (NREL & INL)
Completed Design & Procurement for 1.25 MW Electrolyzer Installation at Nuclear Plant (Constellation)	Complete Integration & Commissioning of 1.25MW Electrolyzer and 1MW Fuel Cell Systems (NREL - ARIES)	Test 250kW HT Electrolysis System using Fully Emulated Nuclear Integrated Test Stand (INL/FCE)
Tested 100kW Integrated HT Electrolysis System using Fully Emulated Nuclear Integrated Test Stand (INL/Bloom)	Initiated Design of Full Thermal Integration at a Nuclear Plant with HT Electrolyzer in Collaboration with NE (Westinghouse)	Develop H ₂ focused Micro-Grid in Disadvantaged Community (NREL, SDG&E)
Selected (3) SuperTruck III Projects Focused on M/HD H ₂ Fuel Cell Trucks (Daimler, GM, Ford)	Demonstrate 15 Fuel Cell Electric MD Delivery Trucks Operating in Disadvantaged Community (CTE)	Demonstrate Wind Turbine to Electrolyzer Direction Connection for H ₂ Production (NREL - ARIES)
Demonstrate 10 kg/min Average H ₂ Fueling Rate for HD applications (NREL)	Completed design, fabrication & testing of Class 7 H2Rescue Disaster Relief Truck (DOD, DHS, Cummins)	Analyze & Demonstrate 10 tonne H ₂ Bulk Sub-surface Storage (NREL - ARIES)
Held Workshop & Established International Off-Road Working Group (in collaboration w/ International Mission Innovation - Clean Hydrogen)	Kick-off of I-10 H ₂ Fueling Corridor Study in Collaboration with EERE-VTO (GTI)	Demonstrate 1.5 MW H ₂ Fuel Cell for Data Center Resiliency (Caterpillar, Microsoft)
Performed SCS Gap Assessments for Large Scale H ₂ Applications, including Bulk Storage & Rail	Develop Reference Design & TEA for Direct Coupled Wind to H ₂ to Industrial End-Use (NREL)	Prototype Commissioning of multiple Class 4-8 Fuel Cell Electric Trucks through SuperTruck 3 (Daimler, GM, Ford)
Utilized Bulk Cryogenic H ₂ Behavior Validation Data to Enable 40% Reduction in H ₂ Station Footprint based on NFPA 2 (SNL)	Demonstrate 1 tonne/wk Reduction of Iron with H ₂ , enabling 90%+ emissions reduction (MS&T)	Interagency Project Demonstrating Fuel Cells for BEV Fast Charging (GM, DOD, DHS)
	Select New H ₂ Related Industrial Decarb Projects in Collaboration with EERE-IEDO	Rebranding and launch of Interagency Working Group (IWG)

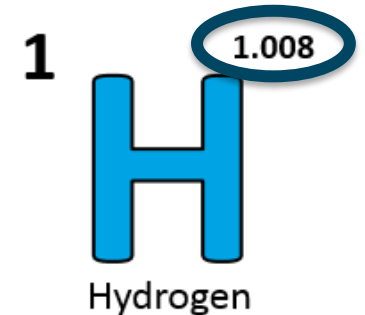
Resources and Opportunities for Engagement

Save the date!

**2024 DOE Annual Merit Review
and Peer Evaluation Meeting
May 6-9, 2024**

**Hydrogen and Fuel Cells Day
October 8**

- Held on hydrogen's very own atomic weight-day



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Learn more at: energy.gov/eere/fuelcells AND www.hydrogen.energy.gov

Systems Development & Integration Team

We are looking for
new feds!

If interested, please
send an email to
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Tomas Green
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Chemical & Industrial



Open Position
Federal



Open Position
Federal



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ORISE Fellow



Open Position
Fellow - SDI



Open Position
Fellow - SDI



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Program Analyst - Contractor



Gary Robb
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Technical Advisor - Contractor



Open Position
Contractor

Hydrogen Shot Fellowship

We are looking for
new fellows!

If interested, please
send an email to
Tomas Green
(tomas.green@ee.doe.gov)



The U.S. Department of Energy (DOE) is looking for talented, bright, early career professionals to partner with DOE Hydrogen Program Managers working to achieve the Hydrogen Energy Earthshot goal of \$1 per 1 kilogram in 1 decade (“1 1 1”).

Are you graduating soon or just starting your career in hydrogen?

Do you want to help make clean hydrogen affordable for all?

The Hydrogen Shot Fellowship might be the opportunity you’re looking for!

Apply today at: www.zintellect.com Keyword: Hydrogen Shot

Systems Development & Integration: Tuesday Session Outline

Tuesday, June 6			
SDI000	Systems Development & Integration: Subprogram Overview	HFTO	Jesse Adams
TA042	Next Generation Hydrogen Station Analysis	NREL	Genevieve Saur
TA017	Innovative Advanced Hydrogen Mobile Fueler	Electricore	Sara Odom
Break (10:30 AM - 11:00 AM)			
TA045	Waterfront Maritime Hydrogen Demonstration Project	Hornblower	Narendra Pal
TA059	MDV TCO and Target Development	ANL	Ram Vijayagopal
TA016	Fuel Cell Hybrid Electric Delivery Van	CTE	Jason Hanlin
Lunch (12:30 PM - 1:45 PM)			
TA058	Freight Emissions Reduction via Medium Duty Battery Electric and Hydrogen Fuel Cell Trucks with Green Hydrogen Production via a New Electrolyzer Design and Electrical Utility Grid Coupling	GM	Jacob Lozier
TA057	High Efficiency Fuel Cell Application for Medium Duty Truck Vocations	Ford	Stan Bower
TA056	Ultra-Efficient Long-Haul Hydrogen Fuel Cell Tractor	Daimler	Derek Rotz
Break (3:15 PM - 3:45 PM)			
SDI004	Hydrogen Coach Bus Fueling Demonstration	INL	Richard Boardman
TA065	Total Cost of Ownership (TCO) Analysis of Hydrogen Fuel Cells in Off Road Heavy-Duty Applications – Preliminary Results	ANL	Rajesh Ahluwali

- 5 parallel sessions
- SDI session runs all 3 days
- Tuesday: Transportation
 - Fueling Related Projects
 - MD/Non-Road Analysis & Demos
 - SuperTruck 3

Systems Development & Integration: Wednesday Session Outline

Wednesday, June 7			
TA001	MEA Manufacturing R&D	NREL	Peter Rupnowski
TA043	SOEC Stack Development and Manufacturing R&D	PNNL	Olga Marina
TA018	High Temperature Electrolysis, Stack and Systems Testing	INL	Micah Casteel
Break (10:30 AM - 11:00 AM)			
TA039	Solid Oxide Electrolysis System Demonstration	FCE	Hossein Ghezal-Ayagh
NE001	Nuclear Project	Energy Harbor	Mark Wymer
NE002	Nuclear Project	Xcel	David Malek
Lunch (12:30 PM - 1:45 PM)			
TA028	Demonstration of Electrolyzer Operation at a Nuclear Plant to Allow for Dynamic Participation in an Organized Electricity Market and In-House Hydrogen Supply	Constellation	Uugi Otgonbaatar
TA048	ARIES / Flatirons Facility - Hydrogen System Capability Buildout	NREL	Jeffrey Mohr
TA037	Demonstration and Framework for H2@Scale in Texas and Beyond	Frontier	Rich Myhre
Break (3:15 PM - 3:45 PM)			
SDI001	Integrated Modeling, TEA, and Reference Design for Renewable Hydrogen to Green Steel and Ammonia	NREL	Steve Hammond
TA060	Offshore Wind to Hydrogen - Modeling, Analysis, Testing, and International Collaboration Work	NREL	Genevieve Saur
TA061	Optimal Wind Turbine Design for H2 Production	NREL	Chris Bay

Poster Session - 5:30-7:30 PM			
SDI001a	Integrated Modeling, TEA, and Reference Design for Renewable Hydrogen to Green Steel and Ammonia	NREL	Jennifer King
SDI006	High Temperature Electrolyzer Megawatt-Scale Test Facility	INL	John Moorehead
TA013	Fuel Cell Bus Evaluations	NREL	Matthew Post
TA030	Demonstration of Integrated Hydrogen Production and consumption for Improved Utility Operations	Orlando Utilities Commission	Paul Brooker
TA051	Low Total Cost of Hydrogen by Exploiting Offshore Wind and PEM Electrolysis Synergies	Giner, Inc	Judith Lattimer
TA054	AEM Water Electrolyzer for Hydrogen Production from Offshore Wind	Alchemr, Inc	Richard Masel
TA063	High Efficacy Validation of Hydride Mega Tanks at the ARIES Lab (HEVHY METAL)	NREL	Katherine Hurst
TA064	Hydrogen Production, Grid Integration, and Scaling for the Future	NREL	Sam Sprik

- Wednesday: Non-Transportation
 - Manufacturing
 - SOEC Testing / Development
 - Systems Integration w/ Nuclear & Renewables
- SDI Posters – Wednesday Evening
- Interagency Session – Wednesday
 - DOT Panel
 - Liftoff Report
 - Joint projects with DOD

Systems Development & Integration: Thursday Session Outline

Thursday, June 8			
TA052	Solid Oxide Electrolysis Cells (SOEC) Integrated with Direct Reduced Iron (DRI) Plants for Producing Green Steel	UCI	Jack Brouwer
TA053	Grid-Interactive Steelmaking with Hydrogen (GISH)	Missouri S&T	Ronal Omalley
SDI002	Hybrid Energy Systems, Microgrid in Underserved Communities (Borrego Springs)	NREL	Kumaraguru Prabakar
Break (10:30 AM - 11:00 AM)			
TA044	System Demonstration for Supplying Clean, Reliable and Affordable Electric Power to Data Centers using Hydrogen Fuel	Caterpillar	Paul Wang
TA062	Validation of Interconnection and Interoperability of Grid-Forming Inverters Sourced by Hydrogen Technologies in View of 100% Renewable Microgrids	NREL	Kumaraguru Prabakar
TA035	Power Electronics for Electrolyzer Applications to Enable Grid Services	NREL	Robert Hovsopian
Lunch (12:30 PM - 1:45 PM)			
SDI005	HYdrogen Systems for PERformance-based Value Stacking (HYPER-V)	NREL	Rishabh Jain

- Thursday: Non-Transportation
 - HySteel
 - Micro-grids using H₂
 - Data centers using H₂
 - Power Electronics

Session Logistics

General Information

- This meeting is a review, not a conference
 - **Questions will be taken first from reviewers**, and then from other audience members as time allows
 - Remote reviewers are reminded to enter their questions in CHAT
 - Remote general attendees can enter questions or comments into Q&A
- The schedule will be strictly followed so that reviewers can move between sessions
- Presentations are 20 minutes followed by 10 minutes Q&A

Thank You, Reviewers!

Your input on our Program and subprograms helps
guide our decisions.

Thank you for your thoughtful, objective, and
timely feedback!

Thank You

Jesse Adams
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U.S. Department of Energy

www.energy.gov/fuelcells
www.hydrogen.energy.gov