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Transforming ENERGY

Integrated Modeling, TEA, and Reference Design for Renewable Hydrogen to Green Steel and Ammonia - GreenHEART

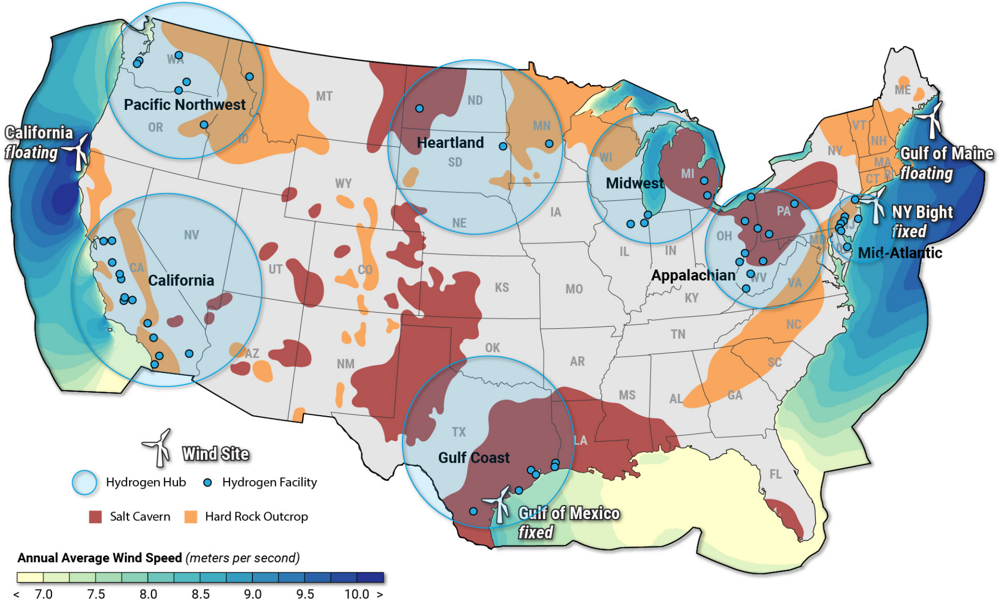
Steve Hammond and Jennifer King (presenter)
National Renewable Energy Laboratory
WBS # 7.2.9.23
May 8, 2024

DOE Hydrogen Program
2024 Annual Merit Review and Peer Evaluation Meeting

Project ID: SDI001

Project Goal – Tightly Coupled Systems

- **Vision:** Develop reference designs for GW-scale off-grid, tightly-coupled, hybrid energy systems purpose-built for green H_2 production, in close proximity to or co-located with industry end uses, that can provide alternative pathways and accelerate the path to decarbonization for hard-to-abate industries.



Team effort (lead noted):
LBNL – Hanna Breunig
ANL – Pingping Sun
SNL – Myra Blaylock
ORNL – Joao Pereira Pinto

NREL contributors –Evan Reznicek, Masha Koleva, Dan Rowland, Matt Kotarbinski, Elenya Grant, Kaitlin Brunik, many others

Overview: Timeline and Budget

Outcomes:

- Phase 0: Market analysis (August-September 2022)
- Phase 1: Analysis for tightly-coupled, co-located green steel/ammonia systems (October 2022 – April 2023)
- **Phase 2: Reference designs for green steel and ammonia (April 2023 – April 2024)**

Timeline and Budget (co-funded between HFTO/WETO)

- Project Start Date: 8/1/2022
- FY22 DOE Funding (if applicable): $2.5M
- FY23-FY24 DOE Funding (if applicable): $3.2M
- Total DOE Funds Received to Date**: $5.7M

** Since the project started

Overview: Barriers and Targets

Technical Barriers

- Design and analyze shared components across renewable power, hydrogen, and steel/ammonia
- Integrate tools developed in isolation for individual technologies into one framework to exploit synergies across technologies

Technical Targets

- Targeting systems that reduce costs due to tight-coupling and co-locating technologies
- **Support Hydrogen Shot and Offshore Floating Wind Shot**

Five-lab Partnership:

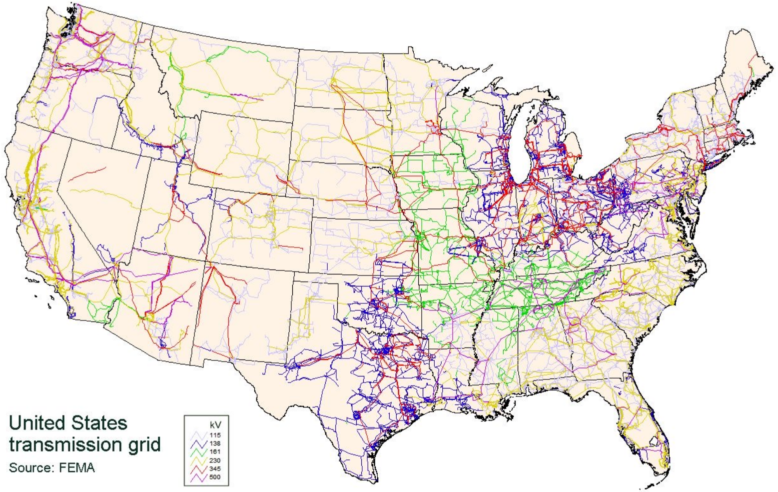
- Project co-leads: Jennifer King and Steve Hammond, **NREL**
- Hanna Breunig/**LBNL**, Pingping Sun/**ANL**, Brian Ehrhart/**SNL**, Joao Pereira Pinto/**ORNL**

Potential Impact: Why is this important?

Demonstrate viability of "off-grid" or "behind-the-meter" industrial decarb applications
Potential Impact: Time to deployment can be reduced

Integrated H2 (directly coupled wind-H2) provides an accelerated deployment pathway and opens up new locations that lack grid infrastructure. Maximize existing infrastructure.

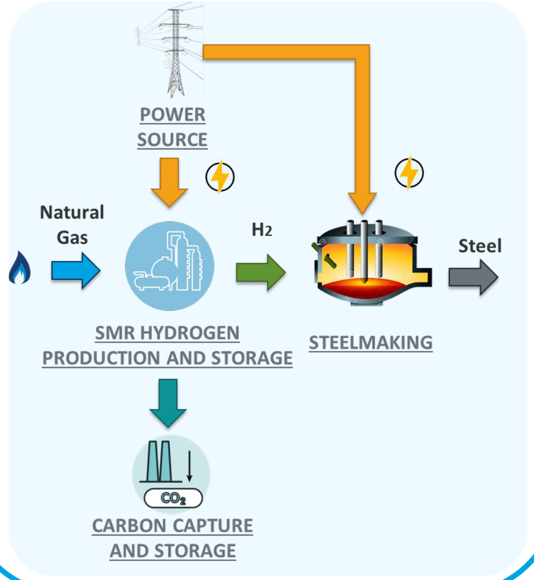
Co-location of assets can provide cost savings and cross-sector **coupling opportunities**.



Approach: Use Case Configurations Considered in Project

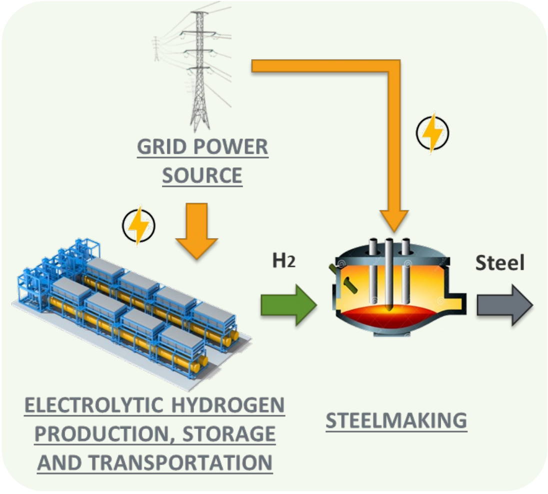
1

Fossil-H2-Steel/Ammonia Production (with CCS option)



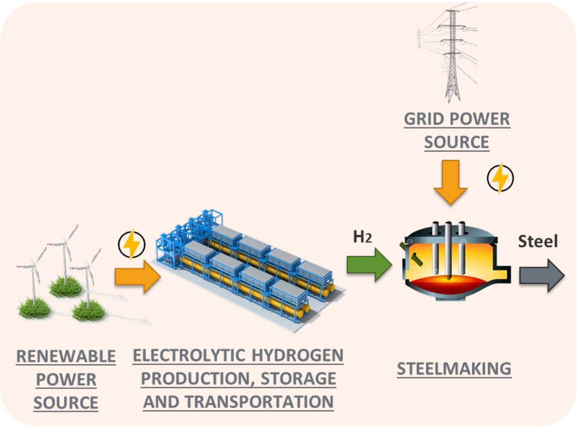
2

Grid Connected H2 Production co-located Steel/Ammonia



3

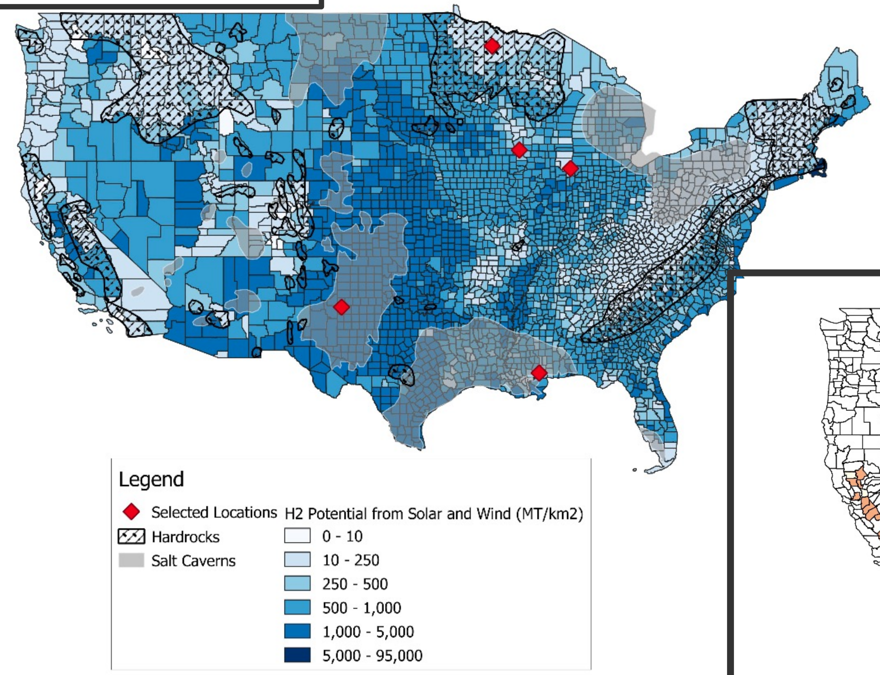
Integrated, Off-grid H2 Production with co-located Steel/Ammonia



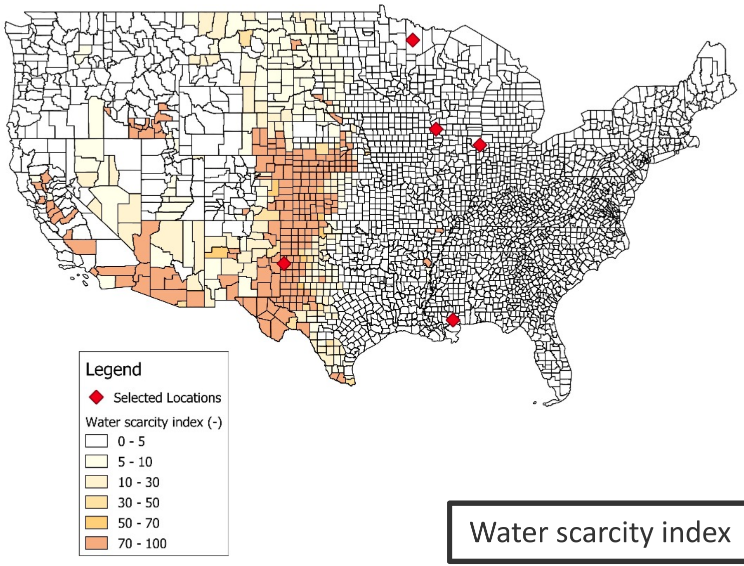
Determine the cost savings and potential advantages to off-grid, tightly coupled wind-H2-industrial end uses

Approach: Nationwide Data Integration

Renewables, hydrogen storage



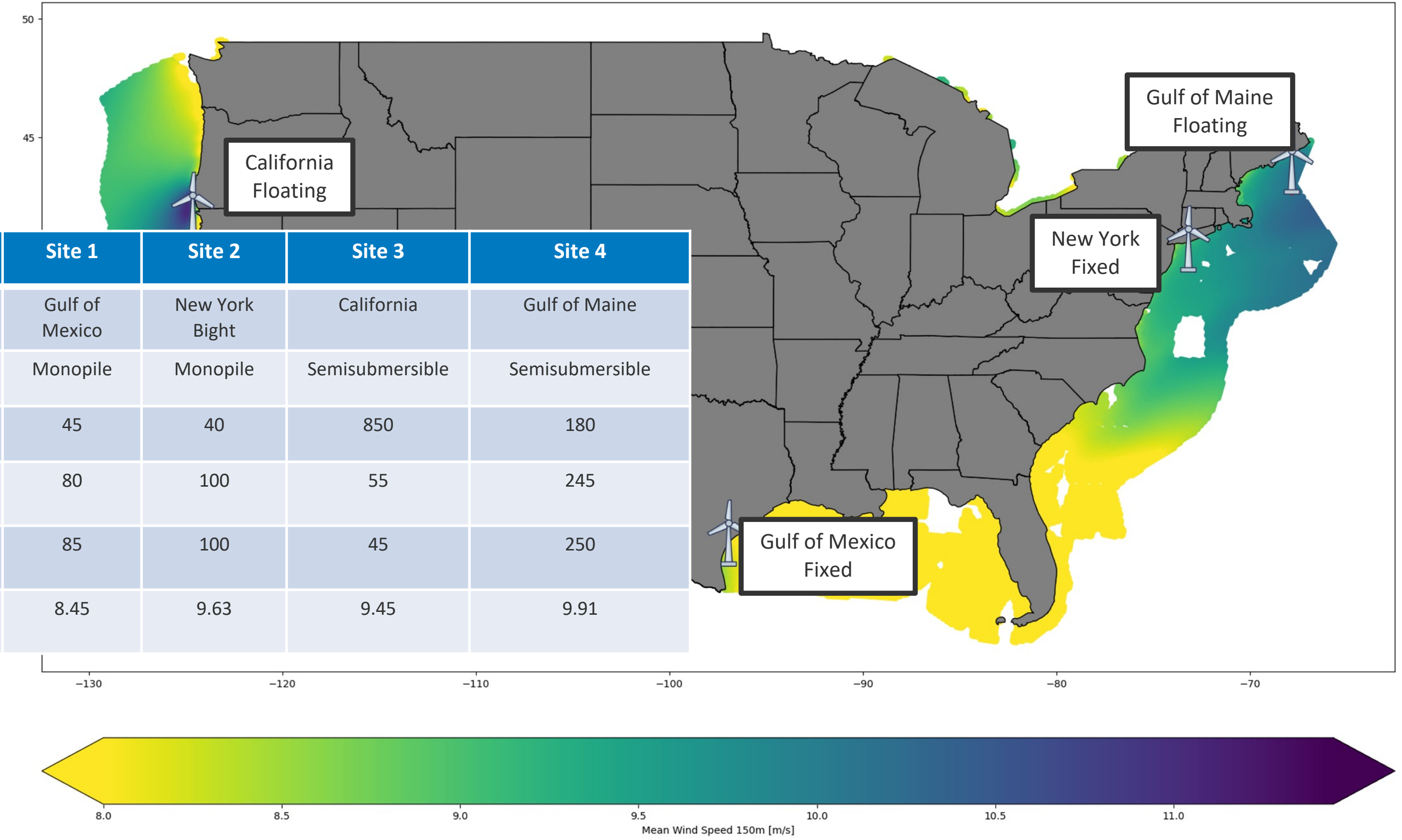
- Phase 1 focused on 5 locations (in red)
- Phase 2 includes nationwide trends for off-grid systems



Water scarcity index

GreenHEART: Green Hydrogen Economy And Renewable Technologies

Approach: Offshore Wind– H2



Site	Site 1	Site 2	Site 3	Site 4
Region	Gulf of Mexico	New York Bight	California	Gulf of Maine
Substructure	Monopile	Monopile	Semisubmersible	Semisubmersible
Depth (m)	45	40	850	180
Port distance (km)	80	100	55	245
Export cable length (km)	85	100	45	250
Avg Wind Speed (m/s)	8.45	9.63	9.45	9.91

FY23 Q4 Annual Milestone

- **Wind to Hydrogen:**

In support of Hydrogen Shot goals, use the new Hybrids to H2 to green steel/ammonia modeling capability to **identify regions in the U.S. where LCOH meets the $1/kg target in 2031.**

In support of DOE goals (Decarbonization and Floating Offshore Wind Shot), extend this modeling capability to include electrical generation from off-shore wind power. Assuming long term targets are met for these new generation capabilities, **identify regions in the US favorable to H2 production using the new respective hydrogen coupling.** The new H2 production capabilities would factor in H2 storage, transportation, and proximity to industry end-use.

Goal: Reduce the cost of floating offshore wind in deep waters by more than 70%, to $45 per megawatt-hour[1] by 2035.

>70% Reduction

2035

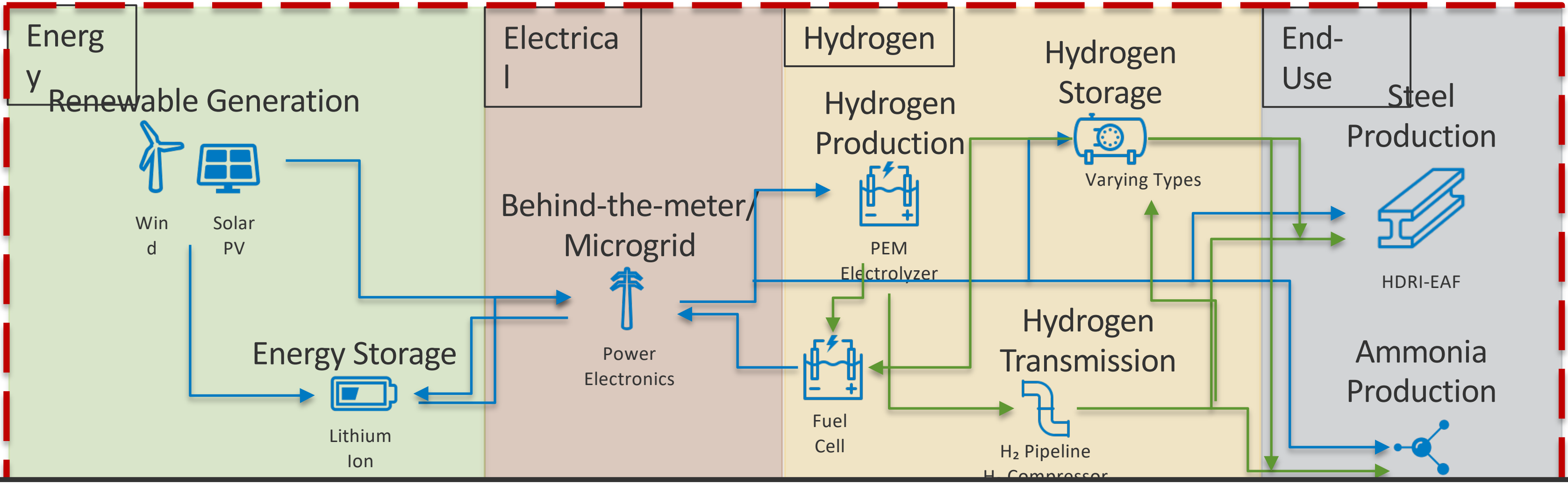
[1] For a reference site with 1,000-meter-deep water, 125 kilometers from the point of grid interconnection on shore.

FY24 Q2 Reference Designs

Locations:
- Onshore (1 location)
- Offshore
  - 1 fixed bottom
  - 1 floating

Reference Conditions:
- Off-grid
- Steady state end-uses
- 1-GW scale system
- Steel/ammonia

Co-locate and Integrated Design
- Energy Flow
- BOS
- Coordinated Controls
- Electrical design



GreenHEART is an open-source code and reference designs available on github.com

Major Accomplishments and Takeaways

Nationwide trends and progress toward Hydrogen Shot

- Many locations can achieve $1/kg with policy credits (dependent on 45V language)
- No locations can achieve $1/kg without policy credits

Offshore wind-H2 systems and impact of Offshore Floating Shot

- **H2 produced** by fixed bottom offshore wind is most cost effective in NY.
- **H2 delivered** by fixed bottom offshore wind is most cost effective in the Gulf of Mexico due to salt caverns
- **Offshore electrolysis** produces slightly cheaper hydrogen than onshore electrolysis

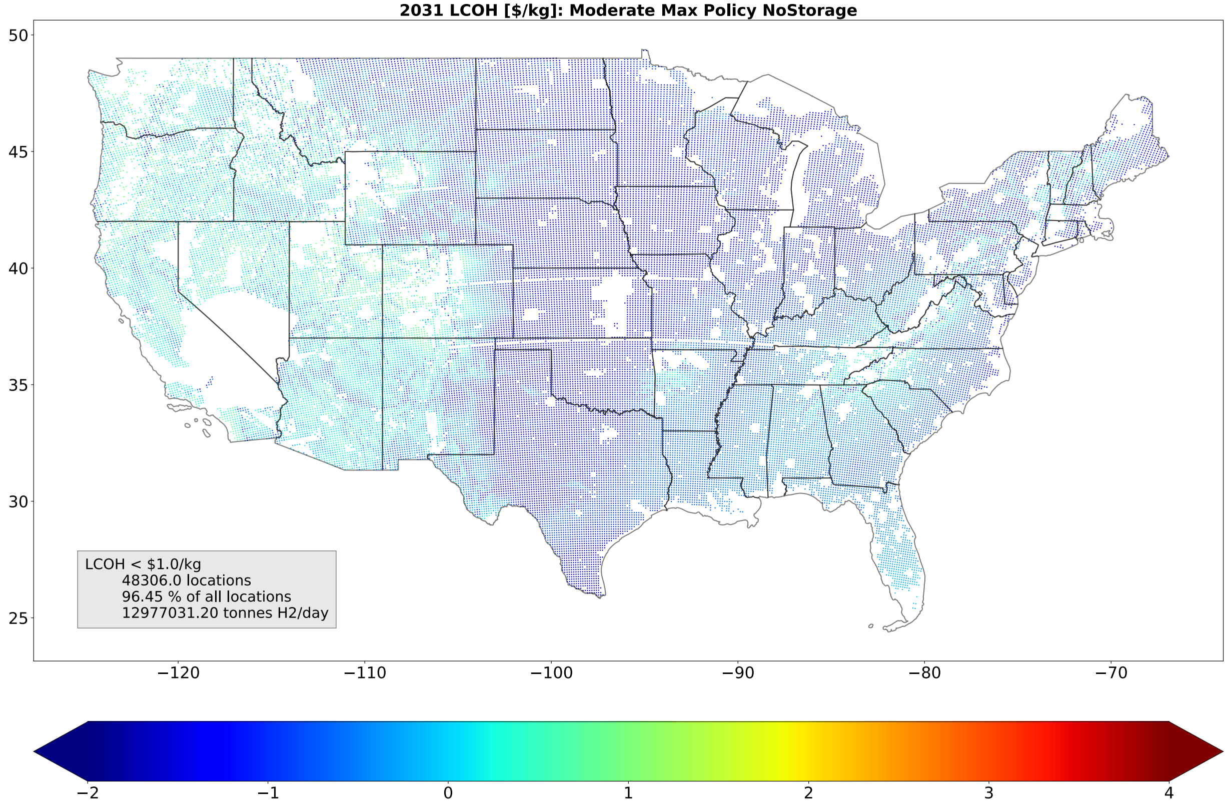
Initial Reference Designs released at the end of Q2 (locations based on FY23 analysis)

- Onshore green steel plant in Minnesota
- Onshore green ammonia plant in Texas
- Offshore fixed bottom green hydrogen in Gulf of Mexico
- Offshore floating green hydrogen on west coast, northern California

H2 Production – Locations where $1/kg can be achieved with Max Policy

Key takeaways

- All locations shown are <$1/kg with max policy.
- No locations achieve <$1/kg without policy.
- H2 PTC, renewable PTC, storage ITC included
- Each location optimized for wind, solar, battery, electrolyzer ratio
- Advanced costs: 99% of locations <$1/kg
- Conservative costs: 86% of locations <$1/kg



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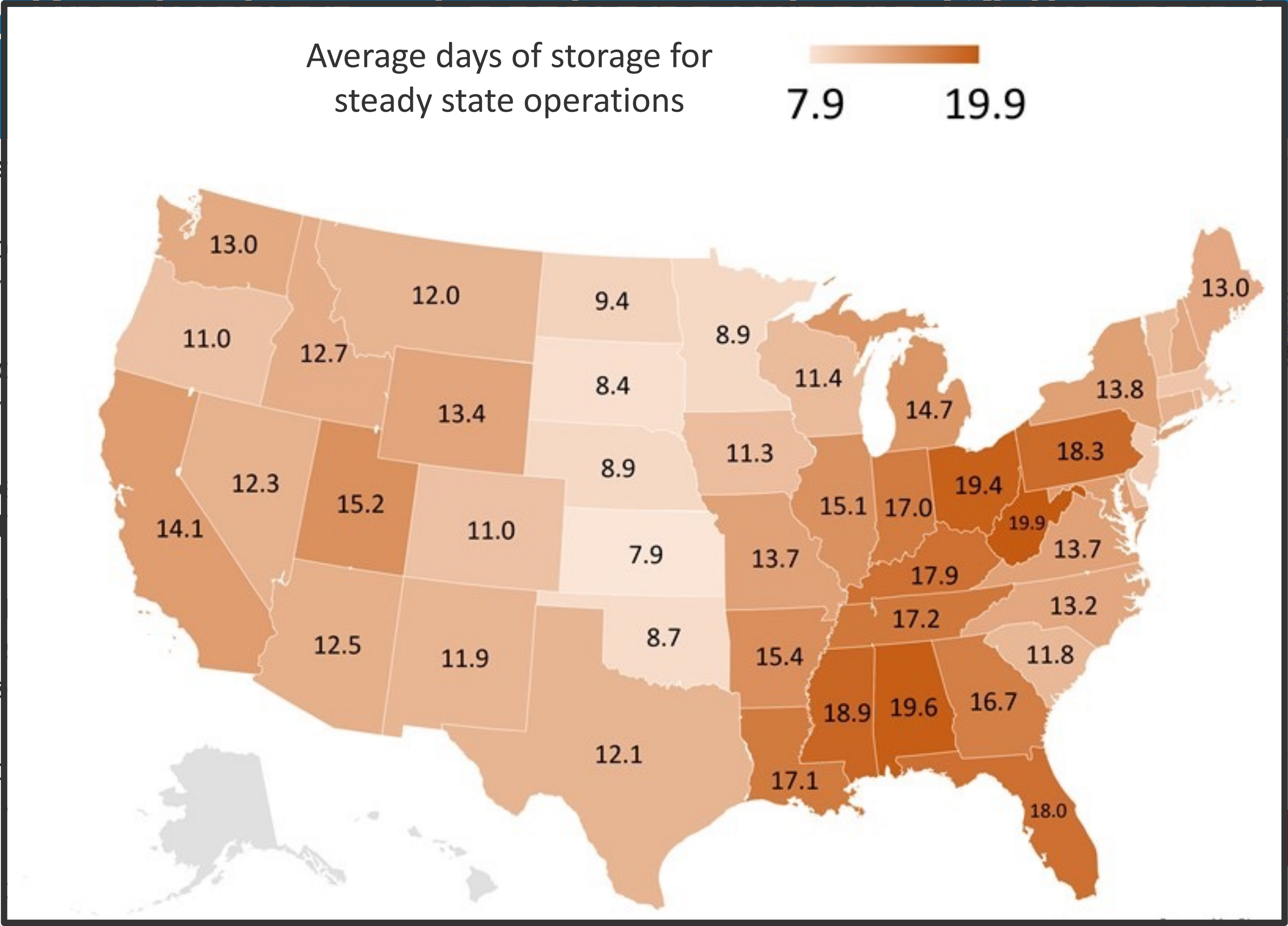

Key takeawa

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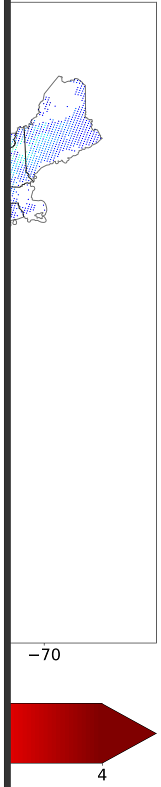
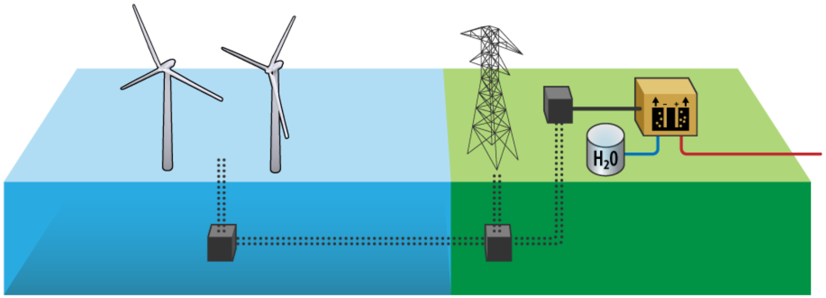


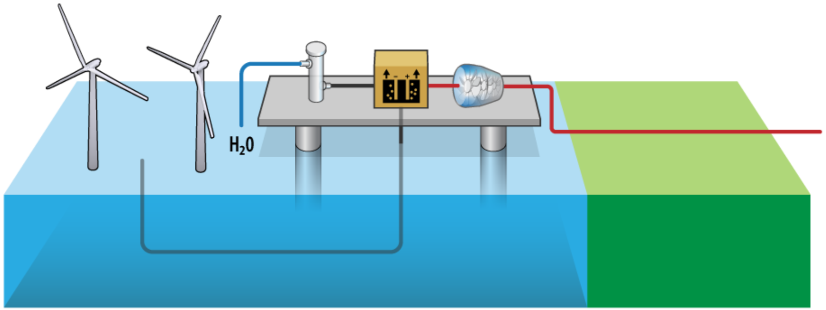
Accomplishments: Layout Configuration

Configuration 1
"Onshore H2"



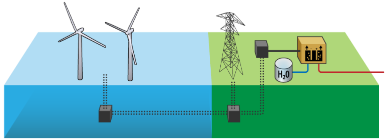
- Offshore Wind
- HVDC/HVAC Transmission
- Onshore Electrolysis
- Onshore H_2 Storage

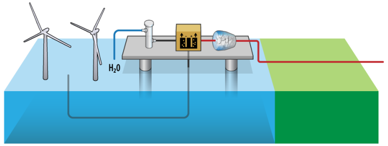
Configuration 2
"Offshore H2"

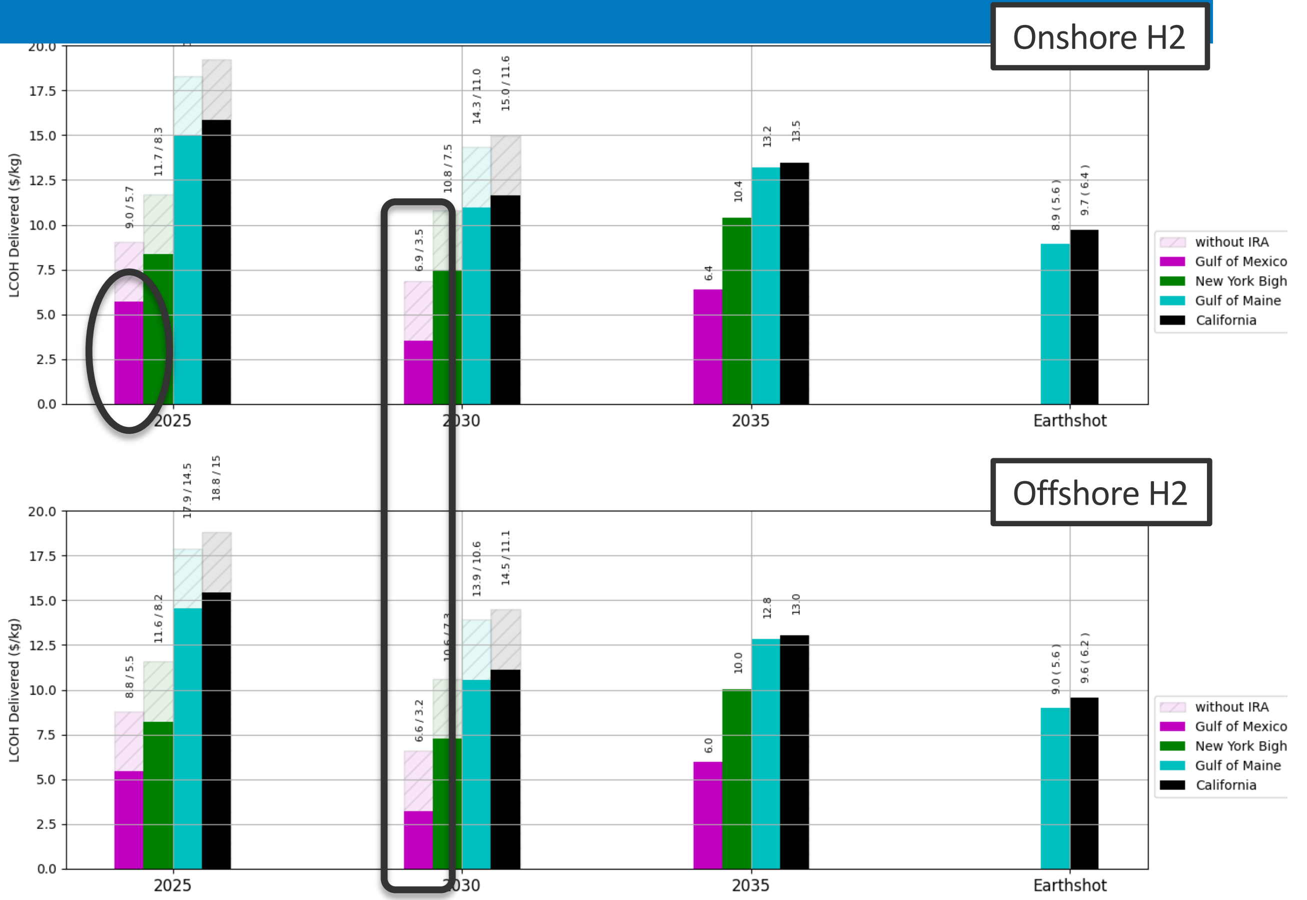


- Offshore Wind
- Offshore Electrolysis
- Pipeline Transmission
- Onshore H_2 Storage

Accomplishments: Hydrogen Delivered







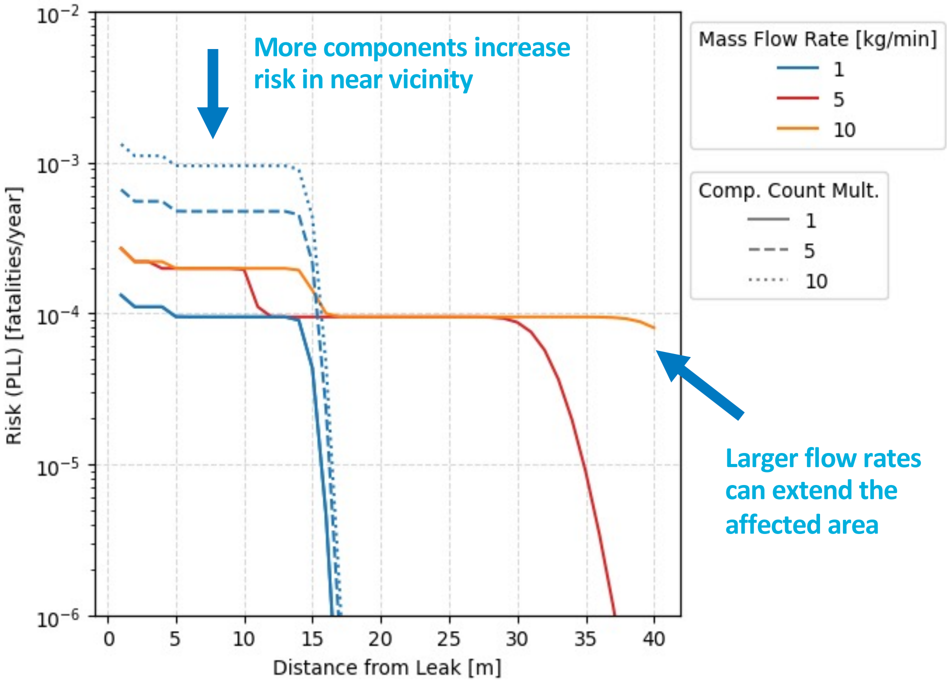
Key Takeaways:

- Gulf of Mexico, with policy, achieves the lowest LCOH delivered due to access to salt caverns.
- Pressure vessel storage applied everywhere else.

Risk Calculations – Ensuring Safe Reference Designs

- Example risk calculations show trade-offs of distributed vs. centralized production systems

- ***Centralized system (focus of ref. designs)***
  - Fewer, larger components
  - Lower risk nearby to system, but larger affected area
- *Distributed system*
  - More, smaller components
  - Higher risk nearby to system, but hazards do not extend as far

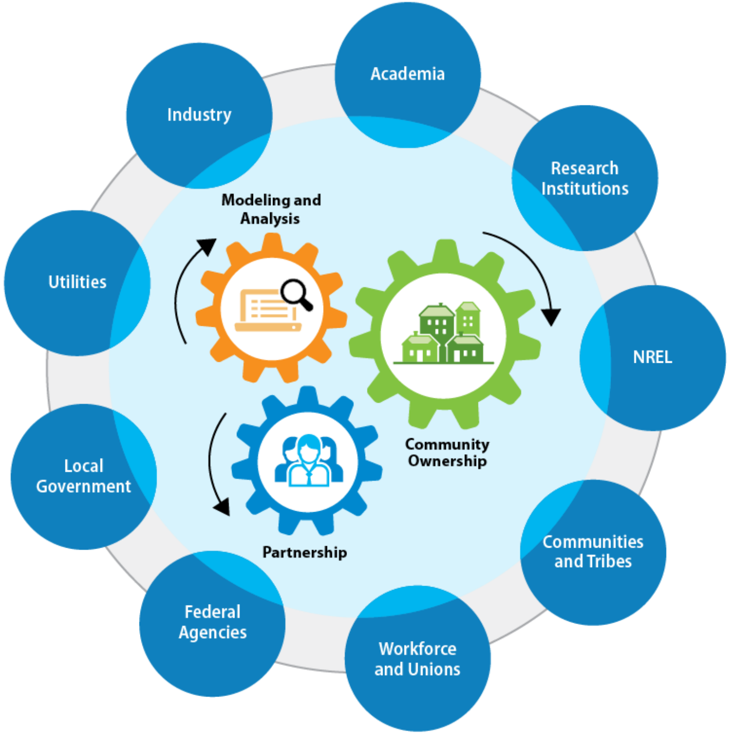


DEIA/Community Benefits Plans and Activities

- Partner with Communities LEAP program targeting J40 communities

- **Communities LEAP – Duluth, MN**
  Explored green steel potential using GreenHEART developed in this project

- **GreenHEART can allow for geospatial analysis** that could include:
  - Energy communities
  - Equity metrics
  - Community specific data



Collaboration and Coordination

- Collaboration has been a key to achieving our projects goals.
- HFTO/WETO collaboration
- Lab collaborators include:
  - **LBNL (sub)** – steel TEA model and inputs on hydrogen storage technologies
  - **ANL (sub)** – GREET for LCA and ammonia modeling
  - **ORNL (sub)** – power electronics design and performance for different configurations of wind and electrolyzers.
  - **SNL (sub)** – to come – safety, codes, and standards necessary to realize green steel and green ammonia
- **University collaborator:** Arizona State University (Sridhar Seetharaman)

Collaboration and Coordination

- **Industrial Advisory Board**
  - Renewables: NextEra, GE
  - Hydrogen: Nel, HyStor, Cummins
  - End uses: Nucor, University of Minnesota, Research Triangle Institute, Shell

- **Additional outreach:** Technical Experts Meeting on "Renewable Hydrogen"
  - Sept 6, 2023 (led by Genevieve Starke)
  - Brought together international experts
  - Precursor to IEA Task to promote collaboration

Remaining Challenges and Barriers

- **Challenges:**
  - Iterating on realistic reference designs with enough granularity to pursue tightly coupled systems as technology evolves.
  - Finalizing national impact of off-grid systems using coupled grid and fuels capacity expansion models.
  - Demonstrating, at scale, the value of tightly or directly coupled systems.
  - Understanding the safety challenges with these novel designs

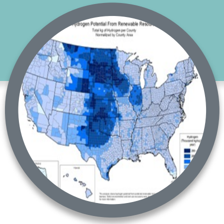
Proposed Future Work

PROJECT PHASES

PHASE 1: General Design, Model Integration, Initial TEA/LCA Assessments	**PHASE 2**: Detailed system design/analysis, demo concepts	**PHASE 3**: Demonstration

ACTIVITIES AND GOALS

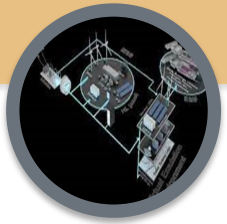
Phase 1
- Initial end-to-end integrated analysis for renewables-H2-steel/ammonia in an Initial Project Sprint
- Investigate possible advantages to off-grid, tightly coupled GW-scale wind-H2 production for steel/ammonia end uses



Phase 2
- National roadmap + location-specific reference designs
- Detailed system design and control from power electronics to storage technologies to product delivery
- Design possible 10 MW Green Steel Demo at NREL's ARIES

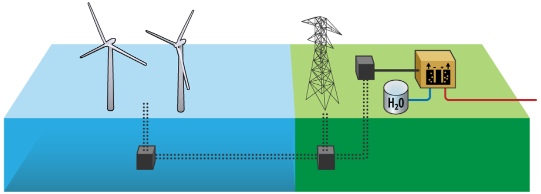
Nearing completion

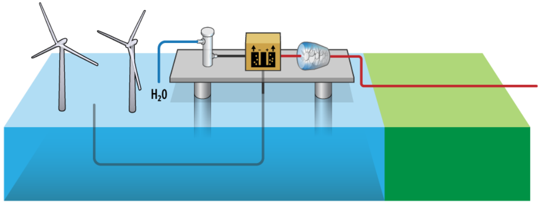
Phase 3
- 10 MW hardware integrated research and demonstration platform at ARIES
- GW-scale emulation of the end-to-end system at ARIES including renewables-H2-steel/ammonia



Summary

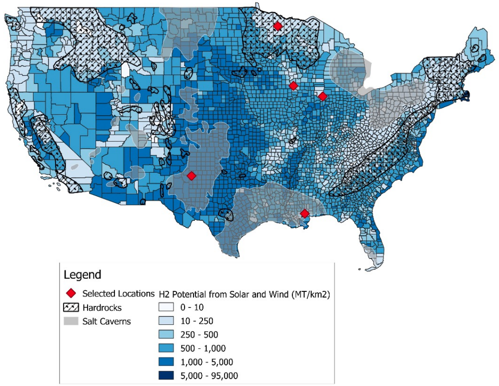
Impact: Off-grid, behind-the-meter applications have the potential to be cost competitive with on-grid configurations. Reference designs centered around these configurations





Other Major Accomplishments:

- *Nationwide trends* and progress toward Hydrogen Shot - many locations achieve $1/kg with policy
- *Offshore wind-H2 systems* and impact of Offshore Floating Shot – Gulf of Mexico was lowest cost for hydrogen delivered



Established and Engaged Industrial Advisory Board

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