A Novel Stack Approach to Enable High Round Trip Efficiencies in Unitized PEM Regenerative Fuel Cells

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Nel Hydrogen

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Project ID #fc331

number one by nature™

Overview

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A Novel Stack Approach to Enable High Round Trip Efficiencies in Unitized PEM Regenerative Fuel Cells (URFC)

PI: Katherine Ayers, Nel Hydrogen

Barriers

- Barriers addressed
- No regenerative fuel cell specific barriers. Optimization between fuel cell and electrolyzer barriers:
- Fuel cells: A. Durability, B. Cost, C. Performance
- Hydrogen Production: F. Capital Cost, G. System Efficiency and Electricity Cost

Timeline and Budget

- Project Start Date: October 1, 2019
- Project End Date: December 31, 2021
- Total Project Budget: $2.5M
  - Total Recipient Share: $500k
  - Total Federal Share: $2M
  - Total DOE Funds Spent*: $10,133

* As of 02/29/2020

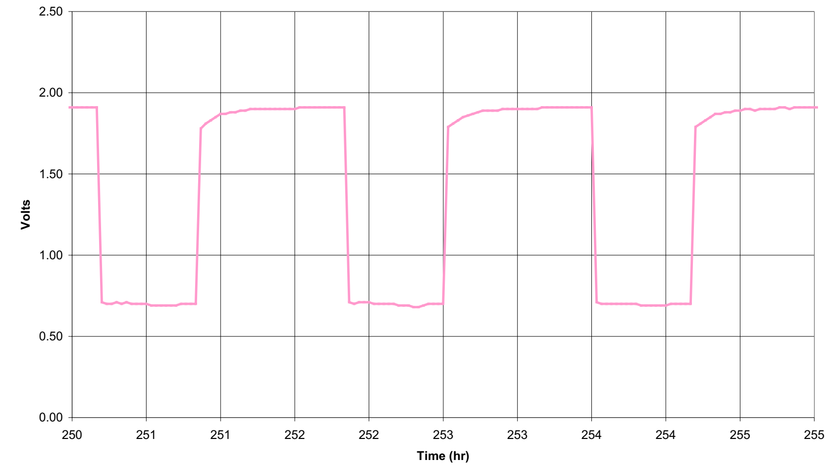
Partners

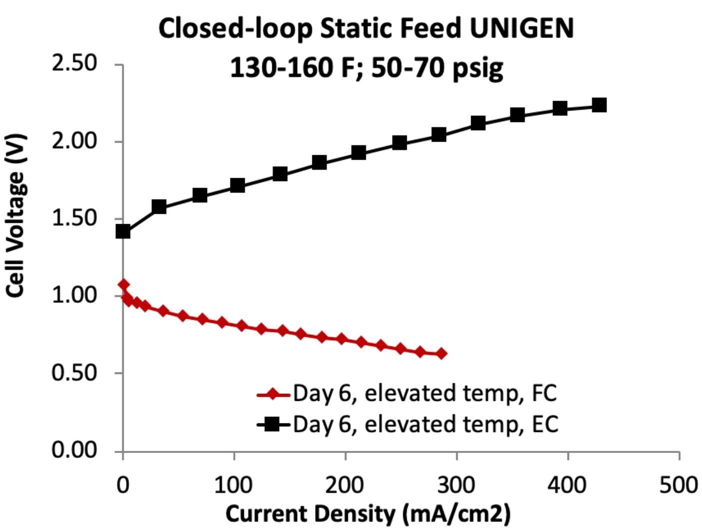
EPRI: Brittany Westlake
Southern Company: Noah Meeks
LBNL: Nem Danilovic, Adam Weber
Gaia: Whitney Colella

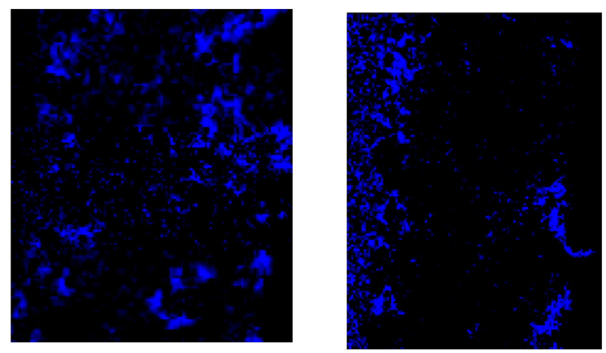
Overview: Past Work with URFCs

- Learnings from static feed fuel cells
- Extreme water management challenges
  - Strong understanding of transport and cell design effects
  - Limited to low current densities
- Current project leverages fundamentals for high efficiency and current density

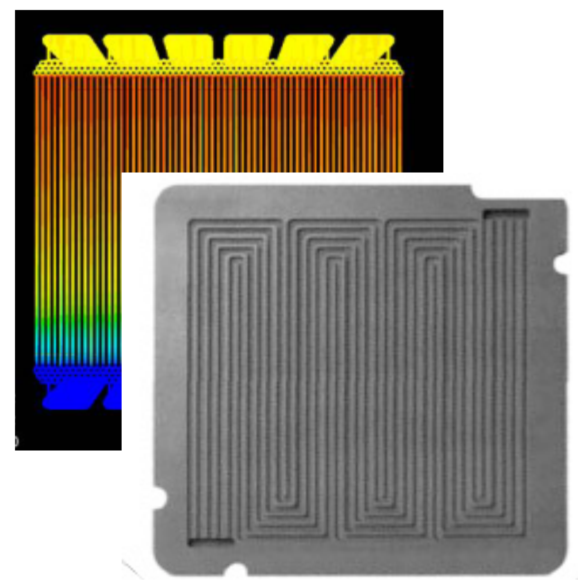
Cycle test







Optimization of wetproof coating through porous layer



Flow field Design

Overview: Advantages and Limitations of URFCs

Benefits

- Single stack reduces weight and footprint
  - Improved energy density vs. battery
- Lower material cost (vs. 2 separate stacks)
- Opportunity to harmonize aspects of fuel cell and electrolyzer stack manufacturing
  - Better leverage of supply chain (same materials for electrolyzer and fuel cell increases overall material sales volume)

Drawbacks

- Traditional electrolyzer membranes severely constrain fuel cell performance
- Optimal catalyst composition not identical for OER and ORR
- Water management is challenging
- Stack has to be sized for highest rate application
  - Oversized for other direction

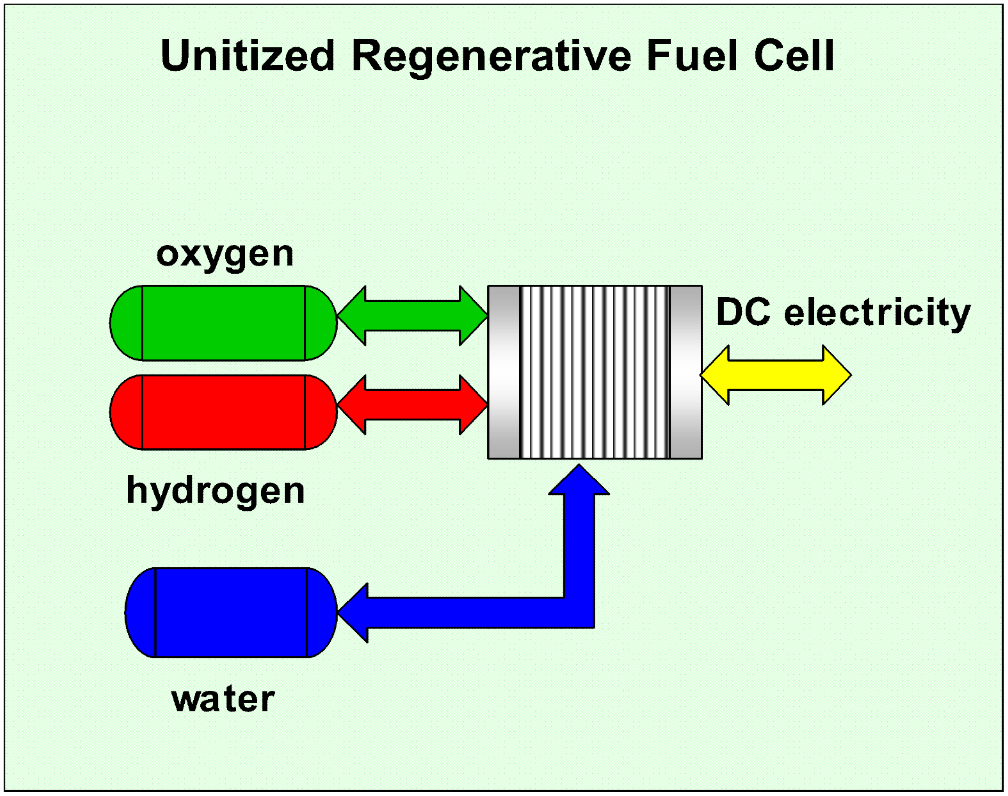
Possible solution: Better match fuel cell and electrolyzer operating conditions to allow more commonality in materials – e.g. low pressure, lower potential

Overview: Fuel cells vs. Electrolyzers – Operating Parameters

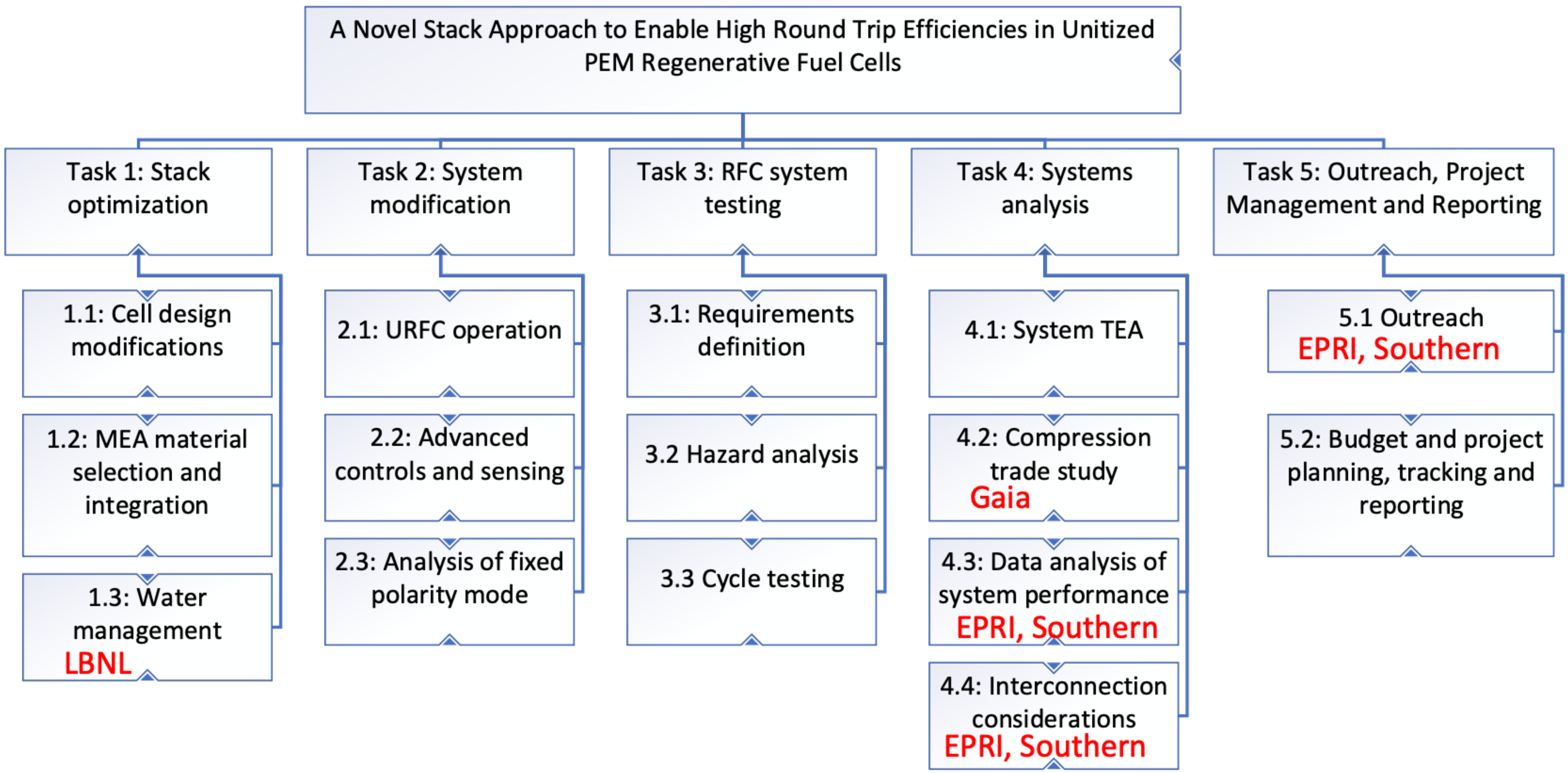
Parameter	Fuel Cell (Automotive)	Electrolyzer	URFC
Relative humidity	Cycling	Constant at 100%	Controlled
Differential pressure	<50 psi	>400 psi	**50-100 psi**
Cell voltage	< 1.0 V	>1.8 V	**<1.0 V, >1.55 V**
Storage temperature	Freeze/thaw	>5°C	>5°C
Operating temperature	80°C	50°C	50-65°C
Fluid flow – O_2 loop	O_2/water vapor	Liquid water/O_2	Alternating
Lifetime expectations	>5000 hours	>50,000 hours	>5000 cycles

Relevance

- The overall project goal is to demonstrate a unitized reversible fuel cell (URFC) system based on polymer electrolyte membrane (PEM) technology that can achieve 50% round trip efficiency and reliable performance under relevant duty cycles, with projected costs below $1750/kW.



Approach



Tasks led by Proton/Nel unless noted

Approach: Project Tasks & Responsibilities

Task	Date	Accountable
1. Stack Optimization	04/1/2020 – 03/31/2022	Nel Hydrogen
1.3 Water Management Modeling	07/01/2020 – 9/31/2021	LBNL
2. System Modification	04/01/2020 – 3/31/2022	Nel Hydrogen
3. RFC System Testing	04/01/2020 – 12/30/2022	Nel Hydrogen
4. System Analysis	10/01/2020 – 03/31/2023	Gaia, EPRI, Southern
5. Outreach	04/01/2021 – 03/31/2023	EPRI, Southern

Accomplishments: Budget Period 1 Milestones

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Milestone #	Project Milestones	Task Completion Date (Project Quarter) Original Planned	Revised Planned	Actual	Percent Complete	Progress Notes
M1.3.1	Complete URFC cell stack design and analysis including seal testing of thin membranes and flow field configuration based on modeling.	2	09/30/2020		10%	In progress
M1.2.1	Down-select up to 2 membrane candidates and up to 3 catalyst materials for durability and cycle testing.	3	12/31/2020		0%	
M1.3.2	Demonstrate at least 100 hours of electrolysis operation at up to 60 psi with cell voltage <1.7 V at 2 A/cm^2.	4	3/31/2021		0%	
M2.2.1	Complete pre-start safety review for URFC upgrade.	5	6/30/2021		0%	
M3.1.1	Develop system requirements for existing URFC rig in order to monitor recommended system parameters and support relevant duty cycles.	1	6/30/2020		40%	In progress
G/NG 1	Demonstrate a minimum of 20 1-hour cycles between fuel cell and electrolyzers operating modes of URFC prototype system operation without membrane failure in a 1-cell stack configuration. A current density of 0.4 A/cm^2 will be achieved fuel cell mode and 0.8 A/cm^2 in electrolysis operating mode, with less than 100 mV total voltage degradation (electrolyzer + fuel cell mode).	6	8/30/2021		0%	

Accomplishments

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- Project activity started on April 1, 2020
- Accomplishments to Date
  - Product Requirements Document (PRD)
  - URFC Stack Design Concept Developed

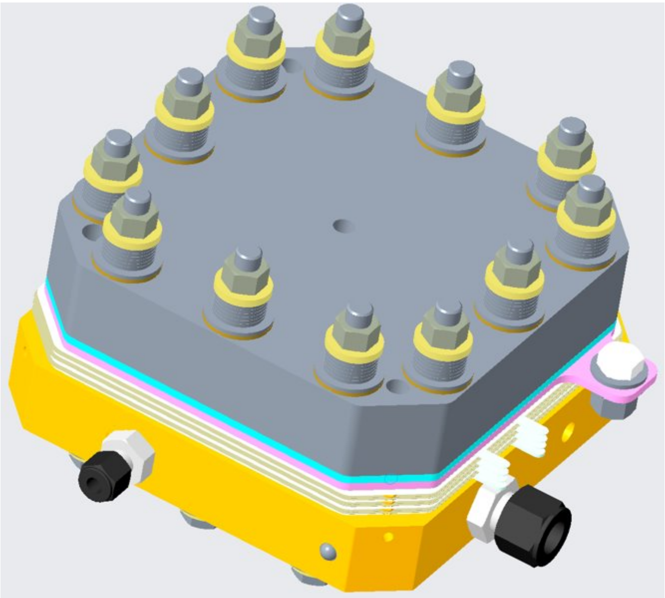
Accomplishments: Product Requirements

- Product requirements were drafted

**Partial list of requirements shown here*

Accomplishments: URFC Stack Design

- Optimize basic electrolyzer cell for low pressure, thin membrane operation
  - Lower sealing load and lower profile seal features
  - Membrane support optimization
- Optimize flow field and GDL/PTL for fuel cell water management
  - Channel geometry to allow liquid flow but deter flooding
  - Hydrophobicity tuning for effective water removal in fuel cell mode
  - Supported by LBNL water distribution/transport modeling



Accomplishments: URFC Stack Design Flow-field Options and Modeling

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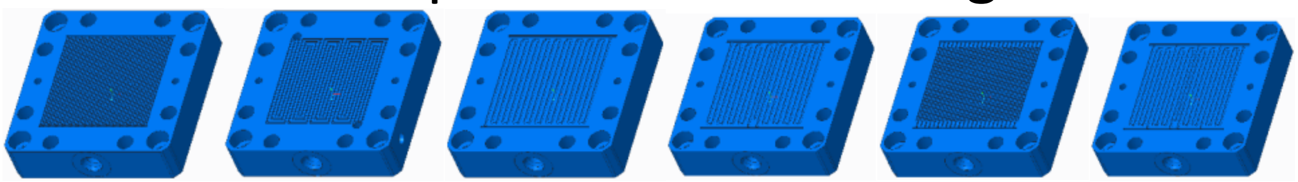
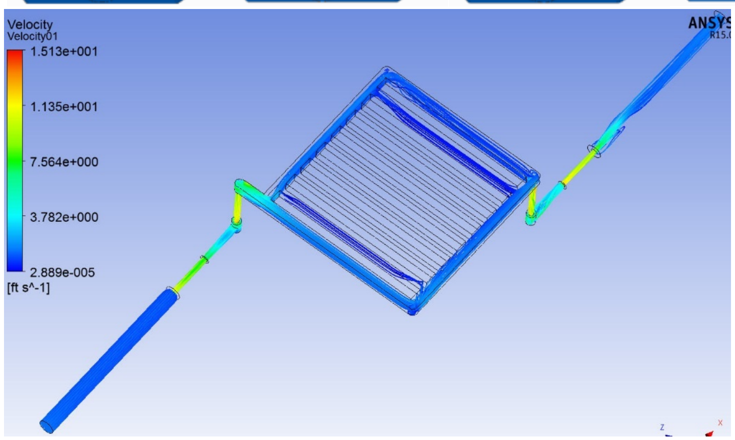
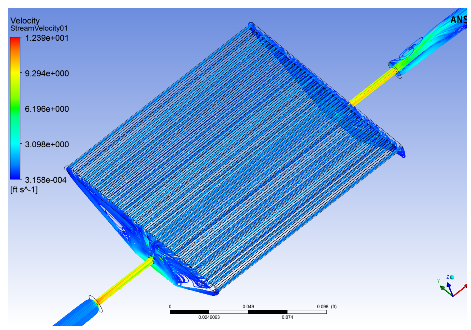
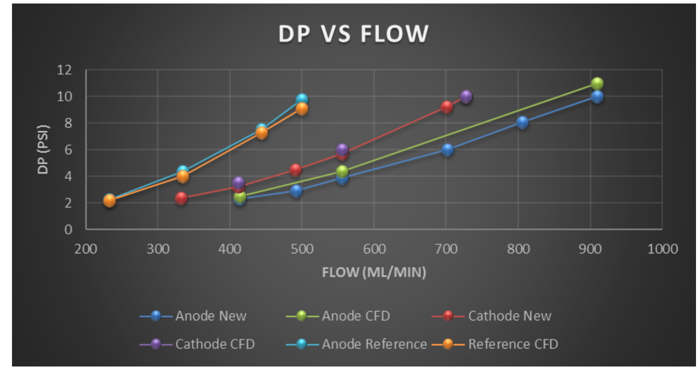








Comparison of CFD results to measured values indicate close correlation

Identified Problem:
Water flow is around the perimeter of the flow field. The inner region will be flooded, but will not have any significant velocity

Solution:
Re-designed flow configuration has the best flow field water distribution. The symmetric design, as well as the inlet and outlet flow header geometry, produces a uniform pressure and flow pattern

Accomplishments: System Modifications

- Identified required system modifications

Front and Rear View of Gas/Fluids System

Front and Rear View of Gas/Fluids System

Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year

Collaboration

Partners	Project Roles
Electric Power Research Institute	System Analysis, Outreach
Southern Company	System Analysis, Outreach
Gaia Energy Research Institute	Technoeconomic analysis
Lawrence Berkeley National Laboratory	Multi-physics transport modeling

Challenges and Barriers

- Electrolyzers currently use thicker membrane to tolerate the high differential pressure typical during operation.
  - Retuning of the cell design is required to see if lower operating pressures and subsequent lower sealing pressures and features enable the use of more efficient, thinner membranes by reducing these membrane stressors.

- Fuel-cell operation is much more sensitive to flowfield geometry and gas-diffusion layer wettability due to the accumulation of liquid water
  - Nel has significant relevant cell optimization experience from recent flow battery and anion exchange membrane electrolyzer programs, which will be integrated into the PEM electrolyzer cell platform to make it compatible with efficient fuel-cell operation.
  - Basic computational fluid dynamic modeling (CFD) will be performed to predict the most likely channel geometries to provide uniform water distribution in electrolyzer mode while minimizing water collection in fuel cell mode.
  - LBNL will develop and integrate the balance of the URFC model, which will be used to understand the water transport in the URFC cell with respect to membrane properties and operating conditions

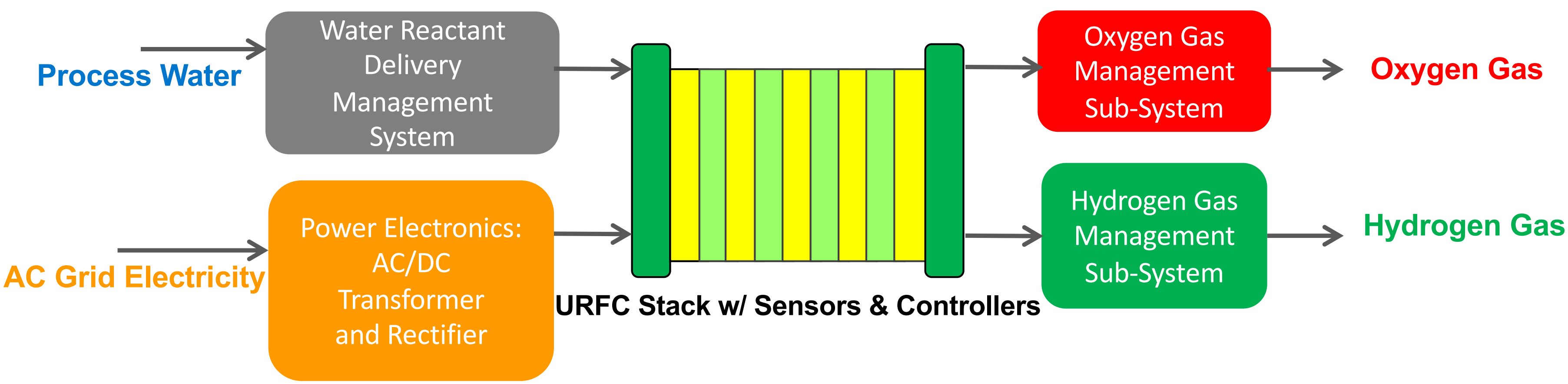
Proposed Future Work: URFC Stack Material Optimization

- Optimization of catalyst for OER/ORR
  - Likely requires some Pt for efficient ORR
  - Blend for high OER activity
- Membrane optimization
  - Survey of candidates
    - Leverage Nel collaborations for knowledge of pre-commercial options
- Cycle testing – pressure and voltage
  - Electrolyzer mode to look for stability at potential
- Leverage existing project collaboration with LBNL

Proposed Future Work: Systems Analysis

1. Conduct URFC system cost analysis
2. Evaluate balance of plant (BOP) components and ancillaries around the URFC for both low and high URC outlet pressures. (A URFC with a lower outlet pressure may require a system design with added BOP components for external compression.)
3. Analyze both URFC system capital and operating costs.
4. Identify potential cost-optimal URFC outlet pressures, for a given set of model assumptions.
5. Benchmark chosen configuration(s) against other solutions.

Electrolyzer Sub-system Design within the URFC System



Technology Transfer Activities

- EPRI will develop webcasts and other appropriate information to demonstrate the technology development and its performance
  - The project team will capture the methodology used to develop testing duty cycles, technology advances from this project research, and system performance information
  - This will allow the utility community to track progress, as well as better understand how UFRC technology could perform in utility applications.
  - In addition, project accomplishments and failures will be documented for this effort to support the development and advancement of reversible fuel cell technology and the development of advanced, flexibility-enabling technologies

Summary

- Objectives:
  - Balance design and operating conditions for optimal Electrolysis and Fuel Cell performance
- Relevance & Impact:
  - Target 50% round trip efficiency
  - Projected costs below $1750/kW
- Collaboration Effectiveness:
  - Project team established
  - Internal team communication and public outreach
- Accomplishments:
  - Project began on April 1, 2020
    - Product requirements have been drafted
    - Stack design is in progress
- Future work:
  - Stack material optimization
  - Systems Analysis