NREL High-Pressure Low-Temperature Electrolysis Cell Hardware

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Disclaimer

The documents and drawings included in this download package describe a design for a low temperature electrolysis hardware that is intended to comply with leak testing according to ASME B31.1. Safe operation at ambient and elevated pressures is the sole responsibility of the end user, which should be evaluated on a case-by-case basis for each individual cell. Factors affecting the sealing capability may depend on, for example, machining quality, cell assembly components, operating conditions, and operating history. Operation at pressure should only be performed on qualified test stands by qualified operators. NREL/ALLIANCE FOR SUSTAINABLE ENERGY, LLC/DOE DISCLAIM ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING THE WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, AND MAKES NO WARRANTY AS TO THE ACCURACY, COMPLETENESS, OR USEFULNESS OF ANY INFORMATION PROVIDED HEREIN. USE OF THIS PACKAGE IS AT THE USER'S OWN RISK.

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Design Overview

This document describes an open-source cell hardware that enables low temperature electrolysis (LTE) testing at elevated pressures. Existing commercial options have several downsides when it comes to R&D testing. They are often not designed for repeated reassembly, may not be able to accommodate porous transport layers with different thicknesses, and do not give state-of-the-art performance. Therefore, this hardware was developed specifically with LTE R&D in mind and its design is being made available to the global LTE community. This work was planned and funded by the U.S. Department of Energy's H2NEW consortium (https://h2new.energy.gov/).

High pressure LTE operation can reduce operating costs, as it is more efficient to produce electrochemically pressurized hydrogen compared to using downstream mechanical compressors. In addition, high pressure hydrogen has a higher energy density, which can either increase a plant's capacity or reduce its footprint.

This open-source hardware features thicker flow field plates with stringent flatness and parallelism tolerances and uses o-seal fittings for the inlets and outlets. The rest of the design, for example the triple serpentine flow field pattern, is almost identical to existing ambient pressure LTE cells used at the National Renewable Energy Laboratory (NREL). Figure 1 shows an exploded view of all the components that make up the cell assembly. 3D CAD models and 2D technical drawings for the numbered parts (5900-00-01 – 5900-00-05) are included separately available for download.

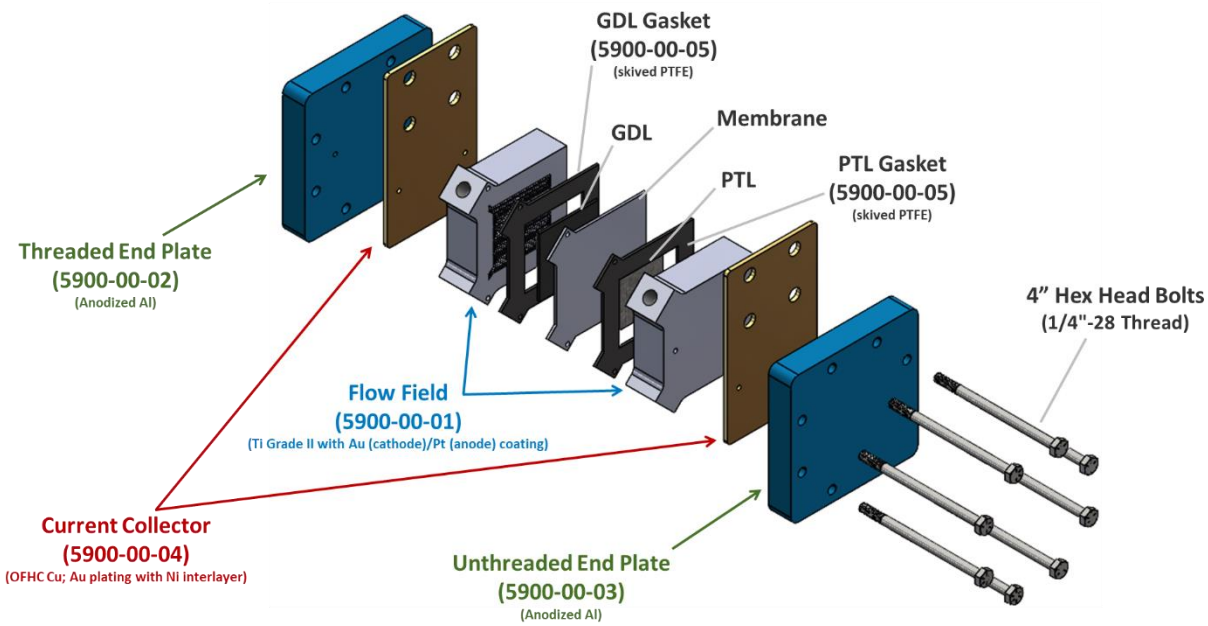


Figure 1. Exploded view of the full high-pressure cell.

Figure 2 provides a more detailed picture of the flow fields. The triple serpentine pattern is directly translated from previous LTE cell designs. The most unique feature is the diagonal orientation of the inlet/outlet ports with their extended metal platforms, which were included to accommodate the minimum thread requirement of the high-pressure (HP) o-seal fittings used for the inlet/outlet

tubing connections. This configuration enables the same end plate and bolt pattern of NREL's ambient pressure hardware to be used for high pressure operation.

The thickness of the HP flow fields was increased from 1/2" to 1" because the increased thickness likely reduces deflection and distributes compression more evenly, leading to better sealing. In addition, flatness and parallelism tolerances of 0.001" were included in the technical drawings, as these parameters also affect the uniformity of cell compression. Surface roughness is not believed to be a critical parameter, as the sealing interface is located between the metal flow field and polymeric gasket (currently PTFE). A small amount of surface roughness may actually be beneficial for sealing due to a "crimping" effect (see, for example, US8349151B2[1]).

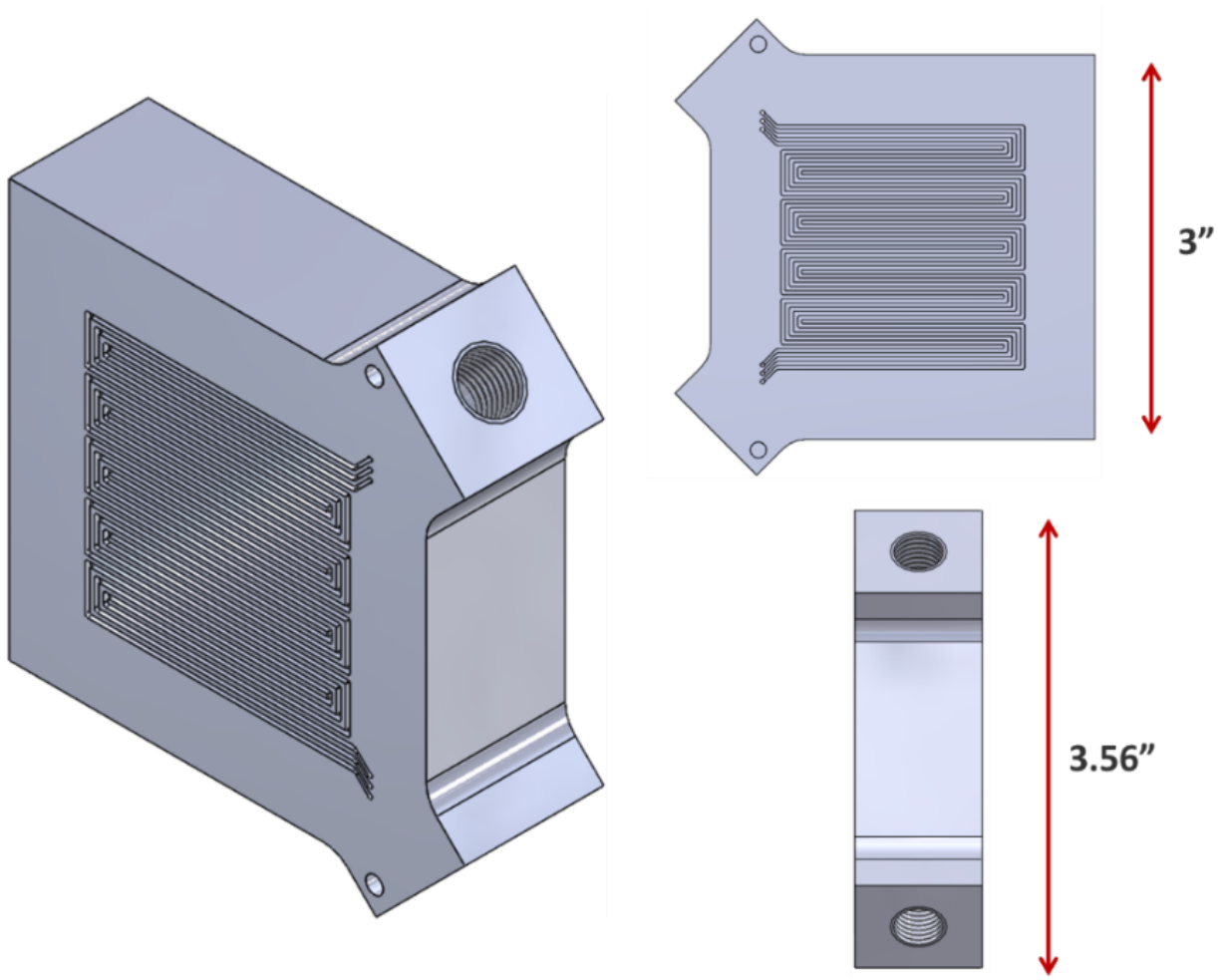


Figure 2. 3D views of the novel flow field.

[1] Edwin W. Schmitt and Timothy J. Norman, Universal cell frame for high-pressure water electrolyzer and electrolyzer including the same, US Patent 8,349,151 B2, issued Jan. 8, 2013, https://patents.google.com/patent/US8349151.

Pressure Rating

The maximum allowable working pressure (MAWP) of the high-pressure cell, verified at NREL, is 30 bar_g (435 psi_g). Pressure relief valves in the test station should be set to 33 bar_g. Higher working pressures may be possible but must be verified separately. All users should perform their own due diligence and leak test their hardware at their facility to verify the MAWP prior to use.

The MAWP of the cell was determined according to the document, "NREL HP LTE Leak Test Procedure (ASME B31.3)", which is made available at the same download location as this document. The leak test procedure follows ASME B31.3 https://asmedigitalcollection.asme.org/ebooks/book/280/chapter/26344536/Leak-Testing.

To summarize: the cell was immersed in a vessel filled with DI water, heated, and pressurized with He to the test pressure of 33 bar_g. The lack of bubbles observed at the test pressure confirmed that the cell was effectively sealed.

Cell Assembly Materials

- 2x Flow Fields (5900-00-01)
  - Material: Grade II Ti
    - Anode and cathode flow fields are geometrically identical
    - Flow fields should be coated with a non-passivating electronic conductor. NREL uses Pt for the anode side and Au for the cathode side, applied via Treadstone Technologies' DOT technique with 80% coverage (https://www.treadstone-technologies.com/dot.php). Other coating methods with sufficient adhesion could also be used.
- 1x Threaded End Plate (5900-00-02)
  - Material: Anodized Al
  - Helicoils are specified for longer lasting threads
- 1x Unthreaded End Plate (5900-00-03)
  - Material: Anodized Al
- 2x Current Collectors (5900-00-04)
  - Material: Oxygen-Free High Thermal Conductivity Cu (aka, Cu 101)
    - Like the flow fields, the current collectors should also be coated with a non-passivating electronic conductor. NREL uses Au, with a Ni interlayer according to MIL-DTL-45204D.
- 2x Cathode Tube Fittings (O-Seal, Stainless Steel, 1/4" 7/16-20)
  - e.g., Swagelok Part No. SS-400-1-OR, https://products.swagelok.com/en/c/straights/p/SS-400-1-OR
  - Passivated according to ASTM A967-05 (NREL follows 7.1.1.3 "Citric 3")
- 2x Anode Tube Fittings
  - Option 1 (only suitable with passivation):
    - O-Seal, Stainless Steel, 1/4" 7/16-20
    - e.g., Swagelok Part No. SS-400-1-OR, https://products.swagelok.com/en/c/straights/p/SS-400-1-OR
    - Passivated according to ASTM A967-05 (NREL follows 7.1.1.3 "Citric 3")
  - Option 2 (for differential pressure only):
    a) 1/4" PFA Compression fitting, e.g., McMaster 52195K53, https://www.mcmaster.com/52195K53/
    b) 1/4" PFA straight adaptor, e.g., McMaster 5694T271, https://www.mcmaster.com/5694T271/

c) 1/4” ID Buna-N 70A o-ring, e.g., McMaster 9408K41, https://www.mcmaster.com/9408K41/

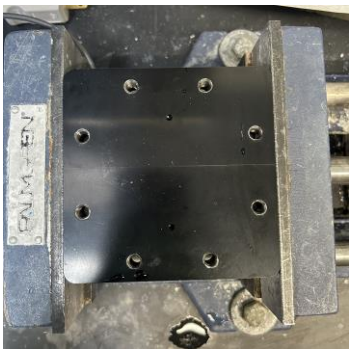
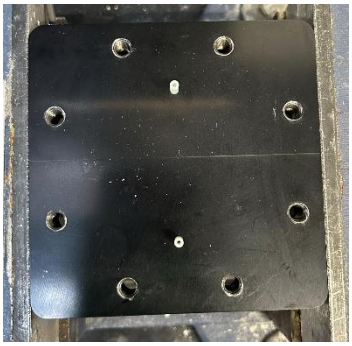
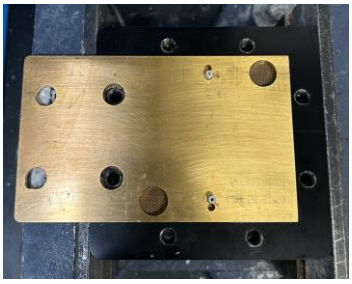
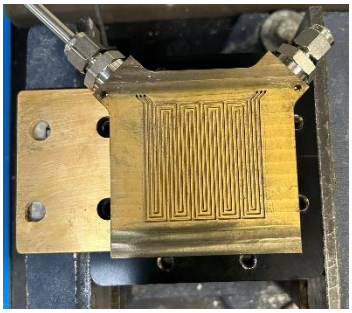
- Screw (a) into (b), remove cap from (b), roll o-ring (c) onto (b):

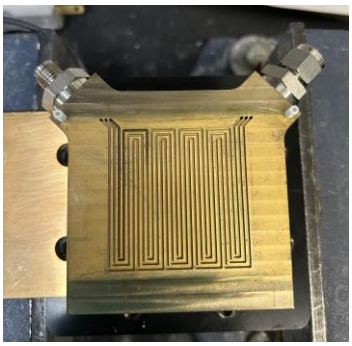
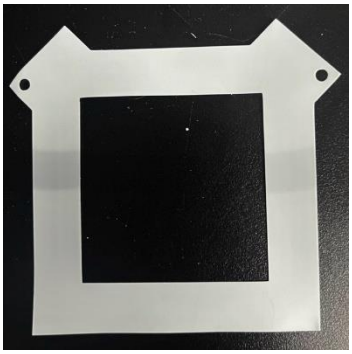
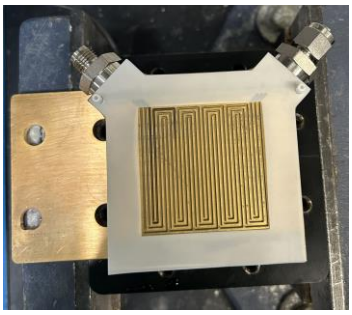
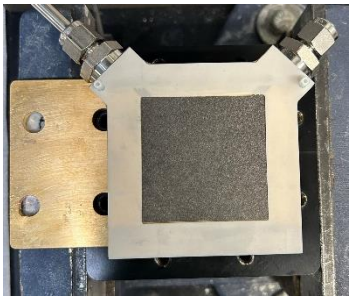
- Option 3 (not yet tested by NREL):
  - O-Seal, Grade II Ti, 1/4” 7/16-20
  - e.g., DK-Lok USA, Part No. DMC4-4UO-Ti, https://www.dklokusa.com/wp-content/themes/dk/library/images/uploads/dk-lok-DK-Lok-Tube-Fittings-updated.pdf

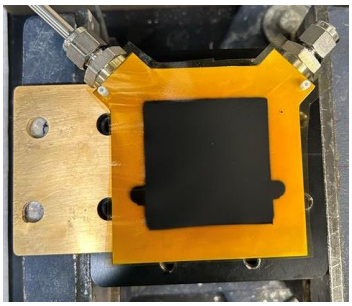
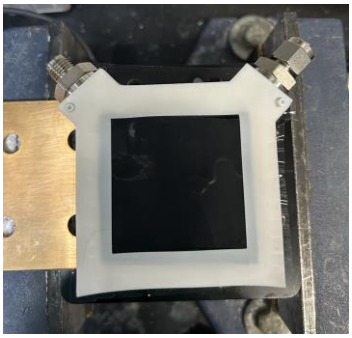
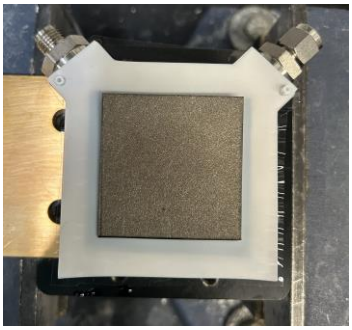
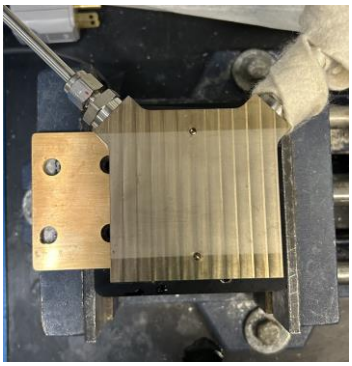
- 8x Bolts (Grade 8 Steel, 1/4”-28 Thread Size, 4” Long, Partially Threaded)
  - e.g., McMaster 91257A571, https://www.mcmaster.com/91257A571/
- 2x Adhesive Backed Pad Heaters (10 W/in^2, 2” x 2”, 120V AC)
  - e.g., McMaster 35475K163, https://www.mcmaster.com/35475K163/
- 2x Gaskets (5900-00-05)
  - Material: skived PTFE, e.g., CS Hyde, https://catalog.cshyde.com/item/films/ptfe-skived-film/15-1f-12
  - Note that thickness of gasket and porous transport media must be carefully selected with respect to each other to create a successful seal.
- 16x regular washers (Stainless Steel, 0.234” ID, 0.5” OD)
  - 2x per bolt (see pattern in the “Belville washers” bullet)
  - e.g., McMaster 92141A013, https://www.mcmaster.com/92141A013/
- 64x Belville washers (Stainless Steel, 0.255” ID, 0.5” OD, 0.0380” Thick)
  - e.g., McMaster 9713K64, https://www.mcmaster.com/9713K64/
  - 8x Belville washers per bolt. It is important that the washers are arranged as follows: 1x regular washer, 2x Belville washers, 2x Belville washers with opposite orientation, 2x Belville washers, 2x Belville washers with opposite orientation, 1x regular washer.
  - The washer pattern should look like: | < < > > < < > > |
- Adhesive backed PTFE coated fiberglass sheet
  - Attach to current collector plate such that no electrical contact is made between current collector and endplate
  - Cut holes where needed for alignment pins and bolt locations
  - e.g., McMaster 5739T51, https://www.mcmaster.com/5739T51/

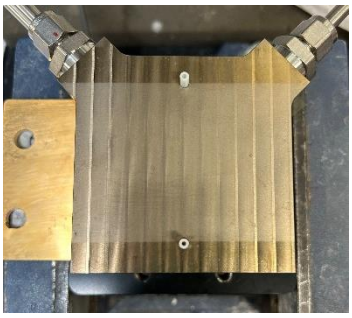
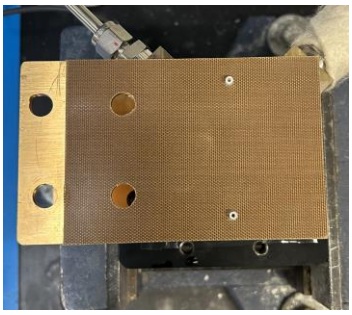
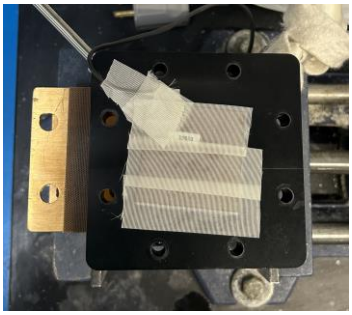
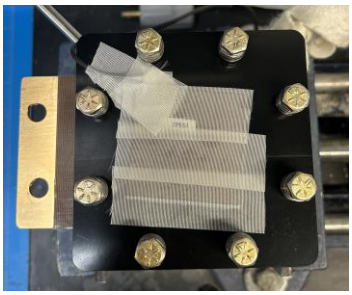
- Alignment pins
  - 3 mm PFA tubing
    - 4x cut to 11 mm length for endplate/current collector/flow field
    - 2x cut to 8 mm length for flow field/flow field
  - e.g., McMaster 5733K51, https://www.mcmaster.com/5733K51/

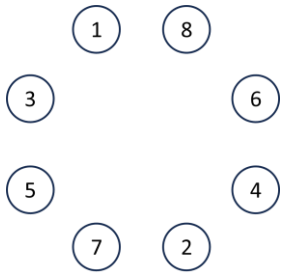
Cell Assembly Instructions

1.	Secure the threaded end plate with the alignment holes facing up on a table or in vice with flat jaws. This endplate corresponds to the cathode side of the cell	
2.	Insert 2x alignment pins (11 mm length) into endplate	
3.	Place cathode current collector onto the end plate, insulator side down (not shown), aligning it with end plate alignment pins *(Note: this picture shows two extra holes in the current collector plate that are not included in 5900-00-04; this picture uses a legacy current collector part)*	
4.	Place cathode flow field onto current collector, aligning it with end plate alignment pins	

5.	Insert 2x alignment pins (8 mm length) into flow field	
6.	Remove curvature from PTFE gaskets by either mechanical or temperature treatment	
7.	Place cathode PTFE gasket on flow field, aligning it with alignment pins	
8.	Place cathode porous transport medium in the open space provided by the gasket. Ensure that there is no overlap along the edges.	

9.	Place catalyst coated membrane (CCM) with cathode side down, aligning holes with flow field alignment pins. *(Note: the protrusions of the catalyst layers shown in the picture are intentional electrode regions used for XRF characterization of the catalyst layers; cathode on the left, anode on the right).*	
10.	Place the anode PTFE gasket, aligning it with flow field alignment pins	
11.	Place anode porous transport media in the open space provided by the gasket. Ensure that there is no overlap along the edges.	
12.	Place anode flow field onto the porous transport media, aligning it with flow field alignment pins	

13.	Insert 2x alignment pins (11 mm length) into the back of the anode flow field	
14.	Place anode current collector onto the flow field, insulator side up (shown as the brown material in the picture), aligning it with flow field alignment pins	
15.	Place the unthreaded end plate onto the current collector, aligning it with flow field alignment pins. This endplate corresponds to the anode side of the cell.	
16.	Insert and finger tighten 8 bolts *(Each bolt should have 10 total washers, in the following order: 1 regular washer; 8 Belville washers, 1 regular washer; arranged as* | < < > > < < > > | *)*	

17.	Use a torque wrench to apply 10 in*lbs to each bolt, moving from bolt to bolt in a star pattern:	
18.	Repeat Step 17 with 20 in*lbs	
19.	Repeat Step 17 with 30 in*lbs	
20.	Repeat Step 17 with 40 in*lbs	

Performance Benchmarking

To benchmark the performance of the high pressure hardware, a standard catalyst coated membrane (CCM) was fabricated, tested, and compared to baseline data acquired using an ambient pressure hardware ("LTE Cell"). The CCM was composed of a Nafion 115 membrane with ultrasonic spray-coated electrodes: 0.1 mg cm^{-2} Pt/C (TKK TEC10E50E) for the cathode and 0.4 mg cm^{-2} Ir/IrOx (Alfa Aesar Premion) for the anode. This CCM is the so-called Future Generation MEA ("FuGeMEA"), the baseline reference material used by the H2NEW consortium. An active area of 5 cm^2 was used for testing. The cells were assembled with identical materials and procedures and conditioned for 36 hours prior to testing. DI water was supplied to the anode side only at 50 ml min^{-1} and 80°C. The water temperature control point was directly at the inlet of the hardware. In addition, the endplates were heated to 80°C using pad heaters, a dedicated PID controller, and the thermocouple hole in the cathode as the temperature control point.

Figure 3 shows a performance comparison between the HP cell and a typical ambient pressure LTE cell used at NREL. The differences in cell voltages are minor and within acceptable cell-to-cell variation. The cell voltages were identical up to 4 A cm^{-2} and very similar up to 6 A cm^{-2}, with the HP cell featuring slightly lower voltages above 4 A cm^{-2}. Similarly, the high frequency resistances (HFR) were nearly identical, indicating that the differences in cell voltage were not due to ohmic losses.

The IR-Free voltages are also shown in Figure 3, calculated as:

$$V_{IR-Free} = V_{cell} - i \cdot HFR$$

Like the cell voltages, the IR-Free voltages are essentially identical up to 4 A cm^{-2}. Above 4 A cm^{-2} the HP cell featured slightly lower IR-Free voltage compared to the ambient pressure LTE cell. It is possible that the strict flatness/parallelism tolerances of the HP cell resulted in more uniform compression across the active area, leading to improved catalyst layer utilization. Regardless, the results affirm that the HP cell delivers a comparable performance to the ambient pressure LTE cells when operated with identical materials.

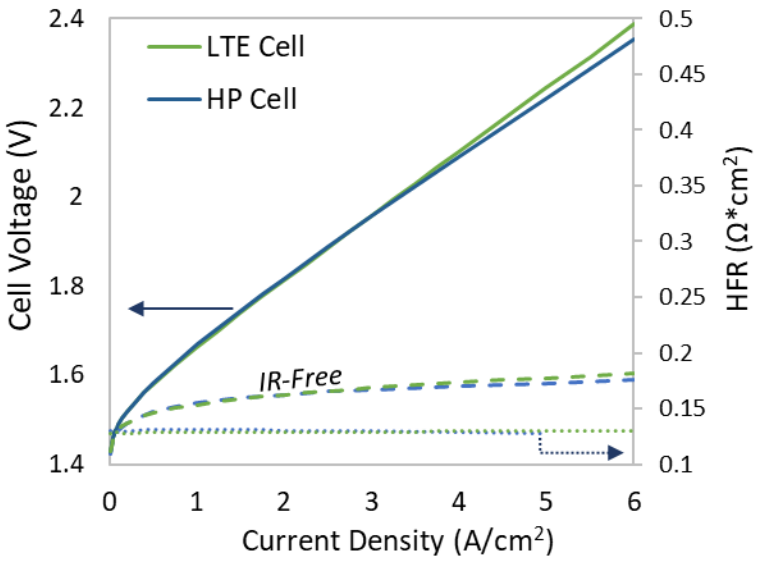


Figure 3. Performance comparison of Nafion 115 CCM using HP cell vs. ambient pressure LTE cell.