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

FECM’s Hydrogen Activities

June 6th, 2023

Evan Frye, Program Manager, Office of Resource Sustainability
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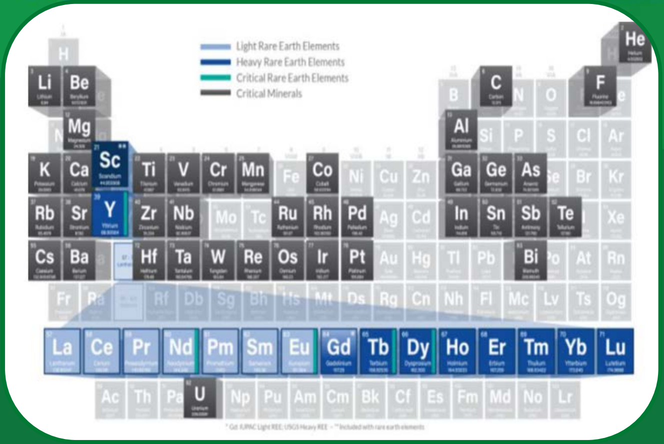


FE to FECM – A New Mission

FECM's focus:

- Mitigation of environmental impacts from resource recovery and use
- Management of carbon dioxide emissions, including legacy emissions

New climate goals:

- 50% emissions reduction by 2030
- 100% clean electricity by 2035
- Net-zero carbon emissions by 2050

FECM RDD&D Priorities

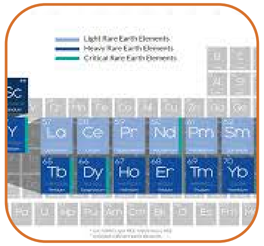
Advance Carbon Dioxide Removal & Low Carbon Supply Chains for Industry

Demonstrate and Deploy Point Source Carbon Capture

Accelerate Carbon-Neutral Hydrogen (H_2)

Reduce Methane Emissions

Low-Carbon Industrial Supply Chains



Advance Critical Minerals, Rare Earth Elements (REE), and Mine Remediation

Increase Efficient Use of Big Data and Artificial Intelligence

Address the Energy Water Nexus

Invest in Thoughtful Transition Strategies

FECM Hydrogen Equities

- **Production**
  - Gasification
  - CCS
  - SOECs
  - Reforming
  - Pyrolysis
- **Pipeline Transport**
- **Underground Storage**
- **Use**
  - Turbines
  - Solid Oxide Fuel Cells

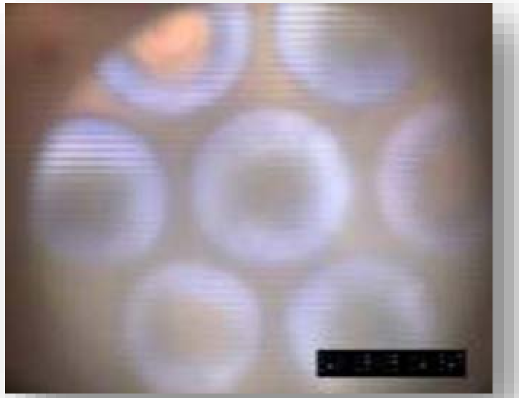
Advanced Turbines Program

Advanced Combustion Turbines

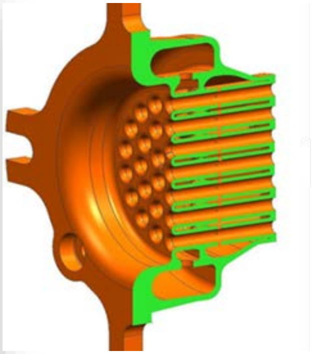
- Syngas, natural gas, **H_2, NH_3 Fuels** (NGCC)
- Achieve low NOx emissions

OVERALL GOAL:

Large frame, industrial and aeroderivative turbines able to fire 100% H_2 by 2030



High-Hydrogen



Advanced Gasification Program

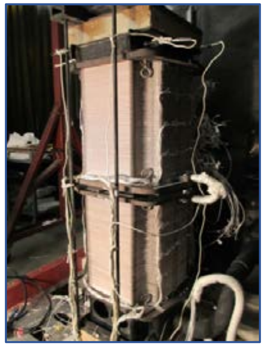
Gasification Process Improvements	• Modular design integration capability for cost reduction • Microwave-assisted gasification
Air Separation Technology	• Reduce oxygen production costs (membranes, novel cryogenics, advanced sorbents, etc.)
Achieving Negative CO_2 Emissions	• Reduce CO_2 emissions using biomass & CCS • Process Intensification

SOFC Program

Enable:

- Highest efficiency and lowest cost electric power generation from hydrogen
- Efficient and cost-effective distributed/utility scale hydrogen production
- Flexible, modular, hybrid SOFC/SOEC system design

Cell and Stack Performance Improvements



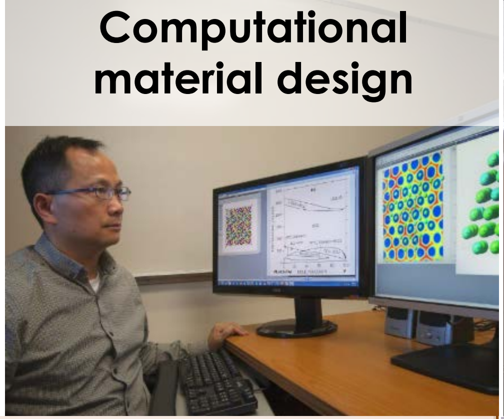
Proof-of-Concept Systems

(courtesy LG Fuel Cell Systems)

Advanced Energy Materials Program

Goals:

- Evaluate impacts of hydrogen on materials using modeling tools.
- Enhance the nation's supply chain for high-temperature materials and create a skilled workforce.
- Develop Ceramic Matrix Composite (CMC) materials for turbines to address 70% efficiency and turbines firing 100% hydrogen.

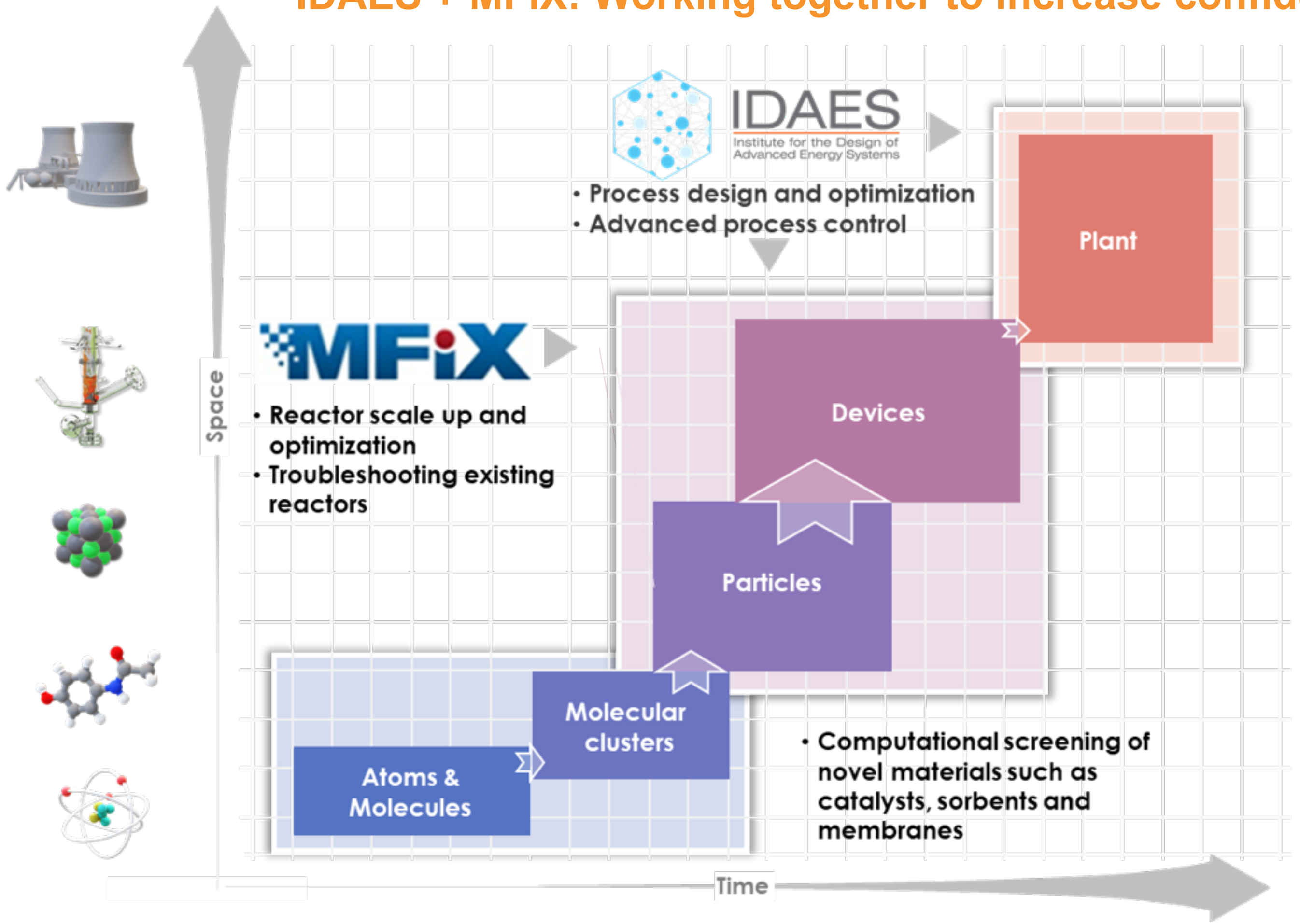


Sensors, Controls and Novel Concepts Portfolio

- Advanced sensors for new hydrogen technologies
- Control and optimization strategies for new hybrid systems (SOFC with H_2 turbine, etc.)
- Operations-based predictive maintenance

Simulation Based Computational Tools

IDAES + MFiX: Working together to increase confidence systems modeling realism and fidelity

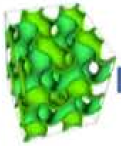


Computational Tools Working Together

- **IDAES** is a process systems engineering framework for the design and optimization of innovative steady state and dynamic processes
- **MFiX** is a suite of multiphase flow simulation software for designing and troubleshooting devices such as gasifiers and combustors

Carbon Capture Program

Lab & Bench

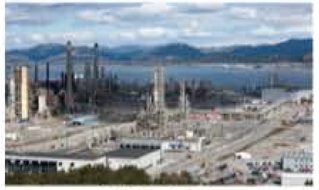


TRL 2-4

Small Pilots

TRL 4-5

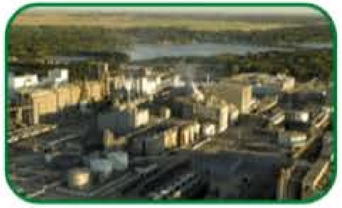
Large Pilots



TRL 5-7

FEED Studies

Demonstration



What we've learned in 20+ years:

- "First generation" (e.g. liquid solvent) systems work:
  - At commercial scale at some power plants and industrial facilities
  - With high efficiency (90+%) at moderate cost
  - With manageable non-CO2 pollution

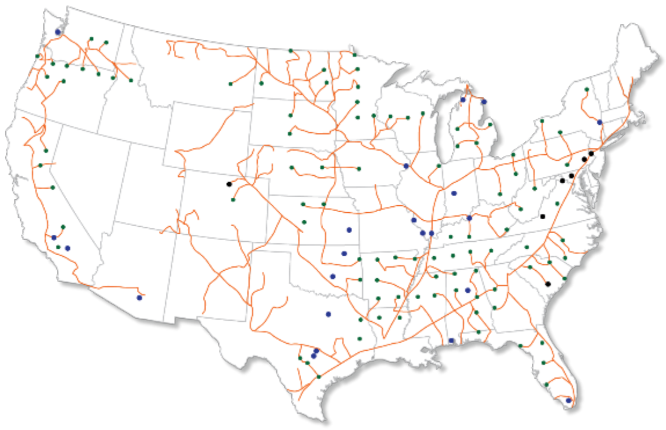
What we're learning now:

- Which "next generation" systems have the greatest potential
- How to increase capture efficiencies (>95%)
- How to enable low carbon supply chains (i.e., cement, steel, hydrogen, etc.)
- Co-Benefits Analysis..How to further reduce other pollutants
- How to accelerate deployment

Carbon Transport and Storage Program

CO_2 Transport

- FEED studies for large-scale transport networks
- Cost analyses for build-out scenarios
- Sensors for corrosion and metallurgy



Storage

- Well integrity and mitigation
- Monitoring, verification, and accounting
- Storage complex efficiency and security

Hydrogen Energy Earthshot Initiative (HEEI)

Analyses to Identify Pathways to Achieve the Hydrogen Shot

- ✓Baseline studies for most commercial pathways
- Ongoing study on methane pyrolysis pathways to achieve the HEEI
- ➢Significant cost reductions could come from unit siting choices, natural gas market conditions and by-product sales
- FECM continues to fund R&D, pre-FEED, FEED studies and demonstrations that can result in lower costs of clean hydrogen.
    - o Membranes & Sorbents for CCS
    - o Process Intensifications (WGS, Reforming)

How FECM Efforts Fit In With Other DOE Offices

EERE

Feedstocks:
- Renewables and Water

Technologies:
- Electrolysis – Low- and High-Temperature
- Advanced Water Splitting – Solar/High-Temp Thermochemical, Photoelectrochemical
- Biological Approaches

FECM

Feedstocks:
- Fossil Fuels – Natural Gas and Solid Wastes

Technologies:
- Gasification, Reforming, Pyrolysis
- Carbon Capture & Storage
- Advanced Approaches – Co-firing and Modular Systems
- SOFCs/SOECs/rSOFCs

Nuclear Energy

Feedstocks:
- Nuclear Fuels and Water

Technologies:
- Electrolysis Systems for Nuclear
- Advanced Nuclear Reactors
- Systems Integration and Controls – LWRs and Advanced Reactors

Areas of Collaboration

Reversible Fuel Cells, Biomass, Municipal Solid Waste, Plastics, Polygeneration, High-Temperature Electrolysis, Systems Integration

Funding Opportunities

FOA 2400: Fossil Energy Based Production, Storage, Transport and Utilization of Hydrogen Approaching Net-Zero or Net-Negative Carbon Emissions

- First issued in FY21
- $63M awarded to date, 30 awards made
- **17 Topic Areas spanning clean hydrogen production, transportation, use and storage**, and additional enabling topics such as sensors & controls, CCS, ammonia turbines
- Opens and closes with different topic areas active at any time

To Find Funding Opportunities, Visit:

- Fedconnect.com
- Grants.gov
- SAM.gov

Filter/Search for DOE to find open solicitations!

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Fossil Energy and Carbon Management

FY2023 Natural Gas Decarbonization and Hydrogen Technologies (NG-DHT) Program Overview

Evan Frye
Office of Resource Sustainability
Office of Fossil Energy and Carbon Management

June 6, 2023

Methane Mitigation Technologies Division

Methane Emissions Mitigation

Advanced materials, data management tools, inspection and repair technologies, and dynamic compressor R&D for eliminating fugitive methane emissions across the natural gas value chain

Methane Emissions Quantification

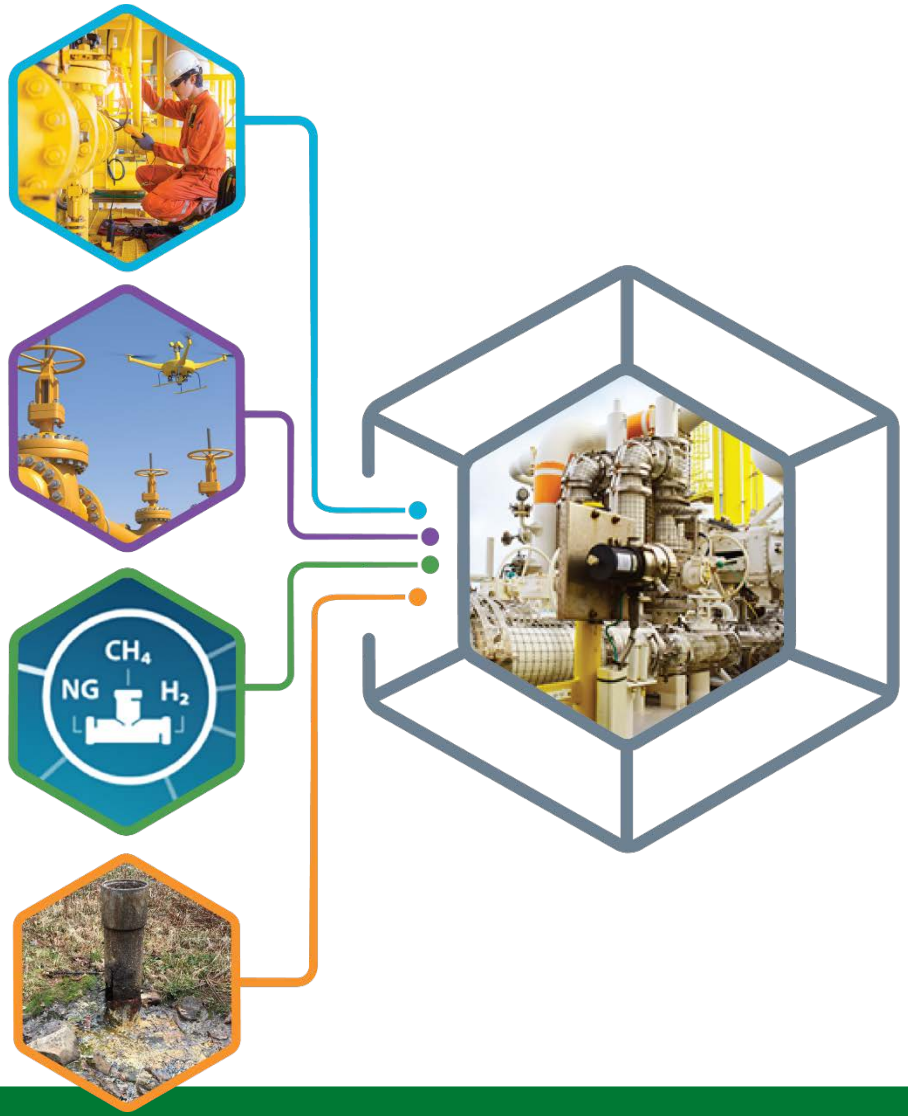
Direct and remote measurement sensor technologies and collection of data, research, and analytics that quantify methane emissions from point sources along the upstream and midstream portion of the natural gas value chain

Natural Gas Decarbonization and Hydrogen Technologies

Technologies for clean hydrogen production, safe and efficient distribution, and geologic storage technologies supported by analytical tools and models

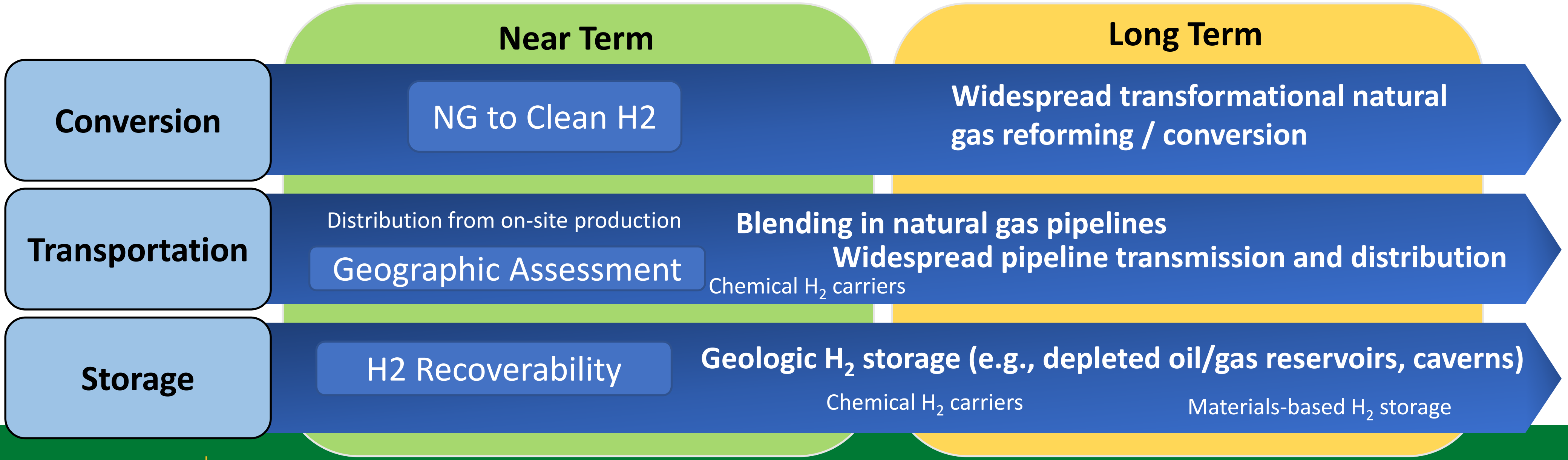
Undocumented Orphaned Wells Research

Developing tools, technologies, and processes to efficiently identify and characterize undocumented orphaned wells in order to prioritize them for plugging and abandonment.



Natural Gas Decarbonization and Hydrogen Technologies

- The **Natural Gas Decarbonization and Hydrogen Technologies** (**NG-DHT**) Program was formally initiated in 2022 Omnibus.
- The NG-DHT Program coordinates with other DOE offices to support the transition towards a clean hydrogen-enabled economy through the decarbonization of natural gas conversion, transportation, and storage.
    - Supports transformational concepts for clean hydrogen production from domestic natural gas resources, with emphasis on decarbonization opportunities and value tradeoffs within energy markets.
    - Works to ensure the suitability of existing natural gas pipelines and infrastructure for hydrogen distribution, while emphasizing technology opportunities to detect and mitigate emissions.
    - Identifies underground storage infrastructure to handle high volume fractions of hydrogen, while seeking demonstration opportunities for novel bulk storage mechanisms.



FOA2400 - Fossil Energy Based Production, Storage, Transport and Utilization of Hydrogen Approaching Net-Zero or Net-Negative Carbon Emissions

- **AOI 14 – Clean Hydrogen Production and Infrastructure for Natural Gas Decarbonization**
  - **AOI 14a – Methane pyrolysis/decomposition, in situ conversion, or cyclical chemical looping reforming**
  - **AOI 14b – Hydrogen Production from Produced Water**
- **AOI 15 – Technologies for Enabling the Safe and Efficient Transportation of Hydrogen Within the U.S. Natural Gas Pipeline System**
- **AOI 16 – Fundamental Research to Enable High Volume, Long-term Subsurface Hydrogen Storage**

NETL RIC Natural Gas Decarbonization and Hydrogen Technologies

- **Production of Hydrogen and Carbon from Associated Gas Catalytic Pyrolysis**
- **Assessment of State-of-the-art H2 Production via Pyrolysis**
- **H2 Sensing Materials Development for Safe Hydrogen Transportation**
- **Advanced Multi-functional Electrochemical H2 Sensor**
- **Real-time in-Pipe Gas Blend Monitoring with Raman Gas Analyzer**
- **Techno-economic Pipeline Model for Transporting Blends of Natural Gas and Hydrogen**
- **Comparison of Commercial, State-of-the-Art, Fossil-Based Ammonia Production Technologies**

NATIONAL ENERGY TECHNOLOGY LABORATORY

Subsurface Hydrogen Assessment Storage & Technology Acceleration (SHASTA)

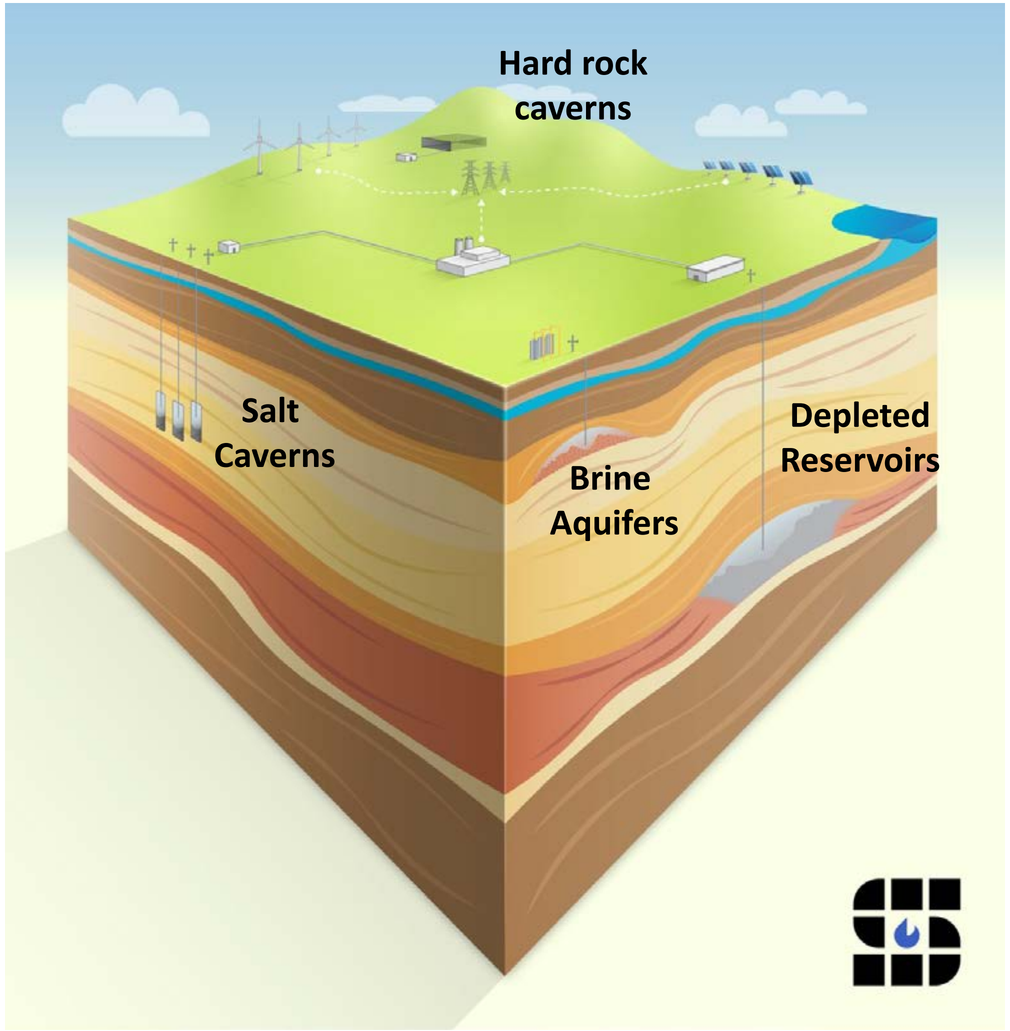
Identify and address key technological hurdles and develop tools and technologies to enable broad public acceptance for subsurface storage of pure hydrogen and hydrogen/natural gas mixtures

Specific Goals:

- Quantify operational risks
- Quantify potential for resource losses
- Develop enabling tools, technologies, and recommended practices
- Develop a collaborative field-scale test plan in partnership with relevant stakeholders

Focus on reservoir performance and well component compatibility in the storage system

- Pipelines and surface components upstream from the wellhead are covered by separate DOE research activities



SHASTA – Interagency Agreement with U.S. DOT PHMSA

Goal:

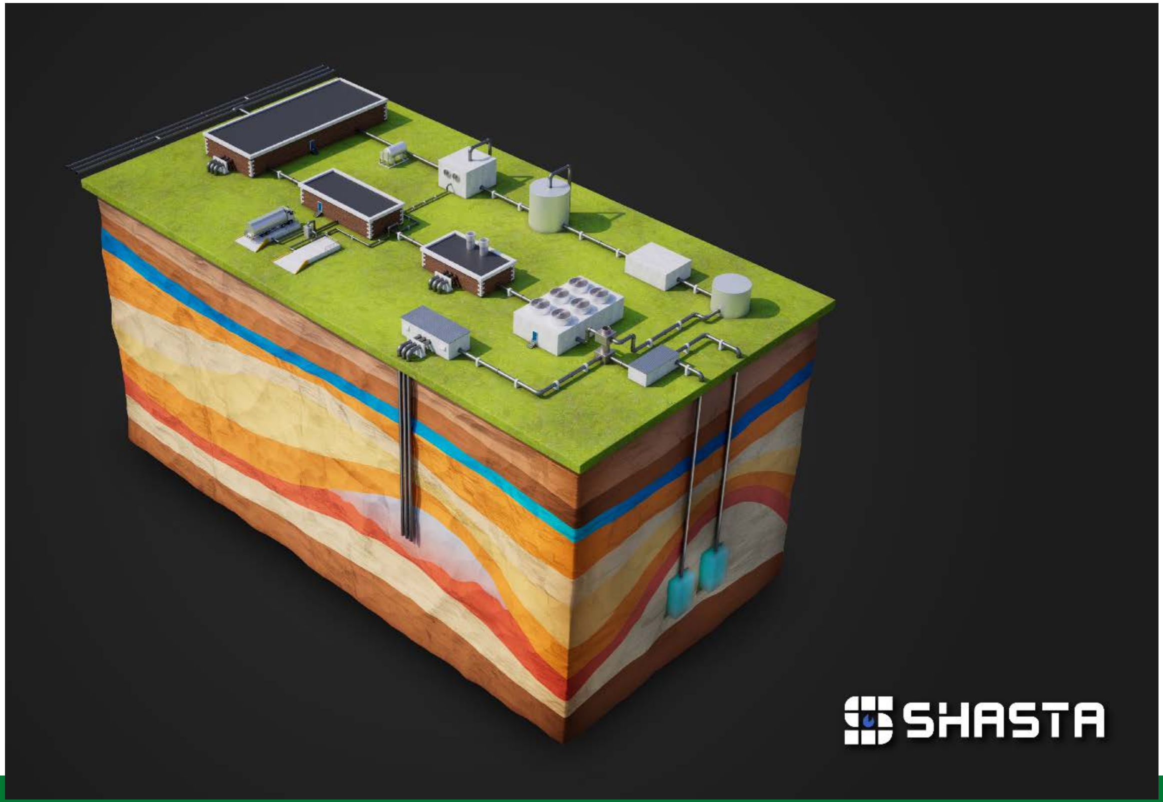
- Leverage expertise at the U.S. Department of Energy's National Laboratory system through the Office of Fossil Energy and Carbon Management (FECM) funded SHASTA project to provide PHMSA with the scientific basis to support safe and effective regulatory guidance and oversight for underground hydrogen storage (UHS).

Purpose:

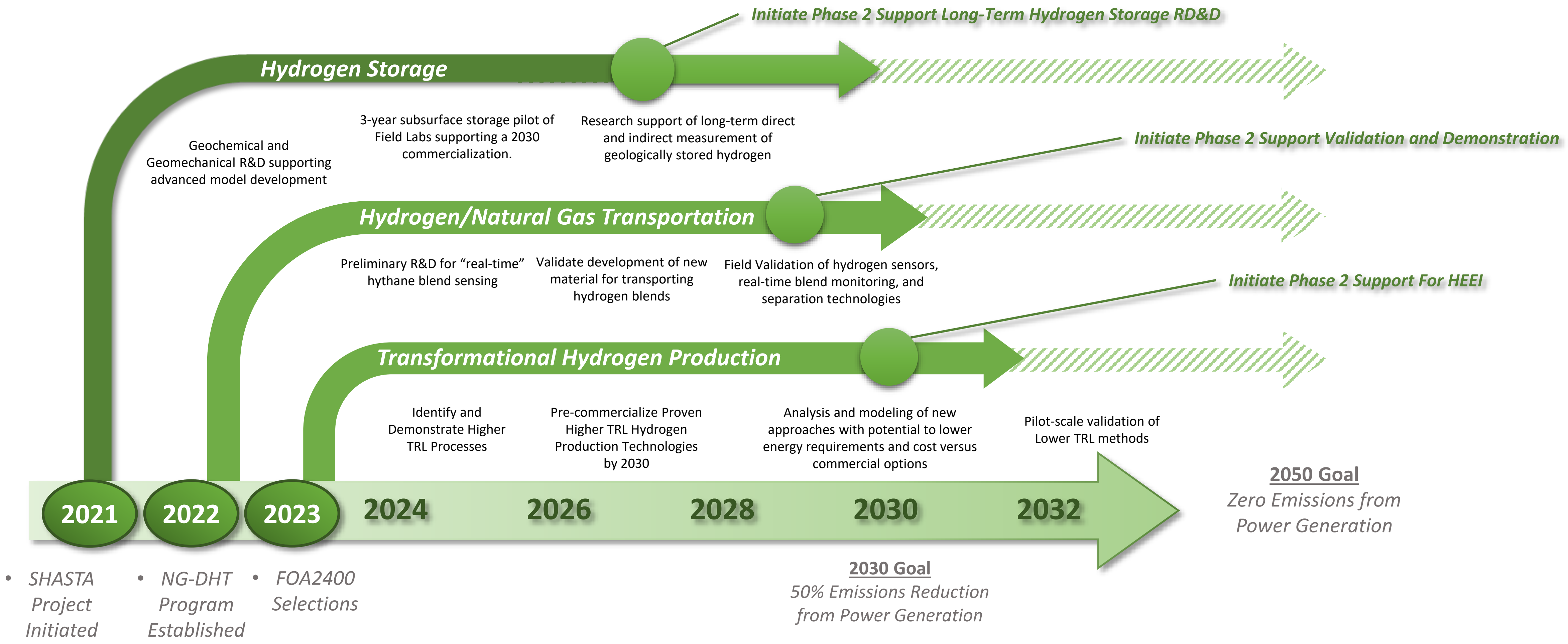
- Identifying sources for potential hydrogen resource and storage reservoir asset loss
- Identifying possible mitigations/remedies relative to governing entities that may have regulatory primacy or authority

Objectives:

- Identify regulatory needs for Underground Gas Storage (UGS) operations to define UHS metrics
- Assess existing UGS facilities' suitability for hydrogen storage
- Quantify operational expectations and risk for H2 resource loss and asset degradation based on geologic and operational conditions



NG-DHT Technology Development Timeline



Technology Transfer

- Assessing Compatibility of Natural Gas Pipeline Materials with Hydrogen, CO2, and Ammonia – ORNL
- Hydrogen Storage Potential in U.S. Underground Gas Storage Facilities – SHASTA
- Liquid Organic Hydrogen Carriers Technical and Market Assessment and Cost Model Overview – NETL (publication pending)
- Underground Storage of Hydrogen and Hydrogen/Methane Mixtures: Influence of Reservoir Factors and Engineering Choices on Feasibility, Storage Operations, and Risks – SHASTA (manuscript under review)
- Managing Reservoir Dynamics When Converting Natural Gas Fields to Underground Hydrogen Storage – SHASTA (manuscript under review)
- **November 6-9, 2023 – Resource Sustainability Project Review Meeting – Pittsburgh, PA**

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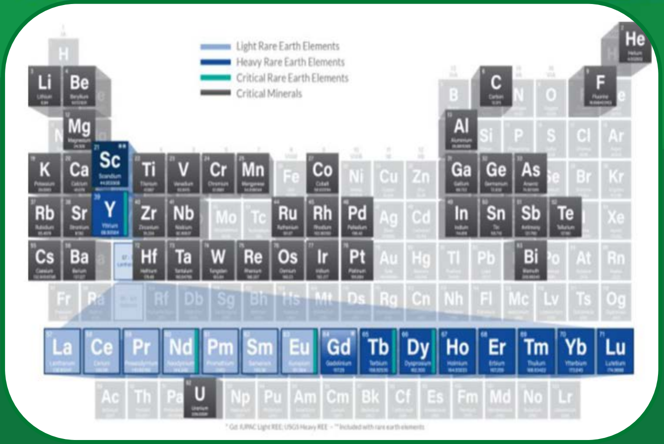
Questions?





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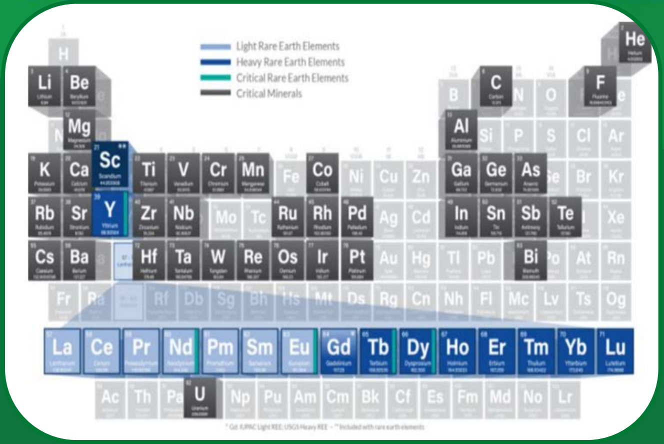
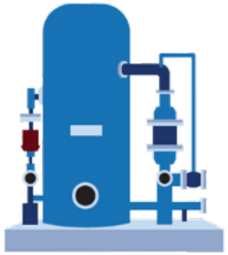
BACKUP



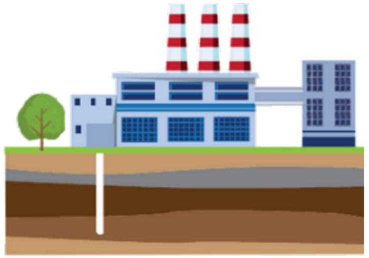


FECM Strategic Vision

Justice, Labor, and Engagement



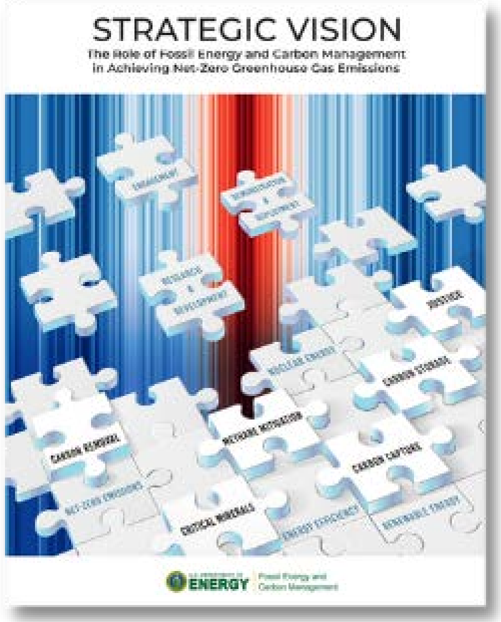
Technologies that Lead to Sustainable Energy Resources



Carbon Management Approaches toward Deep Decarbonization

FECM Role Achieving Net-Zero Greenhouse Gases

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.



Read FECM's Entire Strategic Vision by Scanning the Code Above

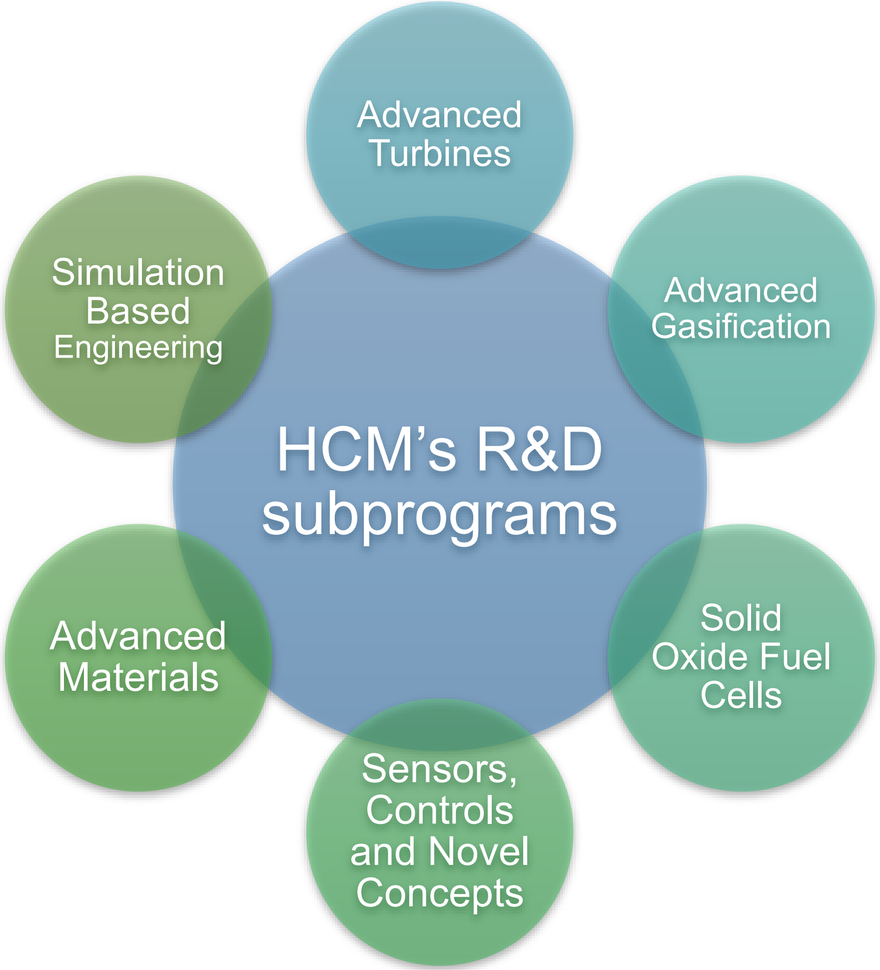
How FECM Efforts Fit In With EERE

EERE	FECM
Feedstocks: • Renewables and Water **Technologies:** • Electrolysis – Low- and High-Temperature • Advanced Water Splitting – Solar/High-Temp Thermochemical, Photoelectrochemical • Biological Approaches	**Feedstocks:** • Fossil Fuels – Natural Gas and Solid Wastes **Technologies:** • Gasification, Reforming, Pyrolysis, CCS • Methane Pyrolysis • Advanced Approaches – Co-firing and Modular Systems

Areas of Collaboration

Reversible Fuel Cells, Biomass, Municipal Solid Waste, Plastics, Polygeneration, High-Temperature Electrolysis, Systems Integration

Hydrogen with Carbon Management Division



Enable:

- Non-traditional feedstocks such as MSW, waste coal and biomass
- Hydrogen end use in electricity and other energy sectors
  - Solid Oxide Fuel Cells
  - Hydrogen Turbines
- Crosscutting technologies such as Advanced Materials, Sensors and Controls and Simulation Based Engineering

Office of Carbon Management Hydrogen Goals

Goals:

- **Gasification systems:**
  - Hydrogen production with at least 98% CO_2 capture
  - Small, modular gasification systems to accelerate construction and reduce installed costs
  - Produce hydrogen at less than $1/kg H_2

- **Turbines:**
  - Large frame (utility scale), aeroderivative, and industrial scale turbines able to fire 100% H_2 by 2030

Office of Carbon Management Hydrogen Goals

Goals:

- **SOFC/SOECs:**
  - Enable reversibility for hydrogen production
  - Cell materials and fabrication to improve performance and lower cost
  - Understanding cell and stack degradation mechanisms

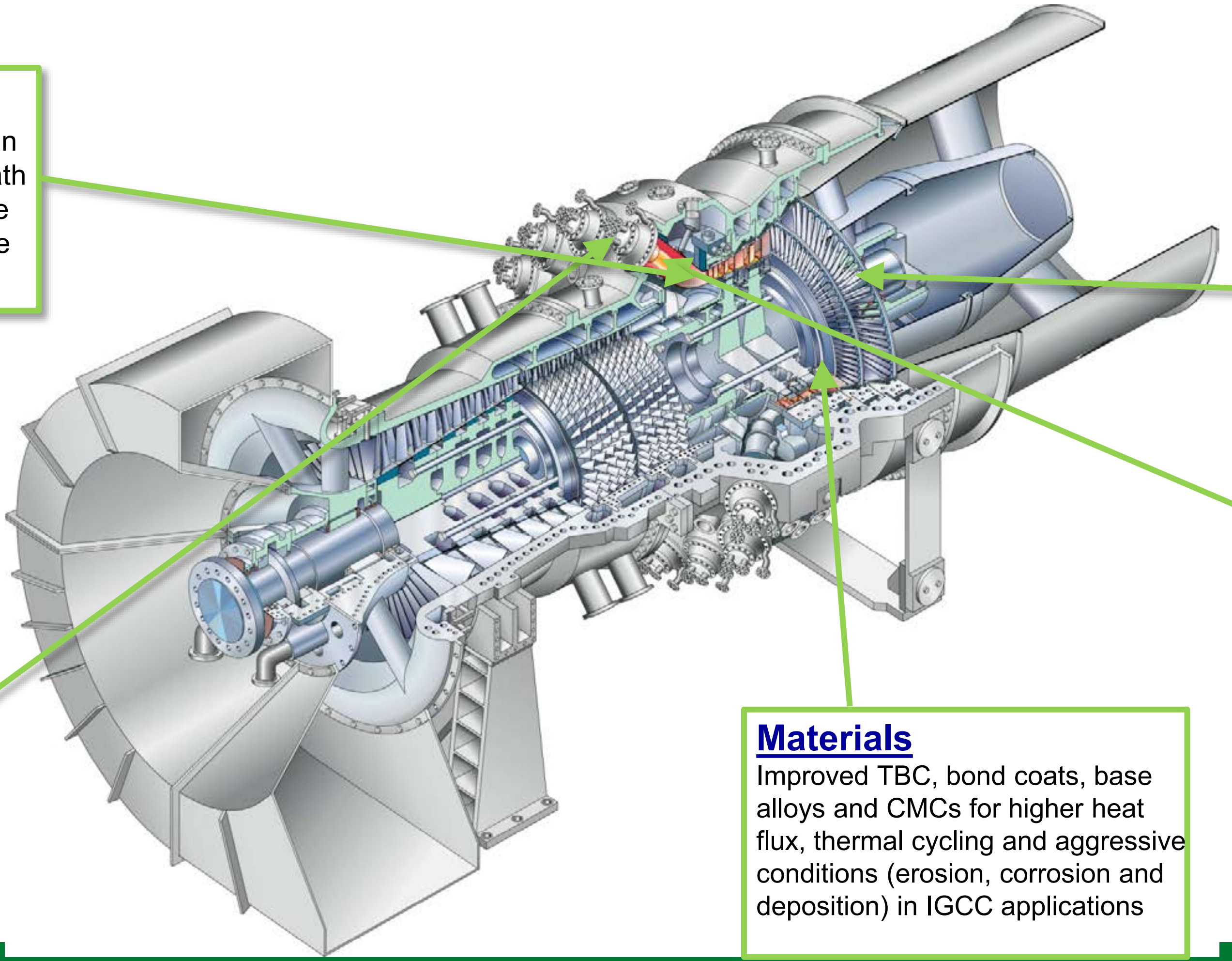
- **CCS:**
  - Increase capture rates and efficiencies
  - Lower costs

Office of Carbon Management Hydrogen Goals

Goals:

- **Crosscutting technologies:**
  - Enable hydrogen sensing for harsh environments
  - Market analyses of hydrogen production & sale
  - Reactor and process design simulation tools
  - High temperature, hydrogen tolerant materials

Targeted Areas for Turbine Improvement



Transition
Improved transition design to shorten combustion path to first stage and increase temperature to the turbine

Turbine
Improved aerodynamics, longer airfoils for a larger annulus / higher mass flow and improved internal cooling designs to minimize cooling flows while at higher temperatures

Combustor
Combustion of hydrogen and NG fuels with single digit NOx, no flashback and minimal combustion instability

Materials
Improved TBC, bond coats, base alloys and CMCs for higher heat flux, thermal cycling and aggressive conditions (erosion, corrosion and deposition) in IGCC applications

Leakage
Reduced leakage at tip and wall interface and reduced recirculation at nozzle/rotating airfoil interface for higher turbine efficiency and less purge

Photo courtesy of Siemens Energy

Current Gasification System Research

Modular Technology: Helping Gasification Access New Markets

Smaller, modular gasifier

- Faster development
- Lower capital investment
- Lower financial risk

New Markets

Business Impacts:

- CapEx/OpEx reduction
- Reduce the cost of functional prototypes
- Utilize local feedstocks (including biomass and wastes)

SOFC R&D Goals

Cell and Stack Degradation Modeling

- Development of comprehensive predictive modeling tool
- Atoms to system scale bridging
- Validation through experiment

Electrode Engineering

- Mitigation of prominent degradation modes
- Improved materials & fabrication to improve performance
- Enable reversibility for hydrogen production

Systems Engineering and Analysis

- Public dissemination of SOFC market potential, performance, and cost advantages
- Hybrid configuration assessment

SOFC Program – Technology Evolution

CELLS → STACKS → MODULES → SYSTEMS

10 kWe-Class Stack Tests
- Improved efficiency, 35 – 41%
- Reduced degradation, <2%/1000 hr
- Cost target at high volume achieved (extrapolated)

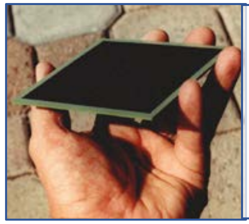
200 kWe Prototype Field Tests

~5 KW Electrolyzer Systems
(in Progress)

Utility-Scale Demo
(Envisioned)

Cell and Stack Performance Improvements
- Increased cell area by 5x
- Increased cell power by 10x
- Degradation reduced to 0.2 - 0.5%/1,000 hrs

MWe-Class SOFC Pilot
(planned)



Cell Development
- increased power
- Established material set
- Improved reliability
- Reduced cost

~10 KW SOFC Systems
(in Progress)

Proof-of-Concept Systems
- Two POC systems, 50kW & 200 kW
- Efficiency improvements to >55%

Technology Validation

200 kWe POC
(courtesy LG Fuel Cell Systems)

50 kWe POC
(courtesy FuelCell Energy)

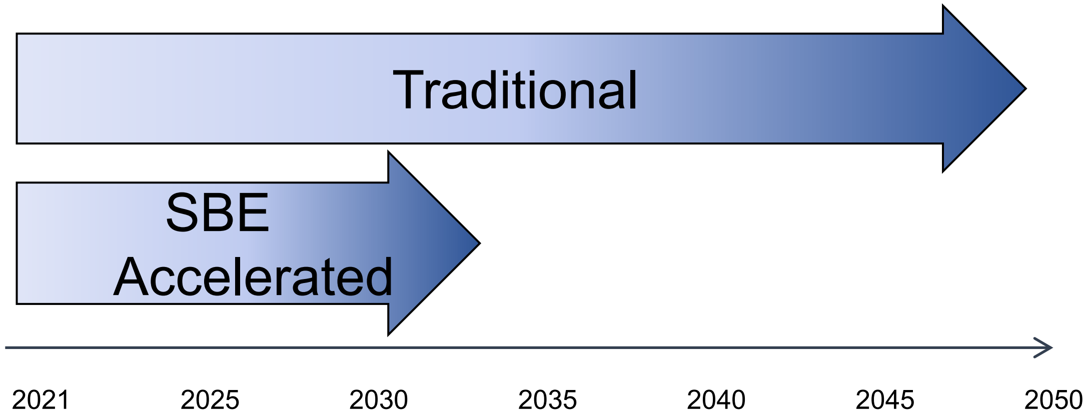
Simulation Based Engineering

Simulation-based engineering tools are critical to achieving policy priorities

- Model technologies and systems to manage and reduce carbon across the full life cycle
- Allows DOE to meet or exceed 2035 and 2050 goals for decarbonization

Modeling/Simulation is an essential design step

- SBE has unique toolsets to solve complex problems that cannot be otherwise understood
- FECM/NETL has developed and successfully applied SBE tools for overcoming challenges to FECM technologies

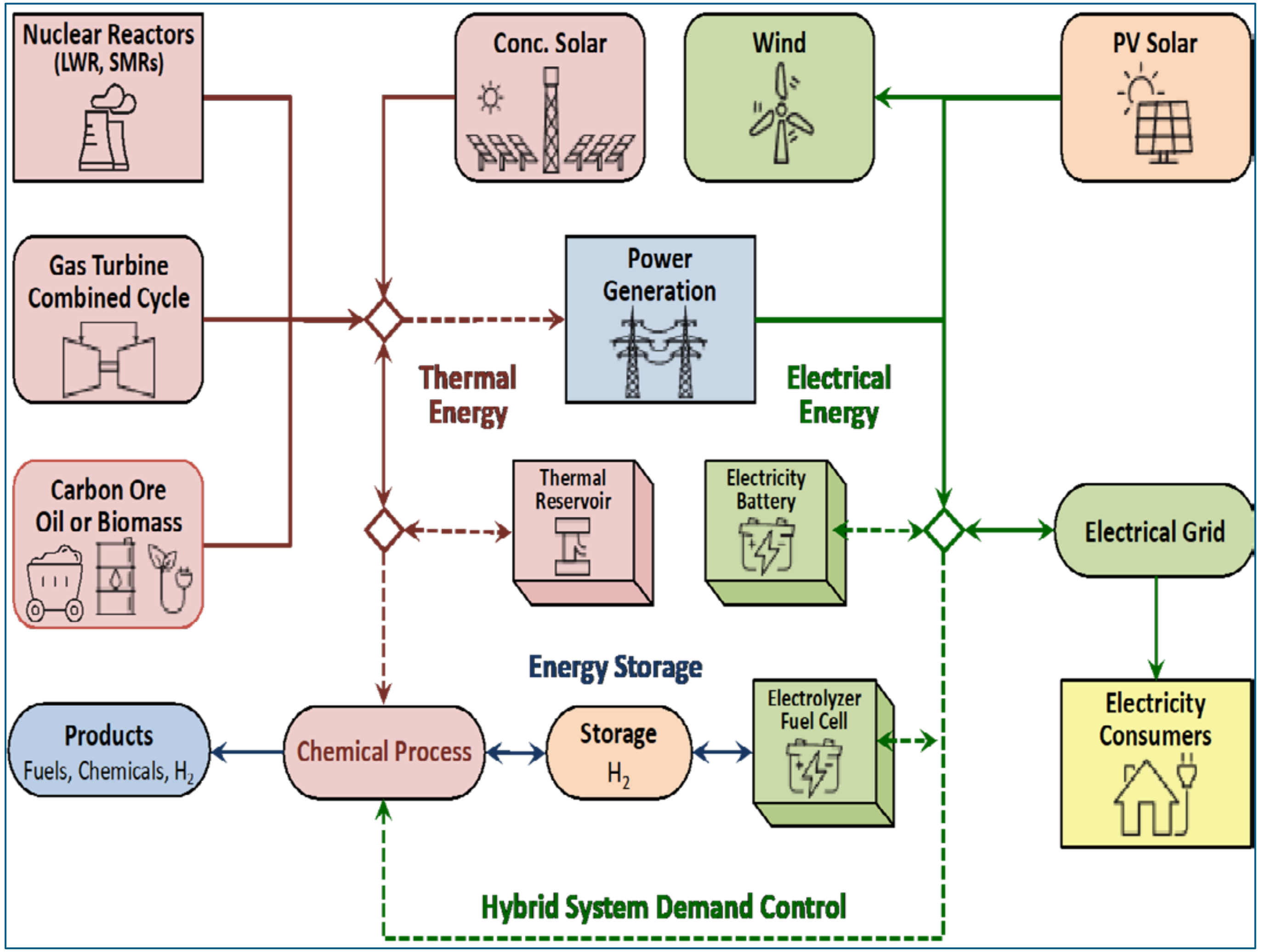


SBE deploys FECM technologies faster

Challenges and Opportunities for Future Energy Systems

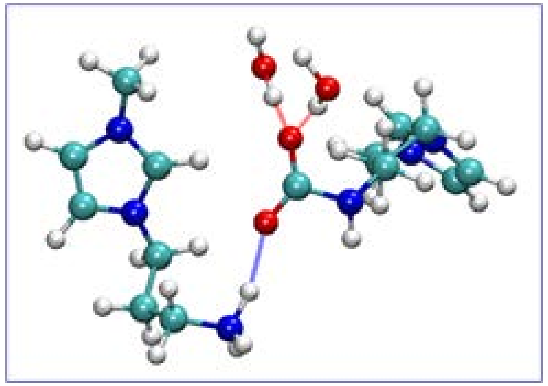
An evolving energy ecosystem requires greater flexibility

Simulation-based engineering remains pivotal to technology transition



Approaches to Carbon Capture

Solvents



Membranes

Sorbents