Hydrogen Energy Storage System at Borrego Springs Towards an H2 Enabled 100% Renewable Microgrid

Kumaraguru Prabakar (PI), Ph.D., M.B.A.,
National Renewable Energy Laboratory
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DOE Hydrogen Program
2024 Annual Merit Review and Peer Evaluation Meeting

Project ID: SDI002

Project Goal

MAJOR GOALS & OBJECTIVES

Implement, characterize, and analyze advanced H_2 distributed energy resources and controls towards a 100% renewable Borrego Springs microgrid:

- ✓ **Establish** intelligent control of H_2 distributed energy resources to stabilize the microgrid and reduce PV curtailment.
- ✓ **Develop** hardware and conduct power hardware-in-the-loop (PHIL) performance analysis to de-risk field deployment.
- ✓ **Analyze** baseline and future operational characteristics of the Borrego Springs microgrid under different H_2 configurations and characterize resilience improvements.
- ✓ **Share lessons learned** with the community and other stakeholders-via white papers, presentations, educational site visits, and other materials.

Photos by SDGE

Overview

Timeline and Budget

- Project start date: 09/01/22
- Project end date: 08/30/24
- Total project budget: $4,674,000
  - Total DOE share: $4,160,000
  - Total Cost share: $514,000
  - Total DOE funds spent*: $823,000
  - Total cost share funds spent*: $150,000

    * As of 03/07/2024.

Barriers

- Barriers and targets
  - Hydrogen assets are not considered in utility techno-economic analysis. Target to include updated hydrogen asset models for community techno-economic analysis.
  - Synthesize hydrogen asset sizing requirements for specific community resilience goals.
  - Develop hardware-in-the-loop (HIL) setup and demonstrate microgrid controller operation of grid-forming fuel cell inverter operation towards community resiliency goals.

Partners

- National Renewable Energy Laboratory (NREL)
- San Diego Gas & Electric Company (SDG&E), field deployment lead.
- PXiSE Energy Solutions, microgrid controller vendor.

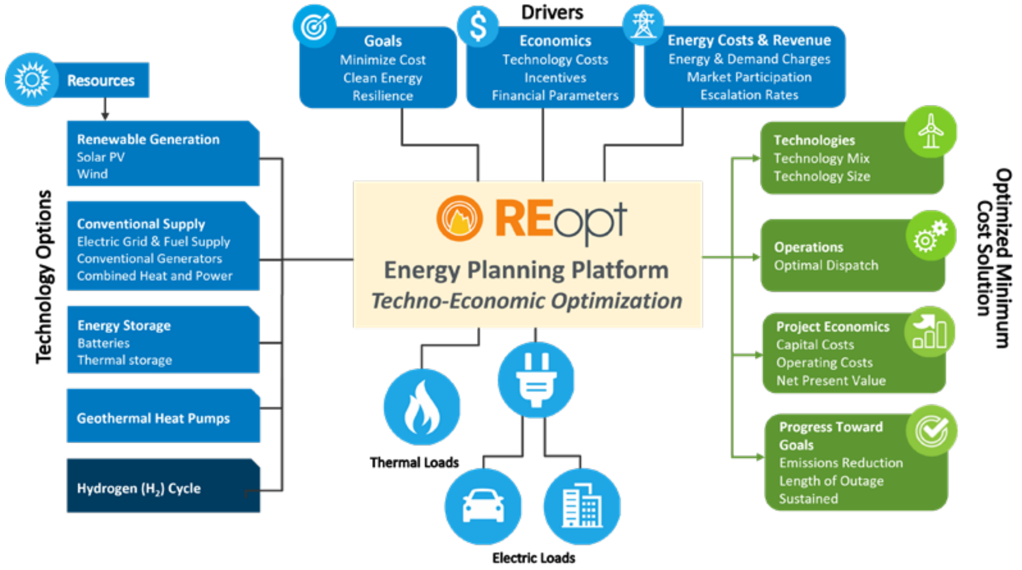
Safety Planning & Culture

- This project involves experiments at 480 volt, power rating of lower than 2 MVA, and hydrogen usage for fuel cell operation.
- ARIES requires projects to undergo rigorous internal review.
  - The project team has worked with safety officers and other internal personnel at NREL to review the experimental setup and use appropriate protection measures (fuses, circuit breaker controls and others).
  - Operations personnel undergo site specific training and engineering safety training regularly as recommended by DOE.

Relevance/Potential Impact (analysis)

In this project, NREL will add a hydrogen energy storage system (which includes fuel cells, storage tanks, and an electrolyzer) as one of the technology options available in REopt®—a publicly available techno-economic decision-support platform developed by NREL researchers for energy system planning.

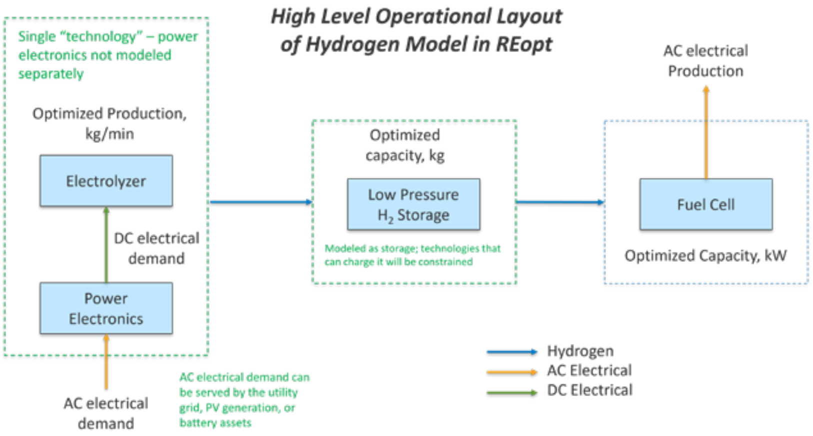
- Integrating a hydrogen energy storage system into REopt will advance the DOE Hydrogen Program goals through the following project objectives:
  - Identify the optimal sizing of hydrogen fuel cells, electrolyzers, and storage tanks required to achieve a 100% renewable microgrid for Borrego Springs.
  - Quantify the reduction in greenhouse gas emissions and criteria pollutants resulting from (1) replacing on-site diesel generators with a hydrogen storage system, and (2) using hydrogen assets to supply site loads during grid-connected microgrid operations.
  - Improve accessibility of planning for H2 assets for a wide range of REopt users, including developers, researchers, government organizations, and utility and industry partners.



Approach (Analysis)

Phase I—Model Development

- Integrate hydrogen storage system components into REopt:
  - Components that will be modeled near term include hydrogen fuel cells, storage tanks, and an electrolyzer.
  - Future work could include the addition of high-pressure storage and compressor models to support hydrogen transportation analysis.
- Integrate hydrogen fuel cells, storage tanks, and an electrolyzer into REopt's resilience performance model to quantify the outage survivability of the optimal hydrogen microgrid based on component reliability and availability.



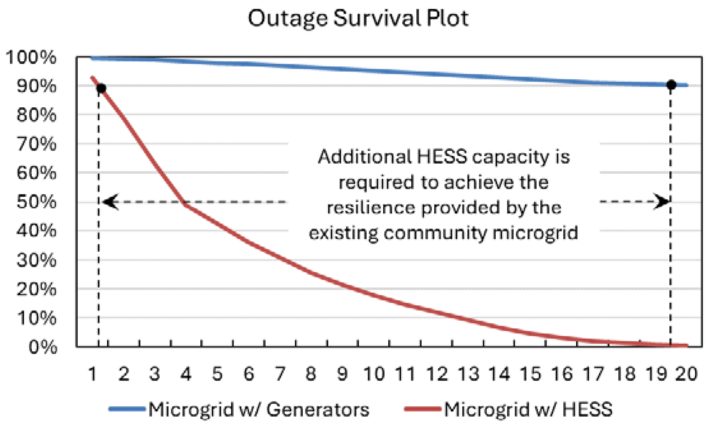
Phase II—Analysis

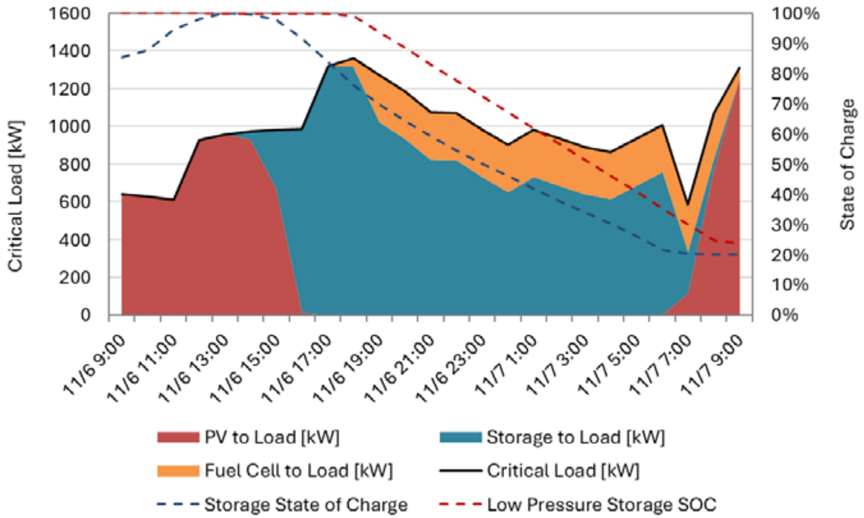
- **Scenarios analyzed:**
  - Benchmark the current microgrid operation without hydrogen assets.
  - Quantify the benefits of integrating hydrogen storage system components into the microgrid with financial and resilience analyses in REopt:
    - Report metrics for the planned hydrogen system.
    - Report metrics for a 100% renewable microgrid scenario.
- **Outputs and metrics:**
  - Optimal system sizes required to achieve the analysis goal
  - Optimal dispatch strategies (including minimizing PV curtailment)
  - Economic metrics (including capital costs, O&M costs, fuel costs, utility costs, and net present value)
  - Resilience metrics (outage survivability, reported as probability of survival)
  - Emissions metrics (including climate and health emissions).

Summary of Results (scenarios 1 and 2)

Resilience from planned hydrogen assets (scenarios 1 and 2):

- The existing microgrid offers up to **20 hours** of resilience, whereas the planned hydrogen energy storage system (HESS) will offer up to **1 hour** of resilience.
- The planned hydrogen asset sizing does not provide enough resilience because:
  - The state of charge for both the battery energy storage system (BESS) and HESS are depleted during the night.
  - The critical circuit rooftop PV capacity available is too small to recharge the BESS and HESS as well as to supply loads during the day.

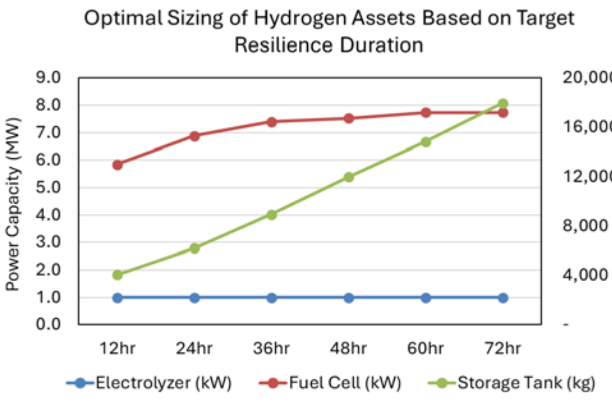


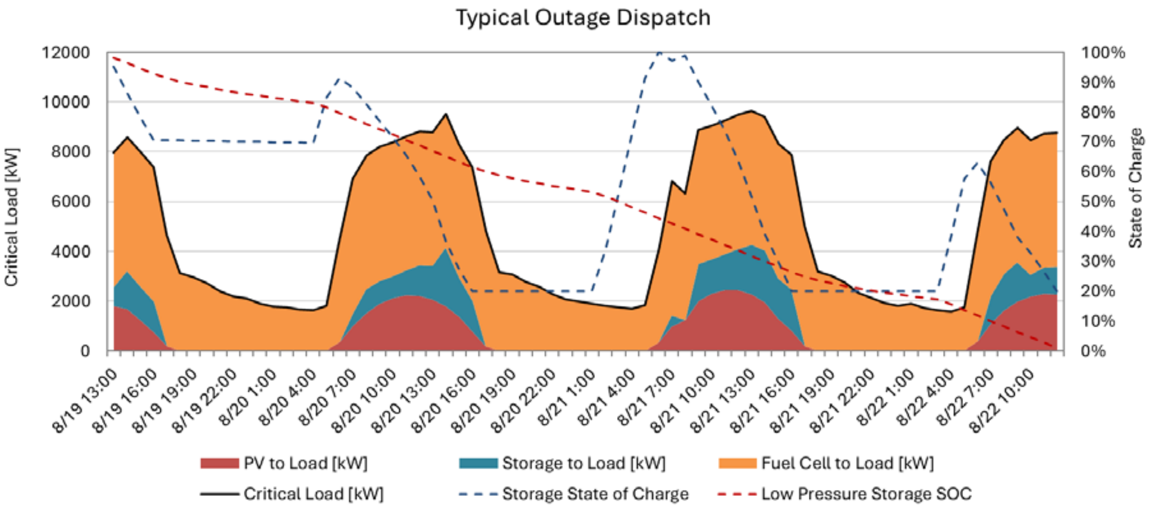


Summary of Results (scenarios 3)

Optimal hydrogen asset sizing for target resilience (Scenario 3):

- Hydrogen asset sizing based on target resilience duration is shown below. The target resilience hours is an important determinant in sizing the hydrogen assets for the microgrid
- The critical circuit rooftop PV capacity available during an outage is not sufficient to recharge the storage as well as supply loads during the day. This forces the stored hydrogen at the start of an outage required to be sufficient to sustain critical loads for the duration of the outage. Therefore, allowing the additional existing PV to replenish the hydrogen storage will significantly reduce the storage sizing.





Preliminary Analysis Results: Do Not Cite

Key analysis takeaways

- NREL has developed a model for the **techno-economic optimization and resilience quantification for H_2 assets** and **tested** three scenarios (Scenario 1: Business-as-Usual, Scenario 2: Resilience Quantification With Planned H_2 Assets, and Scenario 3: Optimal Sizing of H_2 Assets).

- **Scenario 1 results** show that the **existing storage capabilities** (BESS and diesel generators) are enough to **sustain ~20-hour outages**, while historically the microgrid has faced close to 12-hour outages. **Load shedding** can significantly increase the microgrid's **outage survivability**.

- **Scenario 2 results** show that, after **decommissioning existing diesel generators**, the **planned H_2 assets** provide **1 hour** of outage survivability, and load shedding only minimally improves resilience results.

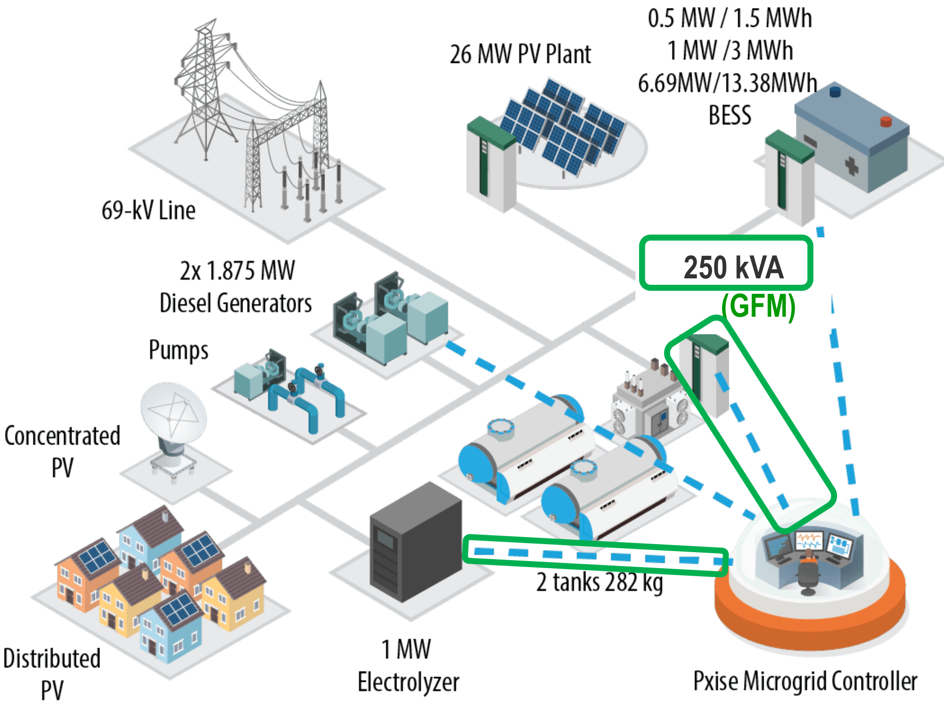
- **Scenario 3 results** provide **optimal sizes of H_2 assets** (electrolyzer, storage tank, and fuel cells) for outage durations up to 72 hours. Based on outage dispatch and survival probability results, the following **alternative options** could reduce the overall cost:
  - Allow **more existing PV** assets to **contribute** to critical load, minimizing the amount of overall storage needed.
  - **Increase the size** of the existing **battery** energy storage to reduce the amount of hydrogen needed.
  - Load shedding to reduce overall load being provided during the outage.

Relevance/Potential Impact (lab demonstration)

- The proposed project leverages existing and planned SDG&E funded storage.

Electrolyzer	Power consumption	1 MW
	H_2 Production Rate	18 kg/hr.
H_2 Storage	Working Capacity (total)	282 kg
	# tanks	2
	Operating Pressure Range	145-580 psig
Fuel Cell	Power Output	250 kVA **(grid-forming)**
	H_2 Consumption	17 kg/hr.
Microgrid Controller	**H2 assets integrated into Borrego Springs microgrid controller**	

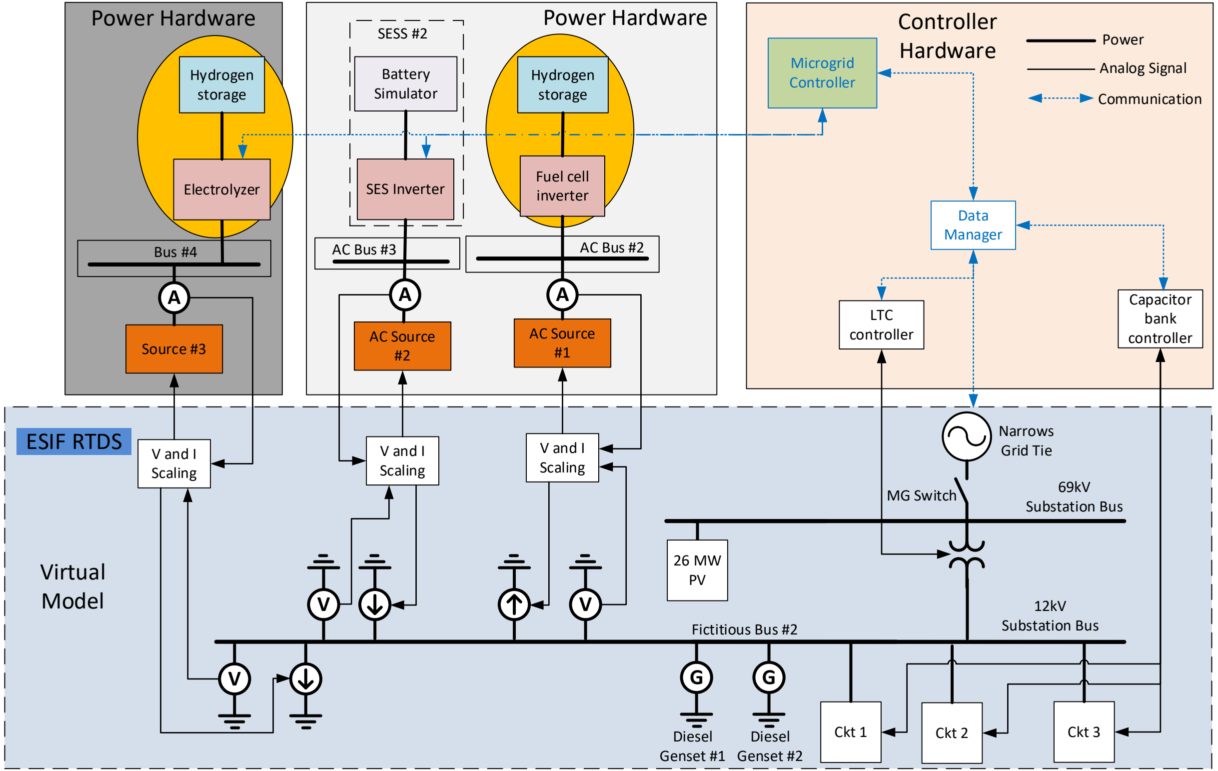
- Upgrade inverter with grid-forming capability
- Integrate hydrogen assets into Borrego Springs microgrid controller to demonstrate optimized control strategy
- **Green denotes planned upgrades through the proposed project.*



Hydrogen Energy Storage System (HESS) upgrade elements

Relevance/Potential Impact (lab demonstration)

- Use Advanced Research on Integrated Energy System (ARIES) assets to run PHIL and controller hardware-in-the-loop (CHIL) experiments to de-risk field deployment.



Hardware-in-the-loop progress

Lab demonstration:

- Currently hosting PXiSE Energy Solutions' microgrid controller under a different project along with the Borrego Springs model in the controller.
- The Digital real-time simulation model of Borrego Springs is running at NREL's Energy Systems Integration Facility (ESIF) with the battery energy storage asset in PHIL and the PXiSE microgrid controller in CHIL.
- The PHIL setup with battery energy storage inverter is operational and reliable.

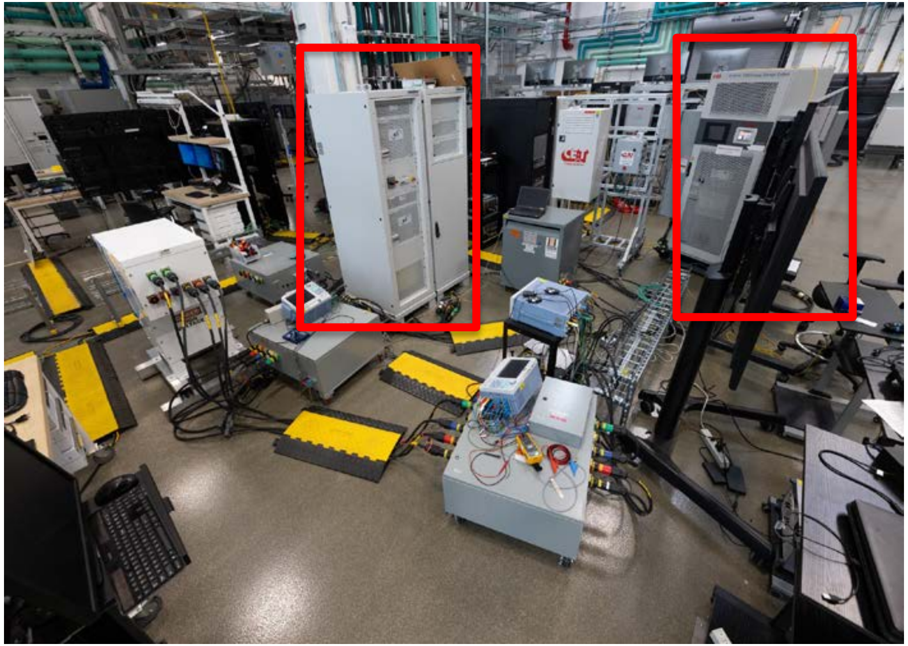
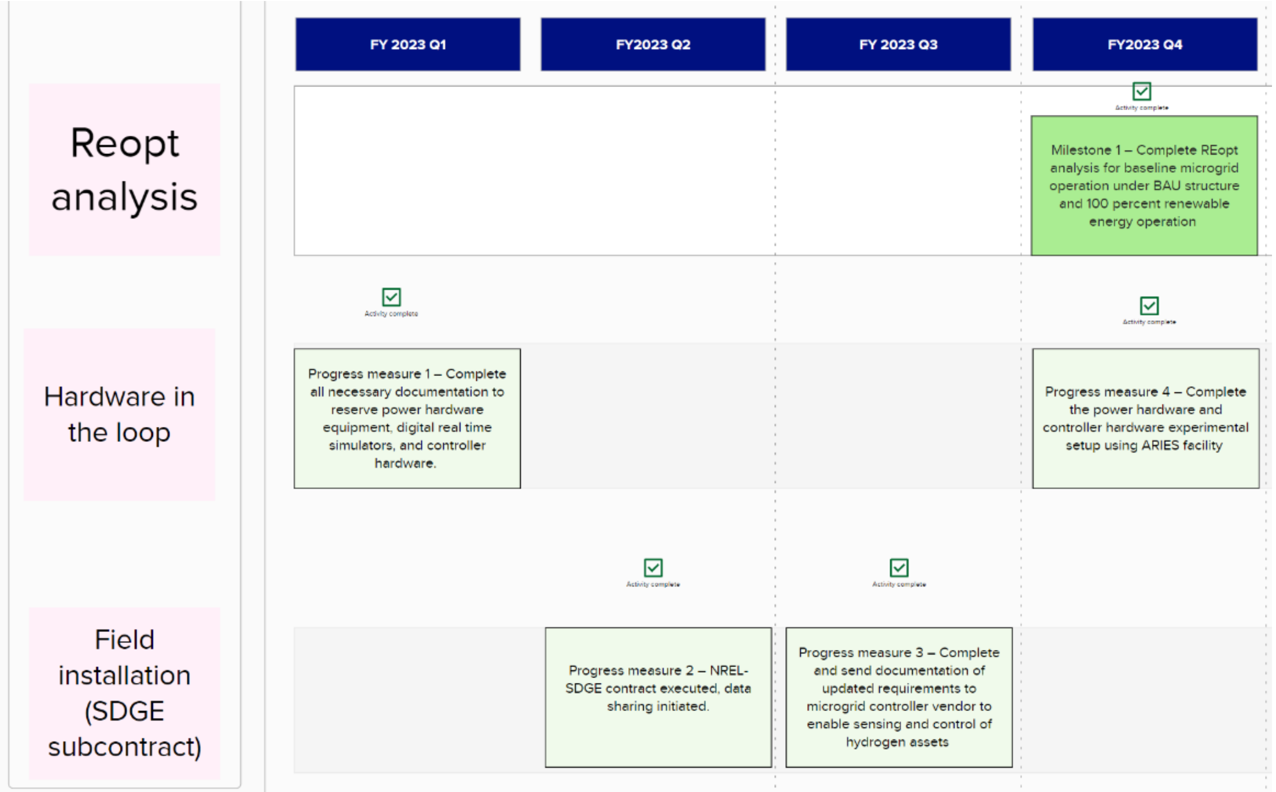


Photo by NREL

Field deployment update

- The project team had issues with their first contractor to install the electrolyzer, and other hydrogen assets, and too-high costs with subsequent bids.
- SDG&E has decided not to continue to pursue the installation of hydrogen assets in Borrego Springs.
- NREL will not be able to complete the original scope of work, including the hardware in Borrego Springs, but has a few aspects of project we recommend be completed.



Impacted progress measures and milestones

	FY2024 Q1	FY2024 Q2	FY2024 Q2	FY2024 Q3
Reopt analysis		Milestone 3 - Report the differences in operational strategy and results as compared to the BAU scenario.		
Hardware in the loop				Milestone 6 – Community education and outreach
Field installation (SDGE subcontract)		Milestone 2 – Commission hydrogen assets in Borrego Springs microgrid Milestone 4 – Complete inverter firmware and microgrid controller upgrades for specified use cases	Milestone 5 – Initiate field testing and microgrid operations	

Response to Previous Year Reviewers’

Primarily positive feedback. Selected comments and responses below

<table>
<tr><th>Reviewer comments</th><th>Response</th></tr>
<tr><td>The approach of HIL analysis and Renewable Energy Integration and Optimization Platform (ReOPT) development to add missing modules is a great approach. However, it is not clear that the objectives of optimal sizing from ReOPT are reflected in the hardware selections</td><td rowspan="2">Reopt-based techno-economic analysis has provided sizing of hydrogen assets to meet community resilience goals. This would be evaluated in electromagnetic transient (EMT) domain modeling to verify the stable operation of the system. Due to the lack of “rule of thumb-” or “formula-” based approaches to understand the stability of a real-world system, EMT analysis is necessary to understand the final inverter sizing for the assets.</td></tr>
<tr><td>As discussed during the presentation, decisions around equipment sizing have been somewhat arbitrary so far because of financial limitations rather than technical optimization-type analysis. If these are properly caveated for this project, this is a relatively minor but still important limitation. It is suggested for the future that the project allow for a larger system that is more optimized, which would be an important future extension, presumably based on successful completion of this phase.</td></tr>
<tr><td>It would be great to learn more about how the microgrid (once completed) would function in a power outage situation, what loads would be picked up or shed, and the implications for the community.</td><td>The utility operation plan dictates the predetermined hierarchy of loads that are critical, interruptible, and priority.</td></tr>
</table>

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Reviewer comments	Response
It is recommended that the team go beyond California Independent System Operator (CAISO) pricing to look at the true electricity price in a resilience event. This true price may be infinite if no grid power is available. Understanding the actual pricing (based on supply and demand), in collaboration with SDG&E, may influence the techno-economic analysis (TEA) and get more accurate results.	REopt analysis was performed in collaboration with SDG&E to keep the analysis high fidelity and the results as accurate as possible.
Dissemination and publication of the results of this project will be crucial in advancing hydrogen adoption.	The project team has presented the work in an IEEE PES General Meeting Panel session and an IEEE PES ISGT LA panel session.

Response to Previous Year Reviewers’

Primarily positive feedback. Selected comments and responses below

<table>
<tr><th>Reviewer comments</th><th>Response</th></tr>
<tr><td>The project should add external national labs or industrial partners with expertise in fuel cells, electrolyzers, and bulk hydrogen storage.</td><td rowspan="2">The NREL project team is currently leading another project with SoCalGas that contains a larger industrial advisory board with electrolyzer manufacturer, fuel cell manufacturer, energy management system vendors, and universities. The NREL team and the SDGE team has dedicated hydrogen personnel with expertise on electrolyzer and fuel cell operation.</td></tr>
<tr><td>The team lacks resident expertise in hydrogen assets that are planned for addition to the microgrid: hydrogen fuel cell, electrolyzer, and hydrogen storage.</td></tr>
</table>

Response to Previous Year Reviewers’

Primarily positive feedback. Selected comments and responses below

Reviewer comments	Response
The project needs to clearly provide its tasks and subtasks, which is required for DOE projects, as well as quarterly milestones and annual go/no-go milestones. The project needs to identify fuel cell and electrolyzer vendors as soon as possible. In addition, the project needs to accelerate the progress because of the delay in the first year.	The project team followed DOE’s PMP recommendations. The information on progress measures, and milestones were presented in the AMR review slide deck. The initial delays were caused by delays in subcontracting processes.
The project does not include clear and measurable milestones, despite having such a large budget ($4.67 million), nor does it provide clearly described tasks and subtasks. The project has a significant delay (the start date was September 1), but the cause of the delay is unknown. The project barely generated any data.	

Collaboration and Coordination

Partner	Comment
SDG&E, Subcontractor	Utility partner, field deployment lead.
PXiSE Energy Solutions, Subcontractor to SDG&E	Microgrid controller vendor.

Remaining Challenges and Barriers

- Complete the development of hydrogen modules in REopt tools.
- Complete review process of the analysis assumptions, scenarios and results.
- Identify and finalize interoperability points for the hydrogen assets in microgrid controller.
- The planned field deployment and demonstration of the hydrogen assets at the Borrego Springs site will not be completed.

Proposed Future Work (analysis)

- Complete the development of hydrogen capabilities in Reopt.
- Complete the review and validation of the HESS model developed in REopt to be able to make the model publicly available.
- Prepare final report for the overall Borrego Springs analysis.
- Write and publish journal article(s) for the novel hydrogen modeling and resilience methodology developed in this project.

Any proposed future work is subject to change based on funding levels

Proposed Future Work (lab experiments)

- Complete test plan documentation.
- Complete modeling of hydrogen assets in microgrid controller.
- Complete integration of hydrogen assets in digital real time simulation model of the microgrid.

Any proposed future work is subject to change based on funding levels

Summary

- **Optimal performance strategy and resulting annual hourly and annual energy use, emissions, operating costs, battery charge levels, and hydrogen storage levels defined** (via analysis)
- **Demonstration that conventional diesel generators are not required when using H_2 assets using optimized microgrid control scheme** (via analysis and HIL)
- **Resilience benefits of additional H_2 assets** established (via analysis)
- Cost and resilience benefits of **reduced PV curtailment** quantified (via HIL and analysis)
- Balance-of-system requirements established for **large-scale deployment** (via HIL and analysis)
- Development of H_2 assets integrated into the **HIL test bed** using ARIES equipment (via HIL)
- **Transient stability using H_2 fuel cell inverter as grid-forming asset** during islanding operations characterized (via HIL)
- **Operation of H_2 assets under different modes of microgrid operation** and power system events described (via HIL)
- **H_2 fuel cell inverter control strategy and microgrid controller strategy established** (via HIL)
- **White papers**, **publications**, stakeholder and community **site visits.**

Feasibility of H_2-enabled 24/7 100% renewable microgrid demonstrated

Thank You

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NREL/PR-5D00-89180

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Technical Backup and Additional Information

Technology Transfer Activities

- Software record number SWR-23-58 includes the hydrogen asset modeling in the REopt tool.

Special Recognitions and Awards

- REopt with hydrogen asset techno-economic analysis is internally under review for R&D 100 Award application.

Publications and Presentations

- Presented the REopt developments and hardware-in-the-loop developments in 2023 IEEE power and energy society general meeting in hydrogen panel session.
- Presented the REopt developments and hardware-in-the-loop developments in 2023 IEEE power and energy society ISGT conference in hydrogen panel session.