Technoeconomic Analysis of Discrete and Unitized Reversible Fuel Cells for Energy Storage Applications

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Project ID: FC367

Project Goal: Assess unitized RFC potential in context of LDES application and HFTO's tech targets

Vision

Identify potential advantages and/or key areas of RD&D for unitized reversible fuel cells (URFCs) for long duration energy storage (LDES)

What

- Assess probable URFC stack and system cost and performance based on current technological status and HFTO tech targets for discrete electrolyzers and fuel cells
- Compare URFCs to discrete RFCs based on levelized cost of storage (LCOS) for varying storage durations

How

- Perform process modeling of low- and high-temperature discrete and unitized RFC systems to identify potential system equipment costs, round trip efficiencies, and operational flexibility
- Leverage NREL tools such as StoreFAST and ProFAST to calculate LCOS for different future scenarios and perform sensitivity analysis

Why

- Determine the pathways and applications for which URFCs have the most potential in the context of broader electrolyzer and fuel cell development
- Identify ways to fine-tune future URFC RD&D objectives

Overview

Timeline and Budget

- Project Start Date: 10/01/2023
- FY23 DOE Funding (if applicable): $0k
- FY24 Planned DOE Funding (if applicable): $300k
- Total DOE Funds Received to Date**: $200k

  ** Since the project started

Barriers

- Inconsistent Data, Assumption and Guidelines
- Insufficient Suite of Models and Tools

Partners

- This project will solicit data and/or feedback from industry including:
  - Plug Power
  - Ballard
  - FuelCell Energy

Potential Impact: Refining URFC RD&D objectives and identifying most promising applications could streamline their development

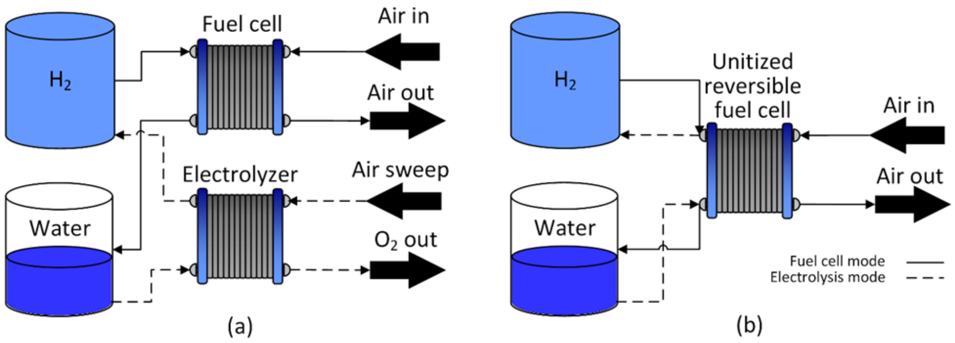
- Hydrogen technologies could provide low-cost long duration/seasonal grid energy storage
- Higher round trip efficiency and lower capital cost enables storage technologies to be competitive at shorter storage durations[1]
- Unitized reversible fuel cells might achieve lower storage system capital cost than using stand-alone or “discrete” fuel cell and electrolyzer systems for grid energy storage

- Refining URFC RD&D objectives to enable LDES advances DOE goals by:
  - Reducing greenhouse gas emissions and other combustion-related pollutants by replacing fossil-based peaker and load-following plants with renewables-powered energy storage
  - Improving grid energy resilience and reliability by enabling dispatchable clean energy infrastructure
  - Providing guidance to industry on URFC best applications to help jump-start URFC manufacturing and create an on-ramp for deployment

[1] Hunter et al., Joule (2021) Aug 18;5(8):2077-101

Approach (1/2): URFC RD&D objective refinements will be determined through

- Review and comparison of HFTO's targets for low- and high-temperature URFCs, PEMECs, SOECs, and PEMFCs
  - Harmonize targets to ensure they track with probable learning spillover effects
- Survey state-of-the-art of URFC cell/stack development and system design
  - System configurations
  - BOP component cost, performance, and operational constraints
- Process modeling of low- and high-temperature unitized and discrete RFC systems to quantify equipment costs, round-trip efficiency, and operational flexibility
- Techno-economic analysis using StoreFAST and/or ProFAST to estimate LCOS for each system type for a range of storage durations
  - Compare URFCs against discrete RFC systems
  - Quantify % improvement of URFCs over DRFCs OR identify cost and/or performance improvements required to enable URFCs to compete with DRFCs



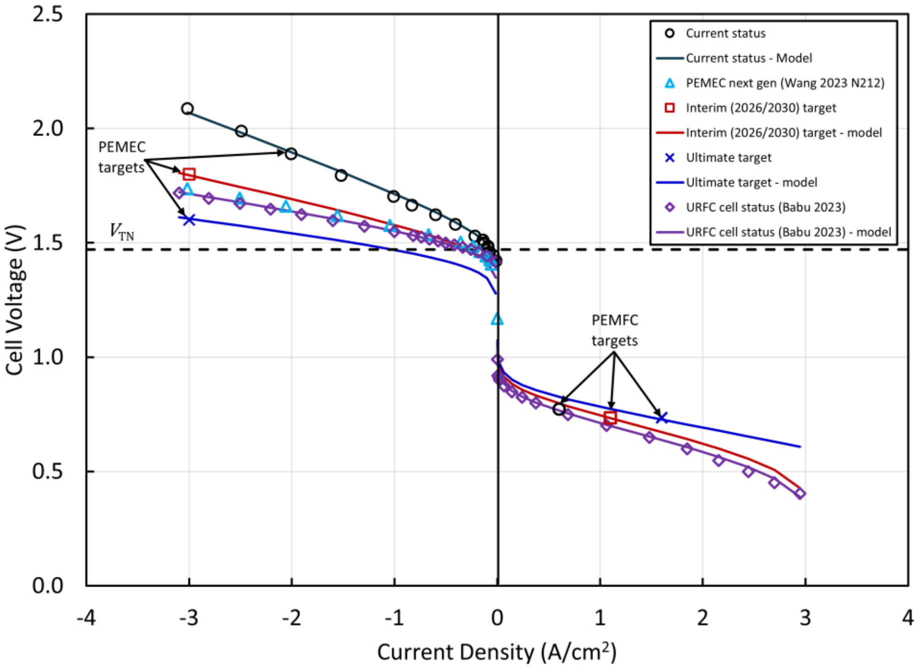
Reversible fuel cells: (a) discrete, and (b) unitized.

Approach (2/2): Milestones

Due Date	Description	Status
January 2024	Review HFTO URFC, PEM EC, SOEC, and PEM FC tech targets; summarize state-of-the-art cell/stack performance and system configurations	Complete
April 2024	Initial equipment cost and RTE calculations for half of the RFC systems	In progress
July 2024	Process modeling results, including equipment costs and RTE calculations for all RFC systems	In progress
September 2024	Techno-economic comparison of URFCs and DRFCs complete and documented in final report	In progress

Accomplishments and Progress (1/6): Low-temp PEM URFC performance might maintain pace with discrete PEM FCs/ECs

- Review of state-of-the-art of PEM URFCs reveals that lab-scale URFC cell performance already meets current discrete PEM FC target and interim PEM EC target[2]
- Based on data, it appears reasonable that PEM URFCs could maintain similar (if not equivalent) performance to discrete PEM ECs/PEM FCs
- Round trip efficiency (RTE) at 1 A/cm^2 (both modes) for RFCs meeting HFTO's PEM FC/PEM EC targets:
  - Status: 42%
  - Interim: 48%
  - Ultimate: 53%



Polarization curves for discrete PEMEC[3,4] and PEMFC targets[5], and current URFC lab scale performance status[2].

[2] Babu et al., Adv Energy mater. 2023 Apr; 13(16):2203952
[3] Wang et al, Energies (2023) Jan; 16(13):4964
[4] HFTO, Technical Targets for Proton Exchange Membrane Electrolysis. https://www.energy.gov/eere/fuelcells/technical-targets-proton-exchange-membrane-electrolysis
[5] HFTO, email correspondence. April 2021.

Accomplishments and Progress (2/6): Low-temp PEM URFC cost will most likely be limited by electrolysis mode

- HFTO provides PEM EC stack and system cost targets[4] and PEM FC system cost targets[6]
- Estimated consistent PEM FC stack cost targets using analysis from James et al.[7]
- Catalyst material makes up a significant portion of electrolysis cost[8], and PEM ECs require higher catalyst loading than PEM FCs[7,8]
- If PEM URFCs maintain similar performance to PEM ECs and PEM FCs, we would expect PEM URFC stack cost to track closely with PEM EC stack cost

- For URFCs, cost is more useful expressed in $\$/m^2$ of active area
  - Easier to compare across system types
  - Optimal current density of URFCs might be different than for PEM ECs and PEM FCs
  - Expressing cost in $\$/m^2$ enables optimization of current density while accurately capturing impact on cost

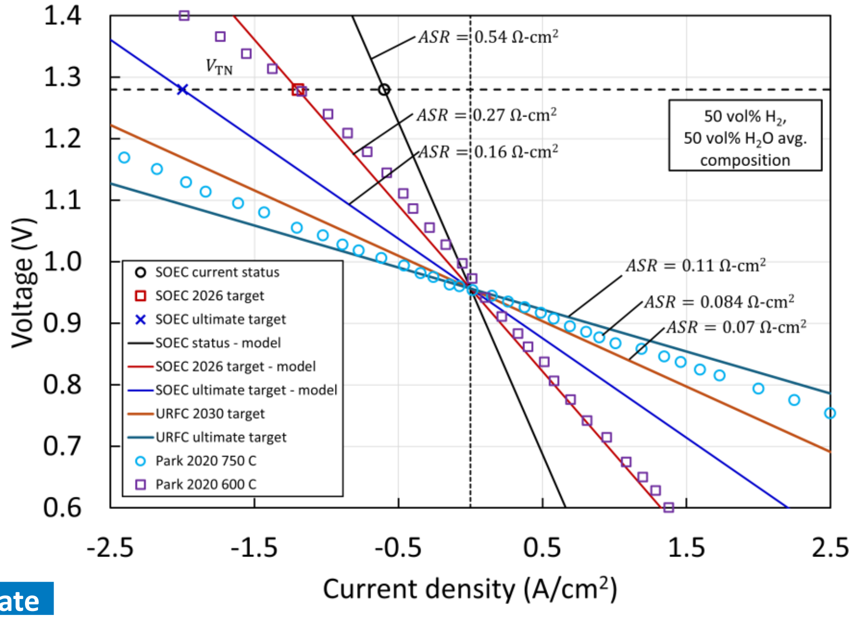
Metric	Status	2026/2030	Ultimate
PEM EC stack cost target ($\$2020/kW_{EC}$)[4]	450	100	50
PEM EC stack cost target ($\$2022/m^2$)[4]	23,404	7,391	3,285
PEM FC estimated stack cost target ($\$2016/kW_{FC}$)[6,7]	115	48	36
PEM FC estimated stack cost target ($\$2022/m^2$)	861	540	405

[4] HFTO, Technical Targets for Proton Exchange Membrane Electrolysis. https://www.energy.gov/eere/fuelcells/technical-targets-proton-exchange-membrane-electrolysis
[6] Marcinkoski et al., Hydrogen Class 8 Long Haul Truck Targets (2019). https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf
[7] B. James, Fuel Cell Cost and Performance Analysis (2022). https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review22/fc353_james_2022_o-pdf.pdf?Status=Master
[8] Badgett et al., Updated Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers (2024). NREL/TP-6A20-8762500.

Accomplishments and Progress (3/6): Reversible solid oxide cells (ReSOCs) appear poised to meet solid oxide electrolysis targets

- Review of state-of-the-art lab-scale ReSOCs at 750 °C reveals that they already exceed discrete SOEC ultimate performance target and HFTO URFC 2030 target
- In practice, SOECs and ReSOCs should achieve similar performance at similar times
- Any cells/stacks that operate below thermoneutral voltage in electrolysis mode will require supplemental system heat
- ReSOC and SOEC costs should also be consistent over time, especially if performance is similar

	Status	2026/2030	Ultimate
SOEC stack cost target ($2020/$kW_{EC}$)	300	125	50
SOEC stack cost ($2022/$m^2$)	3,153	2,628	1,752
ReSOC stack cost target ($2016/$kW_{FC}$)	500	400	300
ReSOC stack cost target ($2022/$m^2$)	3,204	2,623	2,006

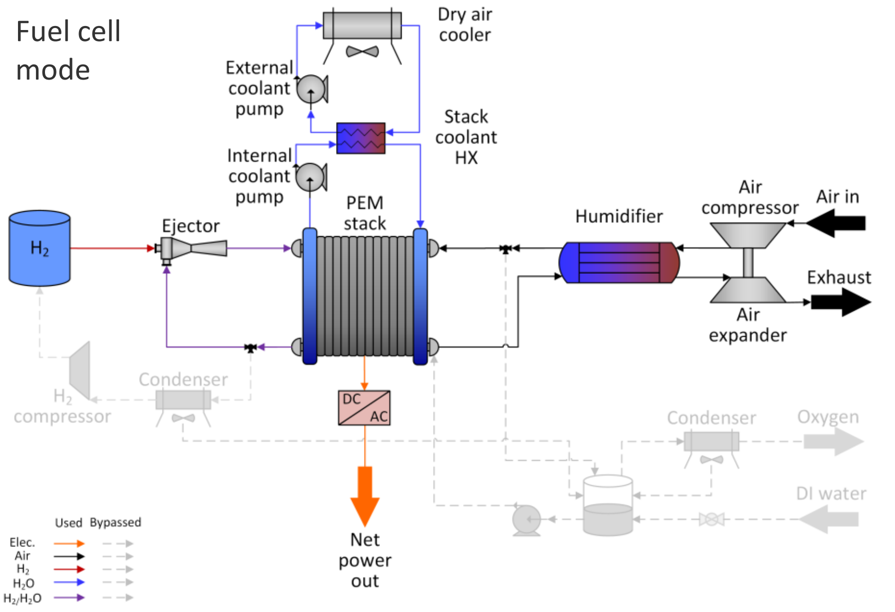


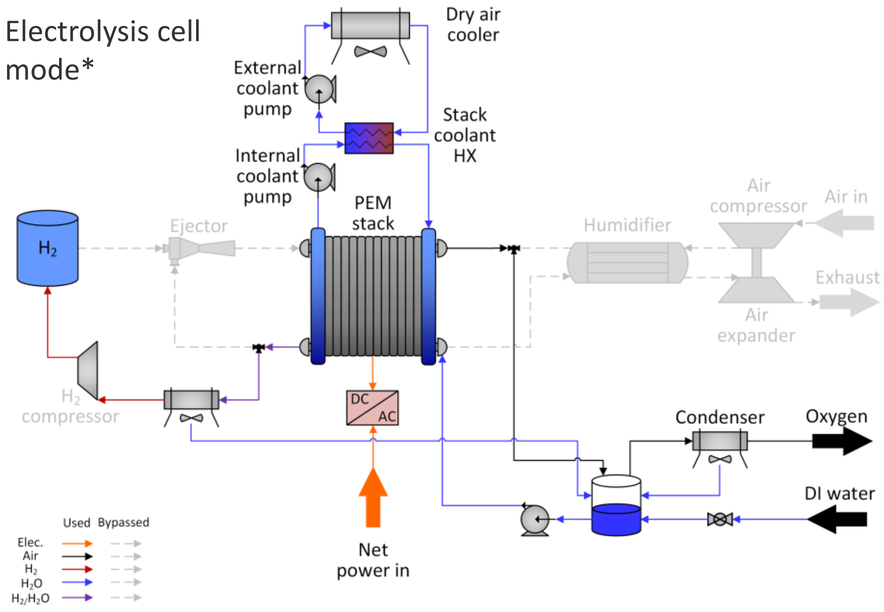
Polarization curves for discrete SOEC[9] and ReSOC targets[10], and current solid oxide URFC lab scale performance status[11].

[9] HFTO, Technical Targetes for High Temperature Electrolysis. https://www.energy.gov/eere/fuelcells/technical-targets-high-temperature-electrolysis
[10] Peterson et al, DOE Hydrogen and Fuel Cells Program Record: Reversible Fuel Cell Targets (2020). https://www.hydrogen.energy.gov/pdfs/20001-reversible-fuel-cell-targets.pdf
[11] Park et al., Mater Chem A. (2020); 8(23):11687-94

Accomplishments and Progress (4/6): PEM URFC systems utilize single stack, opportunity for shared stack cooling

- Stack cooling can potentially be shared between both modes of operation
- Fuel cell mode requires air supply, while electrolysis mode requires hydrogen and oxygen drying

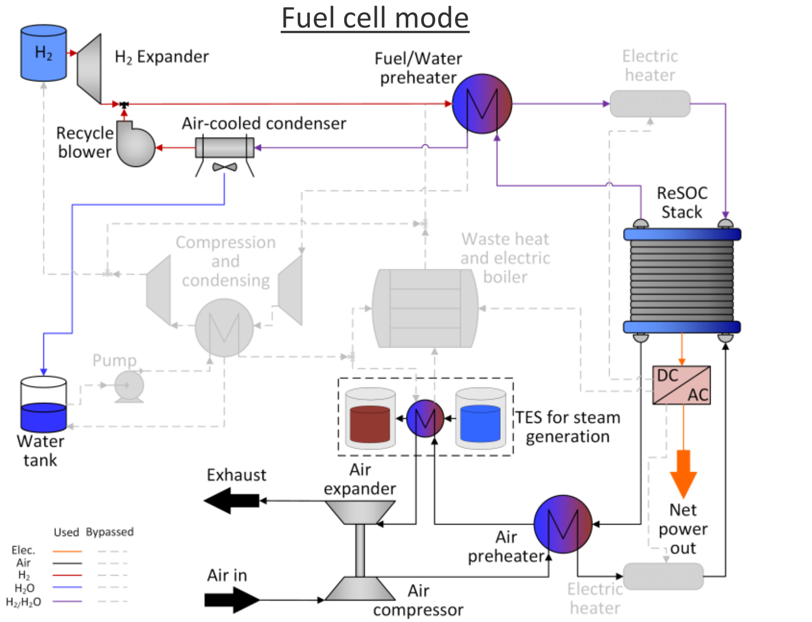


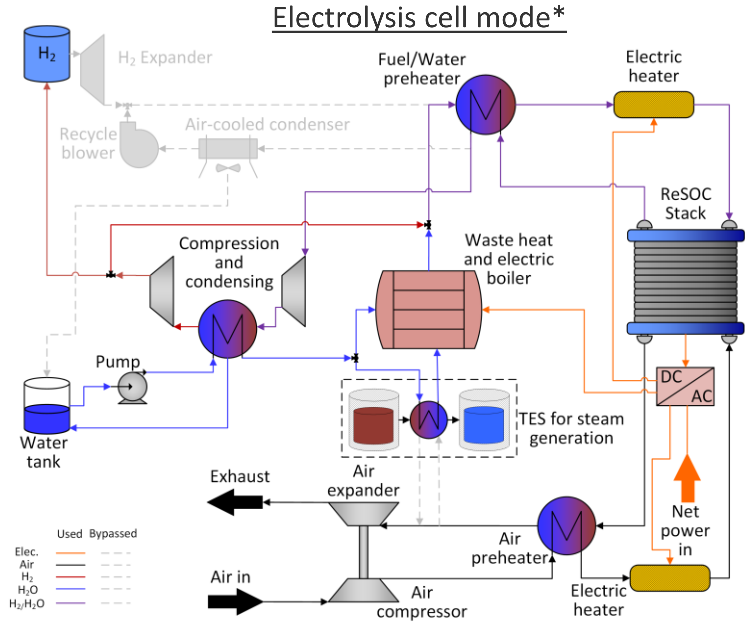


*Hydrogen drying/separation equipment not fully shown

Accomplishments and Progress (5/6): ReSOC systems might share more BOP; opportunity for thermal energy storage

- ReSOC systems might benefit from sharing air/fuel preheaters and air compressor/expander
- Thermal energy storage (TES) might reduce EC mode steam generation energy requirements





*Hydrogen drying/separation equipment not fully shown

Accomplishments and Progress (6/6):
Response to Previous Year Reviewers' Comments

- This project has not been reviewed at any previous AMR.

Collaboration and Coordination

- National Renewable Energy Laboratory (peer review)
  - Bryan Pivovar
  - Alex Badgett

- Hydrogen Fuel Cells Technology Office (review and coordination)
  - Will Gibbons
  - Dimitrios Papageorgopoulos
  - David Peterson

DEIA/Community Benefits Plans and Activities

- This project does not have a Diversity, Equity, Inclusion, and Accessibility Plan
- Refining and streamlining HFTO's URFC technical targets can contribute to workforce development, DEIA, and/or environmental justice in the following ways:
  – Identifying the most impactful areas of URFC RD&D to help jump-start the URFC manufacturing industry
  – Reducing the cost of hydrogen LDES technologies, thereby expediting their deployment to reduce greenhouse gas emissions and other pollutants

Remaining Challenges and Barriers

- Determining system performance and cost differences between URFCs and DRFCs
  - URFCs should be able to achieve slightly lower capital costs due to shared stacks and some shared BOP
  - URFC system performance might suffer due to inefficiencies of designing stack and/or BOP components for both modes
- Uncertainty about potential differences between URFC and discrete RFC installation and indirect costs (outside current project scope)
- Assessing appropriate charging and discharging capacity factors and target storage duration for hydrogen grid energy storage systems
  - Capacity factors should be at least somewhat dependent on round trip efficiency
  - Appropriate storage duration will depend on what the grid needs and when and the competitiveness of other grid-firming technologies
- Analyzing hydrogen grid energy storage systems is complicated by the fact that large-scale hydrogen storage facilities might service multiple sectors (grid, industry, etc.)

Proposed Future Work

- FY 2024 Project Plan
  - Complete process modeling of low- and high-temperature unitized and discrete RFC systems to estimate round trip efficiency, equipment cost, and operational envelope
  - Review recent literature on relationship between LDES technology RTE and capacity factors
  - Perform comprehensive LCOS comparison of each system type
    - Identify potential benefit of unitized RFCs OR
    - Estimate improvements in performance or cost needed for URFCs to compete with discrete RFCs
- Potential work beyond FY 2024
  - Broader analysis of relationship between RTE and charge/discharge capacity factors
  - Investigate potential installation and/or indirect cost savings of URFCs

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

Summary

- Unitized RFC systems have the potential to achieve lower equipment costs with similar performance to discrete RFC systems
- Review of lab-scale cell data suggests that both low-temperature PEM and high-temperature solid oxide URFCs are on track to meet HFTO's discrete electrolysis performance targets
- We expect URFC stack costs to follow PEM and solid oxide electrolyzer stack costs
- Appropriate performance targets for URFCs might differ from those of discrete electrolyzers and fuel cells due to nuances of LDES economics
  - Capacity factor influenced by round trip efficiency
  - Hydrogen storage cost has a significant impact on hydrogen LDES competitiveness

Thank You

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