# Electrochemical Compression

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Contract No: DE-EE0007647

Subcontractors:
- National Renewable Energy Laboratory, Golden, CO
- Rensselaer Polytechnic Institute, Troy, NY
- Gaia Energy Research Institute LLC, Arlington, VA

Project Start Date: October 1, 2016
Project End Date: June 30, 2020

## Overall Objectives

- Develop and demonstrate an electrochemical hydrogen compressor (EHC) to address critical needs of lower cost, higher efficiency, and improved durability.

## Fiscal Year (FY) 2019 Objectives

- Fabricate stack and cell components for 12,688 psi (875 bar) operation, and scale up membranes, membrane electrode assemblies (MEAs), and stack hardware from 50 cm² to 300 cm².
- Assemble an EHC stack and verify EHC stack operation at a pressure of 875 bar.
- Complete preliminary design of a lab-scale prototype system.
- Optimize scaled up stack hardware and demonstrate cell performance of 0.250 V/cell at current densities ≥1,000 mA/cm² at pressures of 12,688 psi (875 bar).

## Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan[1]:

- (B) Reliability and Costs of Gaseous Hydrogen Compression.

## Technical Targets

The DOE technical targets and our current project status are listed in Table 1 for comparison.

## FY 2019 Accomplishments

Achieved Year 2 Milestone

- Successfully operated EHC at 12,688 psi (875 bar) at 0.250 V @ ≥1,000 mA/cm²
  - Demonstrated pressure ratio of >100:1, single stage
  - Highest efficiency for EHC operating at elevated pressures of 5,000 (350 bar) and 12,680 psi (875 bar); 2 $kWh_e/kg\text{-}H_2$ at 350 bar, 4.4 $kWh_e/kg\text{-}H_2$ at 875 bar.

Completed Membrane Development

- Developed membrane architecture that utilizes a high-pressure thermoplastic seal for 875-bar operation
  - Enables bubble-tight seals to 20,000 psi (1,400 bar) and stack operation to 12,688+ psi (875+ bar)
  - Resistant to thermal and pressure cycling.
- Demonstrated scale-up of MEA and membrane-seal to 300 cm².
- Reduced membrane back diffusion by >50% in perflourosulfonic acid (PFSA), 32%; aromatic membranes.

Completed Stack/System Hardware Development

- Demonstrated proof pressure of 20,000 psi (1,400 bar).
- Successfully designed, assembled, and operated an 875-bar EHC stack.

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

- Operated the EHC stack at an inlet pressure range of 1–100 bar, dead-ended hydrogen feed, with dry or wet hydrogen feed sources.
- Reduced stack cost through unitized cell components (reduced part count/cell)
  - Combined flow-distributor and water management membrane compartment into a single unitized component
  - Utilized low-cost stainless-steel cell component materials.
- Completed design of 875 bar EHC system
  - Completed review of EHC system piping and instrumentation diagram (P&ID), process flow diagram (PFD), and electrical diagrams with a Nationally Recognized Testing Laboratory (NRTL) (Intertek)
  - Initiated assembly of the 12,688+ psi (875+ bar) system.

Table 1. Progress toward Meeting Technical Targets for Hydrogen Compressors for Fueling Sites

| Characteristics | Units | 2020 Target[a] | 2019 Giner ELX Status |
|---|---|---|---|
| Compressor specific energy | $kWh_e/kg\text{-}H_2$ | 1.62[b] | 2.0[c] (4.4)[d] |
| Uninstalled capital cost[2] | $ | 170,000 | <400,000 |
| Outlet pressure capability | bar | 950 | 875 |

[a] Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan, Hydrogen Delivery section.
[b] 100-bar delivery/commercial mechanical compressors are >6–8 $kWh_e/kg$ (@ 7-bar delivery).
[c] Operation at 100-bar delivery, 350-bar output.
[d] Operation at 100-bar delivery, 875-bar output.

## INTRODUCTION

Hydrogen compression represents a key technical challenge for the widespread commercialization of fuel cell electric vehicles (FCEVs). To dispense hydrogen to FCEV tanks, hydrogen must be compressed to a minimum of 875 bar. Conventional compressors account for over half of the refueling station's cost, have poor reliability, and have insufficient flow rates [1, 2, 3]. In addition, the compressed hydrogen produced by a mechanical compressor requires extensive purification to remove small amounts of contaminants that can degrade the performance of fuel cells receiving the hydrogen.

EHCs utilize direct current to electrochemically compress hydrogen to high pressures. Recent developments in membrane technology promise a new generation of very efficient low-cost EHCs. The emergence of proton exchange membrane (PEM)-based solid-state EHCs eliminates many of the issues associated with mechanical compression; however, current state-of-the-art EHCs are challenged by issues related to membrane sealing and low operating current density attributed to poor water and heat management.

Giner ELX, Inc. (Giner-ELX) is a leading developer of PEM-based stack technology with over 45 years' experience in advanced electrochemistry. Giner-ELX's technology ranges from highly reliable high-powered electrolyzer stacks operating onboard U.S. Navy submarines to lower-cost electrolyzer systems operating at high differential pressures for commercial applications. Giner-ELX has made significant advancements developing and demonstrating novel membrane technologies that enable zero leakage, high pressure, and high efficiency for use in PEM-based electrolyzers and EHCs.

## APPROACH

The work conducted in this program exploits the use of three novel technologies: (1) dimensionally stable aromatic membranes, engineered with low electro-osmotic drag and low hydrogen diffusivity, that exhibit high durability and improved sealing properties, (2) a water management membrane that enables passive water feed and cell voltage stability, and (3) an advanced high-pressure stack design optimized for safe high-pressure gas compression. Successful development and implementation of these technologies are essential to improving water and thermal management within the EHC to enable high-current-density operation resulting in a low-cost EHC.

## RESULTS

### Membrane Development

Aromatic membranes consisting of perfluoroalkylsulfonate (BP-ArF4) were fabricated and optimized for use in EHC stacks operating at elevated operating pressures. As a comparison, membranes containing perflourosulfonic acid (PFSA) ionomers were fabricated using the same processing conditions. The strength of the membranes and sealing properties were enhanced via the addition of dimensionally stable thermoplastic structures. In previous EHC work conducted at Giner-ELX it was observed that when the operating pressure exceeds ~2,000 psi (~140 bar), the addition of a thermoplastic support within the membrane is required to limit membrane extrusion and maintain the pressure seal. However, the traditional thermoplastic support structures were not sufficient to maintain pressure seals over extended periods when operating the EHC above 7,000 psi (480 bar). To overcome this issue Giner-ELX developed a supported membrane that utilizes a "solid support" in the sealing area of the MEA. During the fabrication process, a high-strength high-density thermoplastic is directly bonded to the edge of the sulfonated-polymer membranes. The membrane does not extend into the sealing area. The newly developed solid-supported membrane (SSM) provides a hard-sealing surface that can withstand high clamping loads and is unaffected by thermal and pressure cycling. A comparison of the different membrane supports and their material strengths is depicted in Figure 1.

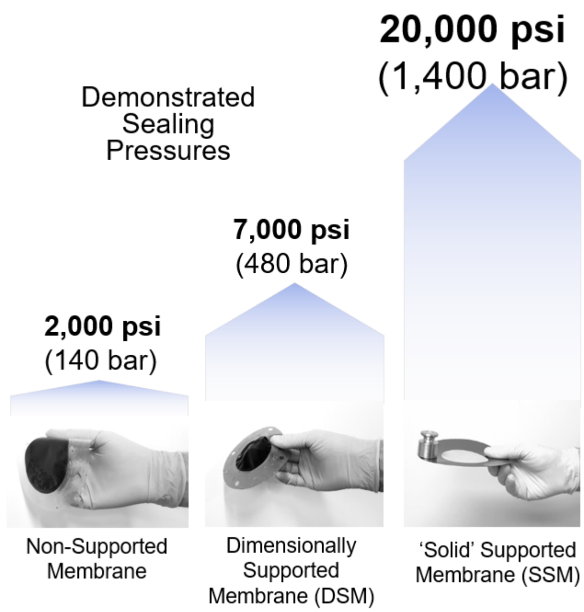


Figure 1. Membrane supports and rated sealing pressures

The SSM is a "dry assembly" and enables unitization of the cell components including the internal distributor plates. The unitized membrane-cell structures were scaled up from 50 $cm^2$ to 300 $cm^2$ (Figure 2). The unitized SSM membrane provides for a more consistent product and enables:

- Stack sealing to 20,000 psi (1,400 bar)
- High clamping loads on the MEA seal area
- Sealing under thermal and pressure cycling
- Ease of manufacturing (i.e., assemblies with dry membrane)
- Reduced cost (i.e., 1 piece/cell unitized cell structures).

Additionally, the materials used to develop the SSM are non-contaminating.

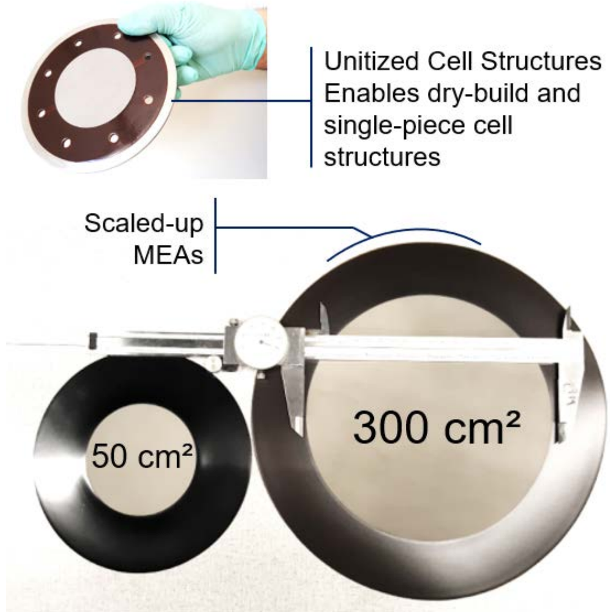


Figure 2. Membrane scale-up, unitization, and dry assembly

After successful proof-pressure testing, the unitized SSMs were incorporated into the stack design. The enhanced EHC stack now includes the means necessary to operate at pressures of 12,688+ psi (875+ bar).

### Back Diffusion

Via the addition of a non-sulfonated polymer to the membranes during fabrication, a reduction in hydrogen back diffusion through BP-ArF4, as well as PFSA membranes, operating at elevated operating pressures was demonstrated. The non-sulfonated polymer is added to the MEA active area. Membranes fabricated with the modified polymers were evaluated in an operating EHC at pressures up to 12,688 psi (875 bar). As compared to "unmodified" membranes, hydrogen back diffusion in modified PFSA membranes was reduced by >50% in aromatic BP-ArF4; 32%. A trade-off between back diffusion and cell performance (voltage) exists and the membranes are optimized by varying the ratio of sulfonated to non-sulfonated polymer to achieve an optimal balance between resistive losses and back diffusion.

### EHC Stack

The mechanical challenge superimposed on the electrochemical design is the development of a cell-stack configuration that can tolerate high differential pressure across the membrane and cell components and the outside environment. The ability to contain the overall pressure in the stack at elevated operating pressures of 875 bar requires the use of thicker endplates that limit deflection, improvements in cell component strength, and the use of SSM membranes to maintain sealing. Giner-ELX demonstrated electrochemical compression at pressures in excess of 12,688 psi (875 bar) using EHC stack designs that utilize the SSM developed during this program (Figure 3).

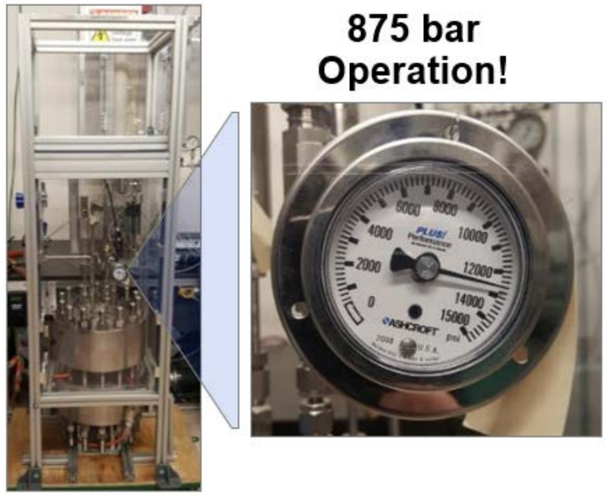


Figure 3. EHC stack operating at 875 bar

In addition to operating the EHC at a pressure of 875 bar under various inlet pressures and operating current densities, Giner-ELX demonstrated the ability of the 875-bar EHC to operate at <250 mV/cell and at an elevated current density of 1,000 mA/cm². Utilizing the SSM membrane and the advanced EHC stack design, the cell voltage performance under constant output pressure of 875 bar was measured at 178 mV/cell at 500 mA/cm² and 276 mV/cell at 1,000 mA/cm². Additional improvements in cell voltage of up to 60 mV over an operating current density range of 500–1,000 mA/cm² have been achieved with the use of hybrid membranes. The hybrid membranes consist of an admix of sulfonated polymers. Giner-ELX and team will continue evaluation and optimization of these new membranes in Year 3.

### EHC System Design

This project requires the assembly of an EHC system, designed as a complete factory-packaged unit so that only minimal site preparation and installation work will be required. Operation will be completely automated, with a computerized control system providing load-following capability, safety interlocks, as well as remote control and monitoring. The EHC system will be pressure tested to the ASME standards, and special considerations will be taken into account for specialized fitting(s) that will be certified to ANSI /HGV 4.10 (Standard for fittings for compressed hydrogen gas and hydrogen rich mixtures).

The EHC system design along with PFD, P&ID, electrical diagrams, component selection, and layout have been completed. With assistance from Intertek, a description of the applicable standards and codes required for certification was generated. Giner-ELX has initiated the assembly of the EHC system. All electrical components are UL listed and rated for operation in classified hazardous areas zoned for Class 1, Division 2, Group B. The system is designed to accommodate various operating conditions and has the following specifications:

- $H_2$ flux rate: System designed for a maximum 10 kg/h, and 0.5 kg/h with current stack
- $H_2$ inlet pressure feed: 1–100 bar, dry
- $H_2$ outlet pressure: 875 bar.

Figure 4. 875-bar EHC system assembly

## CONCLUSIONS AND UPCOMING ACTIVITIES

Significant progress has been made in the EHC membrane and stack development. Giner-ELX and its team members have demonstrated membrane reproducibility and durability as well as a significant reduction in back diffusion and improvements in EHC cell efficiency. The progress made during this program has enabled EHC stack efficiencies in the range of 2.0 $kWh_e/kg\text{-}H_2$ at 350 bar and 4.4 $kWh_e/kg\text{-}H_2$ at 875 bar. In addition, development efforts conducted under this project have resulted in cost reductions of PEM-based EHC stacks and systems. Future plans include:

- Membrane: Fabricate and scale-up MEAs utilizing the optimized aromatic ionomers developed during this program. Unitize the MEAs and cell components using SSM seals.
- Stack: Assemble and operate a multi-cell 875-bar stack utilizing the scaled-up MEAs.
- System: Complete assembly of prototype system design.
    - Initiate operation and system studies.
    - Review and certify EHC design with third-party NRTL (Intertek).

## FY 2019 PUBLICATIONS/PRESENTATIONS

1. W. Colella and M. Hamdan, "State-of-the-Art Electrochemical Hydrogen Compressors (EHCs)," European Fuel Cell Forum (EFCF) 2019, July 2–5, 2019
2. M. Hamdan, "Advancements in Electrochemical Hydrogen Compression," 2019 TechConnect World Innovation Conference & Expo, Boston, MA, June 19, 2019.
3. M. Hamdan, "Electrochemical Compression," Annual Merit Review and Peer Evaluation Meeting (AMR) for the Hydrogen and Fuel Cells Program, April 30, 2019.
4. W. Colella and M. Hamdan, "Techno-Economic Analysis of Innovative Electrolytes for Low Temperature Electrochemical Hydrogen Compressors (EHCs)," 8th International Conference on Fundamentals and Developments of Fuel Cells, FDFC 2019, February 12–14, 2019.
5. W. Colella and M. Hamdan, "Thermo-Economic Analysis of Proton-Conducting Electrochemical Hydrogen Compressors (EHCs)," 8th International Conference on Fundamentals and Developments of Fuel Cells, FDFC 2019, February 12–14, 2019).

## REFERENCES


1. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Fuel Cell Technologies Office, *Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan*, Hydrogen Delivery, http://energy.gov/sites/prod/files/2015/06/f22/fcto_myrdd_delivery.pdf.
2. G. Parks et al., *Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs* (NREL Independent Review: May 2014).
3. https://www.nrel.gov/hydrogen/hydrogen-infrastructure-analysis.html.