SECTION A. Project Title: High-Temperature Electrolysis R1

SECTION B. Project Description and Purpose:

Revision 1:

This Idaho National Laboratory (INL) project, High Temperature Electrolysis, includes on-going high-temperature electrolysis (HTE) work. The objectives of this project are to develop and demonstrate HTE for efficient hydrogen production from steam using solid-oxide electrolysis cells. In addition, co-electrolysis of steam and carbon dioxide (CO2) is under investigation for the production of syngas (H2 and CO).

The changes in this revision include the following:

- Location move from Bonneville County Technical College (BCTC) to INL Engineering Demonstration Facility (IEDF), IF-657 (Labs E3/E4). The project will no longer emit carbon monoxide emissions as part of the work at IEDF.
- Facility modifications for ventilation and associated upgrades will be required at IEDF.
- Equipment purchases including, but not limited to benchtop furnaces, computers, and instrumentation systems. The furnaces are benchtop units and are covered under ERP 3261. Outlets were installed for the benchtop units and were covered under the routine maintenance ECP INL-20-022. Equipment will be kept for continued testing use and the development of additional systems.

The following Consortium H2 partnering Department of Energy (DOE) laboratories will complete the tasks listed below to assist INL with the modeling/and testing:

<u>Pacific Northwest National Laboratory (PNNL)</u>

- Fabrication work
- Testing of samples

<u>National Renewable Energy Laboratory (NREL) and Lawrence Livermore National Laboratory (LLNL)</u>

- Modeling and characterization
- Samples will be kept for characterization

<u>National Energy Technology Laboratory (NETL)</u>

- Modeling

<u>Lawrence Berkeley National Laboratory (LBNL)</u>

- Testing of Samples

<u>NREL</u>

- Radiological work associated with characterization and similar tools (x-rays, ion beams, etc.)

Waste will be generated at INL in association to this project, refer to the Aspects and Impacts section for further information.

The INL portion of the project will discharge used deionized water to the Idaho Falls Sewer System and release hydrogen emissions (<1 L/min) during the experiment of HTE.

INL will keep samples for characterization, less than 500 button cells or approximately about 1 kg of inert solid material will be collected.

Off-site work at other DOE laboratories may generate waste, which will be handled and disposed of according to relevant offsite facility procedures and processes.

Original ECP:

This environmental checklist (EC) documents continued work on high temperature electrolysis which was initiated under EC IFF-00-006; the work was updated in EC INL-06-027 when the project moved to BCTC. Later, with a change in scope, the EC was updated to INL-12-026 (OA 8), and later updated again to EC INL-13-072 (OA 18). Newly identified work is documented in this EC which supersedes previous ECs. This EC covers general operation and INL-initiated and funded research and development (R&D). Work for customers through WFO or CRADA, or in support of different customers and/or funding sources requires separate project-specific ECs.

The objectives of this project are to develop and demonstrate high-temperature electrolysis (HTE) for efficient hydrogen production from steam using solid-oxide electrolysis cells. In addition, co-electrolysis of steam and carbon dioxide (CO2) is under investigation for the production of syngas (H2 and CO).

The test setup includes both single-cell testing and multiple-cell planar stack testing. Stack testing is performed in one of three large furnaces. Each test loop is independently instrumented and operated. Each test loop includes basic instrumentation such as mass-flow controllers, dewpoint sensors, thermocouples, and pressure transducers. For co-electrolysis testing, in-line CO2 sensors and a downstream gas chromatograph (GC) are also included. Solid-oxide electrolysis cells (SOECs) and stacks tested at INL are supplied by industrial partners.

General Operation

For most tests, a mixture of nitrogen, hydrogen and steam is introduced to the cathode side of the electrolysis cells. Electrolysis tests that also involve carbon dioxide will be discussed later. The use of nitrogen as an inert carrier gas allows for independent variation of the partial pressures of the other process gases while operating at atmospheric pressure. The nitrogen is supplied by a compressed gas bottle or a dewar. Hydrogen and carbon dioxide are supplied using compressed gas cylinders. Immediately downstream of each gas-supply regulator is a pressure-relief valve (75 psig release pressure – hydrogen is vented to roof vents). Flow rates of nitrogen and hydrogen (and CO2 for co-electrolysis) are controlled by precision mass-flow controllers. The ordinary regulator setpoint pressure in the flow lines is about 40 psig upstream of the mass flow controllers. The nitrogen/hydrogen mixture is bubbled through a temperature-controlled humidifier where steam is added to the gas mixture by evaporation. The vapor pressure of the water in the humidifier and the resulting partial pressure of the steam exiting the humidifier are dependent on the water bath temperature. The water bath is maintained at a fixed temperature in the range of 20-80°C using feedback control. A pressure-relief valve is also mounted on the humidifier (75 psig release pressure - vented to hydrogen roof vents) to eliminate the possibility of humidifier over-pressurization. Gas mixture temperature, pressure, and dewpoint are measured continuously at the humidifier exit. Knowledge of the dewpoint temperature, along with the nitrogen and hydrogen mass flow rates allows for continuous on-line monitoring of the gas mixture composition. In order to prevent steam condensation downstream of the humidifier, heat-tracing is used along the length of stainless-steel tubing between the humidifier and the electrolysis cell. The heat-traced lines are maintained at a temperature of about 150°C. The heat-traced lines are also thermally insulated so that the hot tubing is not exposed.

The SOECs are maintained at the desired operating temperature (800 to 900°C) using a feedback-controlled high-temperature furnace. There are two outlet streams from the electrolysis cells or stacks. The outlet from the anode side will be air that is slightly enriched with oxygen. This stream is exhausted directly from the furnace into the laboratory. The outlet from the cathode side will be a gas mixture of nitrogen, hydrogen, and steam. This gas mixture is directly vented outside the building at the rooftop level by means of plastic tubing run through the entire length of a large-diameter PVC exhaust vent. The exhaust vent serves as a conduit that houses several smaller plastic exhaust tubes. This arrangement ensures that all exhaust gases are released outside the building and prevents the possibility of off-gas build up inside the exhaust vent should the draft inside the vent be insufficient to remove the off-gases. The cathode-side gas mixture temperature, pressure, and dewpoint are measured downstream of the electrolysis cell outlet in order to determine the rate of steam reduction in the cell. Pressure relief is not required downstream of the furnaces because there are intentionally no valves located downstream of the cells or stacks.

The hydrogen production rate can be independently determined from the measurement of the electrical current consumed by the electrolysis cells using Faraday's law. The voltage and current across the electrolysis cell(s) is continuously monitored. Typical per-cell operating voltages are in the range of 0.9-1.5 V. Typical current densities are in the range of 100-400 mA/cm2, yielding a total current of 0.25-1.0 A for the 2.5 cm2 active cell area "button cells" and 6.4-25.6 A for the 64 cm2 cells in a typical planar stack. In the case of multiple-cell stacks, the individual cells are wired in series electrically, so the amperage for the stack is the same as for each cell. The voltage across the cell stack, however, will increase in direct proportion to the number of cells. In some cases, carbon dioxide will be included in the inlet gas flow mixture along with nitrogen, hydrogen and steam. Since the solid-oxide electrolyte material is a conductor of oxygen ions, carbon dioxide can be converted into carbon monoxide using high-temperature electrolysis. If both steam and carbon dioxide are included in the inlet flow, the process is termed co-electrolysis. We are investigating co-electrolysis-based production of a mixture of H2 and CO (syngas) in solid-oxide cells using H2O and CO2 feedstocks, focusing on process efficiency and optimization of the process for syngas production. During co-electrolysis testing, on-line CO2 sensors, located upstream of the humidifier and downstream of the condenser, are used to provide continuous measurements of gas-stream carbon dioxide content. In addition, a gas chromatograph is used to analyze the outlet gases in detail on an as-needed basis.

For co-electrolysis, the exhaust gases will include hydrogen, nitrogen, carbon dioxide, and carbon monoxide. Again, this outlet gas mixture will be directly vented outside the building at the rooftop level by means of plastic tubing run through the entire length of a large-diameter PVC exhaust vent. The oxygen produced during electrolysis will be diluted with a sweeping flow of air and exhausted to the laboratory.

Large Scale Testing of Solid Oxide Electrolysis Stacks

The stacks typically include advanced electrode-supported cells with an active area of 100 cm2 and outer dimensions of 15 cm x 15 cm. The cells have 4 flow passages on each side to support a cross-flow, internally manifolded stack design. The stacks are located inside of a cylindrical clamshell ceramic-fiber furnace. The inlet gases are pre-heated prior to entering the furnace by means of heat recuperation from the hot outlet gases. The gases are heated to the final 800°C operating temperature within the furnace by means of radiant heating. The inlet gases flow through coiled tubing located inside the furnace upstream of the stack for this purpose.

For multi-kW tests, a mixture of hydrogen, nitrogen and steam is introduced to the cathode side of the electrolysis cells. Hydrogen is required on the inlet side in order to maintain reducing conditions on the nickel cermet electrode of the SOECs. Nitrogen is included in the cathode gas mixture to yield a total dry gas mole fraction of 30% with a hydrogen mole fraction of 17%. The inclusion of nitrogen reduces the required inlet hydrogen flow rate to a value that could be supported by the electrolyser unit and the available mass flow controllers. Air or nitrogen flows across the anode side of the electrolysis cells as a sweep gas. Nitrogen is supplied by a cryogenic dewar for large-scale tests.

Steam is provided by an electrically heated steam generator. The steam generator includes two independently heated zones. The lower boiling zone is controlled at constant power, with the power value depending on the required steam production rate. The rate of steam production for these tests will yield an inlet steam mole fraction of 70%. The upper zone is feedback-controlled on temperature in the single-phase steam region above the liquid. The two-zone strategy allows for steady steam production with a desired amount of superheat. The gas flow lines downstream of the steam generator are heat-traced to avoid condensation. The outlet gas flow mixture flows through a water-cooled condenser where the majority of the residual steam is condensed, and then to the roof vent. Stack power will be provided by a 10 kW DC power supply rated at 100 V and 100 A. Nominal power consumption during operation will be 4.2 kW at 30 A and 70 V. The stacks will be instrumented with intermediate voltage taps on every five cells.

The hydrogen/nitrogen inlet gas flow is mixed with steam downstream of the steam generator. After mixing, the dewpoint temperature of the resulting steam/hydrogen/nitrogen mixture is measured using a precision dewpoint sensor. Another dewpoint sensor is located downstream of the SOEC stacks. The two dewpoint measurements provide an independent direct measurement of the steam consumption rate in the SOEC stacks, which is equal to the hydrogen production rate on a molar basis.

At the nominal operating conditions, the hydrogen production rate will be 25 SLPM, or 1500 L/hr. This production rate will be determined from the measurement of the electrical current supplied to the electrolysis cells using Faraday's law and will also be independently verified based on the change in dewpoint value between the inlet and outlet dewpoint sensors. The voltage and current across the electrolysis cell(s) is continuously monitored. Typical per-cell operating voltage will be 1.12 V.

Experiments to Evaluate Direct Solar Conversion of Steam to Hydrogen using a Solid Oxide Photoelectrochemical Cell

The HTE research team has been evaluating the potential for direct solar conversion of steam to hydrogen. The process involves the use of solid oxide cells with the usual oxygen electrode replaced by a layer of semiconductor material such as titanium dioxide (TiO2), forming a solid-oxide photoelectrochemical cell (SOPC). When exposed to an appropriate light source, electrons within the semiconductor will be excited from the valence band to the conduction band, as in a photovoltaic cell. The photon energy required for this excitation is called the band gap. The magnitude of the band gap required for this transition in titanium dioxide at room temperature is 3.2 eV, which requires ultraviolet (UV) light. However, the band gap decreases with temperature such that at the typical operating temperature for solid oxide electrolysis cells, 800°C, the electronic transitions can be excited using visible light and the electrical energy for water splitting is decreased. Furthermore, the kinetics for water splitting are much more favorable at high temperature. These facts support the possibility of efficient direct solar conversion of steam to hydrogen.

The experiments include both room-temperature and high-temperature testing. The purpose of the room-temperature tests will be to observe hydrogen production in an aqueous electrolyte salt solution using TiO2 on a ceramic substrate with an imbedded silver mesh current collector and a silver mesh counter electrode. A broad-spectrum light source (500 W mercury-xenon solar simulator) with some output in the UV spectrum will be used to achieve hydrogen production at room temperature. The same lamp will be used for the high-temperature experiments. In this case, the lamp will be mounted on a fixture above the single-cell test stand. The top insulation block of the test stand will be modified to accommodate a sapphire window mounted in a cylindrical holder. The light from the solar simulator is focused to concentrate the intensity on the solid oxide cell located inside the furnace. Hydrogen production will be verified by measurements of electric current and inlet and outlet humidity readings.

Solar Simulator

A solar simulator will support test activities. This simulator includes an arc lamp housing and arc lamp power supply, adjustable from 200 to 500 W output. The arc lamp housing includes an aluminum enclosure for the lamp, with lamp igniter, condensing optics, rear reflector and lamp cooling fan. The housing is designed for 50 to 500 Watt Hg, Xe and Hg-Xe DC arc lamps. It uses an F/1 Single Element Fused Silica condenser lens for a 1.3 inch (33 mm) diameter collimated beam at the 1.5 Inch Series output flange. These lamp housings include a number of safety features to prevent lamp damage and accidental exposure. A door interlock prohibits the operation of the lamp while the door is open; a temperature sensor monitors the lamp's operating temperature and controls the cooling fan accordingly.

A 500 W mercury-xenon lamp will be installed in the lamp housing. The housing provides rear reflector and lamp adjusters. A spherical mirror behind the lamp creates an inverted arc image. The condensing lens collects light directly from the arc and from the mirror image of the arc to increase output beam intensity. Adjustment knobs for both lamp and reflector position are located on the back panel of the housing, allowing for adjustment while the lamp is operating. Adjustment of the condensing lens enables focusing of the output beam at various distances. The system also includes a mirror holder to deflect the beam from the horizontal orientation to vertically downward. The mirror holder can be used with either a full reflector front-surface mirror to provide full-spectrum light, or it can be used with a dichroic mirror that provides UV-only light in the 280 – 400 nm range. For solar simulation, an air mass 1.5 filter can be positioned in the output beam using a filter holder. The system also includes an adjustable 3.2 to 4.25 inch extended light shield which can be used to position the output beam horizontally further out from the housing. This component was needed for in-furnace cell testing. The lamp provides a broad-spectrum output from the infra-red to the ultra-violet.

SECTION C. Environmental Aspects or Potential Sources of Impact:

Air Emissions

The work at INL is expected to release air, nitrogen, water vapor, oxygen and hydrogen. Small amounts such as <1 L/min of hydrogen will be emitted. None of these gases are regulated. Work is NO longer expected to release carbon monoxide, a criteria pollutant.

Discharging to Surface-, Storm-, or Ground Water

The non-contact cooling water will be discharged to the Idaho Falls sewer system in accordance with City Sewer regulations.

Disturbing Cultural or Biological Resources

Cultural: Pursuant to the 2023 Programmatic Agreement, this federal undertaking is excluded from Section 106 review as the proposed activity results in no historic properties affected.

Generating and Managing Waste

Scrap metal will be recycled to the extent practicable. All Solid waste will be managed by WGS.

INL waste may include:
i. Industrial, about 1 bag of general lab trash a week.
ii. Hazardous, Solvents <0.5 L/week, RCRA metals < 10 g/week
iii. PPE, wipes, about 1 bag of general trash a week.

Off-site work at other DOE laboratories may generate waste.

Releasing Contaminants

When chemicals are used during the project there is the potential for spills that could impact the environment (air, water, soil).

Using, Reusing, and Conserving Natural Resources

Project description indicates materials will need to be purchased or used that require sourcing materials from the environment. Being conscientious about the types of materials used could reduce the impact to our natural resources.

Scrap metal will be recycled to the extent practicable. The purpose of this work is to develop methods to efficiently extract hydrogen from water. All applicable waste will be diverted from disposal in the landfill when possible. Project personnel will use every opportunity to recycle, reuse, and recover materials and divert waste from the landfill when possible. The project will practice sustainable acquisition, as appropriate and practicable, by procuring construction materials that are energy efficient, water efficient, are bio-based in content, environmentally preferable, non-ozone depleting, have recycled content, and are non-toxic or less-toxic alternatives. New equipment will meet either the Energy Star or SNAP requirements as appropriate (see http://www.sftool.gov/GreenProcurement/ProductCategory/14).

Environmental Justice

NA

SECTION D. Determine Recommended Level of Environmental Review, Identify Reference(s), and State Justification: Identify the applicable categorical exclusion from 10 Code of Federal Regulation (CFR) 1021, Appendix B, give the appropriate justification, and the approval date.

For Categorical Exclusions (CXs), the proposed action must not: (1) threaten a violation of applicable statutory, regulatory, or permit requirements for environmental, safety, and health, or similar requirements of Department of Energy (DOE) or Executive Orders; (2) require siting and construction or major expansion of waste storage, disposal, recovery, or treatment or facilities; (3) disturb hazardous substances, pollutants, contaminants, or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)-excluded petroleum and natural gas products that pre-exist in the environment such that there would be uncontrolled or unpermitted releases; (4) have the potential to cause significant impacts on environmentally sensitive resources (see 10 CFR 1021). In addition, no extraordinary circumstances related to the proposal exist that would affect the significance of the action. In addition, the action is not “connected” to other action actions (40 CFR 1508.25(a)(1) and is not related to other actions with individually insignificant but cumulatively significant impacts (40 CFR 1608.27(b)(7)).

References: B1.15 "Support buildings", B3.6 "Small-scale research and development, laboratory operations, and pilot projects"

Justification: B1.15 Siting, construction or modification, and operation of support buildings and support structures (including, but not limited to, trailers and prefabricated and modular buildings) within or contiguous to an already developed area (where active utilities and currently used roads are readily accessible). Covered support buildings and structures include, but are not limited to, those for office purposes; parking; cafeteria services; education and training; visitor reception; computer and data processing services; health services or recreation activities; routine maintenance activities; storage of supplies and equipment for administrative services and routine maintenance activities; security (such as security posts); fire protection; small-scale fabrication (such as machine shop activities), assembly, and testing of non-nuclear equipment or components; and similar support purposes, but exclude facilities for nuclear weapons activities and waste storage activities, such as activities covered in B1.10, B1.29, B1.35, B2.6, B6.2, B6.4, B6.5, B6.6, and B6.10 of this appendix.

B3.6 Siting, construction, modification, operation, and decommissioning of facilities for small-scale research and development projects; conventional laboratory operations (such as preparation of chemical standards and sample analysis); and small-scale pilot projects (generally less than 2 years) frequently conducted to verify a concept before demonstration actions, provided that construction or modification would be within or contiguous to a previously disturbed or developed area (where active utilities and currently used roads are readily accessible). Not included in this category are demonstration actions, meaning actions that are undertaken at a scale to show whether a technology would be viable on a larger scale and suitable for commercial deployment.

Is the project funded by the American Recovery and Reinvestment Act of 2009 (Recovery Act) ☐ Yes ☒ No

Approved by Robert Douglas Herzog, DOE-ID NEPA Compliance Officer on: 5/16/2024