Standard Operating Procedure

(SOP)

Definitions, Terms and Metrics for High Temperature Electrolysis

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Rev 1

Olga Marina / Chief Scientist	4/14/2019
Prepared By: NAME / TITLE	Date
Approved By: NAME / TITLE	Date
Approved By: NAME / TITLE	Date

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Revision History

This page documents the revisions over time to the SOP. The most recent iteration should be listed in the row space, with consecutive versions following.

Date of Revision	Page(s)/Section(s) Revised	Revision Explanation
04/14/2019	All	First Release

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3. Procedures

Not applicable for this SOP.

a. Scope and Applicability

The purpose of this SOP is to define a standard set of definitions, metrics, units, and conventions for high temperature electrolysis (HTE). The goal is to ensure that the literature is consistent from research group to research group, and data is reported in similar formats, such that results can be compared on a similar basis. This SOP is a first draft and is intended to be revised and added to in collaboration with the HTE community.

b. Definitions and Acronyms

Below are common acronyms and definitions used in high temperature electrolysis and related characterization methods.

Acronym	**Stands for**	**Definition/comments**
ASR	Area Specific Resistance	Resistance of an electrode or a cell normalized by the active electrode area (where the electrochemical reaction takes place).
ASTM	American Society for Testing and Materials	A common source for standard test methods
BCY	Yttrium-Doped Barium Cerate	$Ba(Y)CeO_3$
BET	Brunauer–Emmett–Teller	A method for determining surface area
BZY	Yttrium-Doped Barium Zirconate	$Ba(Y)ZrO_3$
EIS	Electrochemical Impedance Spectroscopy	A method for measuring the resistance of the components
FIB	Focused Ion Beam	Method for depth profiling samples
GDC	Gadolinia-Doped Ceria	Gd_2O_3-doped CeO_2; $Ce_xGd_yO_{2-\delta}$
HHV	Higher Heating Value	See definitions
HTE	High Temperature Electrolysis	Typically above 600°C; uses steam
LHV	Lower Heating Value	See discussion below
LSF	Lanthanum Strontium Ferrite	$La(Sr)FeO_3$
LSCF	Lanthanum Strontium Cobalt Ferrite	$La(Sr)FeO_3$-$La(Sr)CoO_3$ solid solution
LSM	Lanthanum Strontium Manganite	$La(Sr)MnO_3$
LTE	Low Temperature Electrolysis	Typically less than 100°C; liquid water
OCV	Open-Circuit Voltage	See definitions

Acronym	Stands for	Definition/comments
PCEC	Proton-Conducting Electrolysis Cell	SOEC with proton-conducting ceramic electrolyte
rSOC	Reversible Solid Oxide Cell	SOC operates reversibly in fuel cell and electrolysis mode.
SDC	Samaria-Doped Ceria	CeO_2-Sm_2O_3; $Ce_xSm_yO_{2-\delta}$
ScSZ	Scandia-Stabilized Zirconia	$Zr_xSc_yO_{2-\delta}$; ZrO_2-Sc_2O_3
SEM	Scanning Electron Microscopy	Method of imaging component features
SOC	Solid Oxide Cell	Cell consists of a ceramic solid electrolyte and two electrodes supported by a ceramic or metal layer.
SOEC	Solid Oxide Electrolysis Cell	Cell consists of a ceramic solid electrolyte and two electrodes supported by a ceramic or metal layer and operated in electrolysis mode.
SOFC	Solid Oxide Fuel Cell	Cell consists of a ceramic solid electrolyte and two electrodes supported by a ceramic or metal layer and operated in fuel cell mode.
TEM	Transmission Electron Microscopy	Method of detailed structural imaging of electrodes and interfaces
XRD	X-ray Diffraction	Method to determine catalyst crystal structure
YSZ	Yttria-Stabilized Zirconia	$Zr_xY_yO_{2-\delta}$; ZrO_2-Y_2O_3

c. Common terminology used in high temperature electrolysis.

Barrier layer – A protective layer between two cell components to minimize chemical interaction between them.

Conditioning – Preliminary steps of electrode or cell treatment performed before usual operation.

Current collector – Electronically conductive material attached to the electrodes for collecting electrons.

Current density – Current per active electrode area.

Current-voltage characteristics – current-voltage curve

Efficiency – The ratio of useful output to total input.

Electric efficiency – The ratio of electric power produced to the total enthalpy flow supplied.

Higher heating value (HHV) – The higher heating value of a fuel is defined as the amount of heat released by a specified quantity (initially at 25°C) once it is combusted and the products of combustion have cooled to the initial conditions (25°C) with water vapor condensed. The heat contained in the water vapor must be recovered in the condensation process.

Interconnector – Bipolar plate.

Lower heating value (LHV) – The lower heating value (lower calorific value) of a fuel is defined as the amount of heat evolved when a unit weight (or volume in the case of gaseous fuels) of the fuel is completely burnt and water vapor leaves with the combustion products without being condensed [1].

Power density – Power per active electrode area.

Repeat unit – A single unit which periodically repeats itself to form a stack. It is composed of one single cell and two half-interconnects on both sides of the single cell and usually also sealant to assure gas-tightness and contact layers to minimize contact resistances between cells and interconnects.

Nernst potential – Thermodynamic potential of a redox system calculated from the thermodynamic parameters.

Open circuit voltage (OCV) – The cell voltage measured at a zero electrical current.

Stack – A number of repeat units assembled together and connected electrically to form an electrochemical device.

Thermal efficiency – $\eta_t = \dfrac{-\Delta \bar{h}_f / 2F}{E}$ where $\Delta \bar{h}_f$ is the enthalpy of formation, F is the Faraday constant, and E is the cell potential.

Thermoneutral voltage – Thermoneutral voltage relates to the enthalpy of a reaction.

$V_{thermoneutral} = -\Delta \bar{h}_f / 2F$ = 1.29 V at 850°C, where η_t =1.

At thermonetral voltage SOEC operates adiabatically without heat exchange between the electrolyzer and the environment. The electricity input to the electrolyzer matches exactly the enthalpy of the electrolysis reaction.

d. Units of Hydrogen Production

TBD

e. Operating Conditions and Parameters to Report

TBD: constant current, constant voltage, ASR

f. Verification Tests to Perform

Zero equipment (per Karl)
Leak Tests
Conditioning
EIS

g. Health & Safety Warning

Hydrogen is a flammable gas. It is combustible at levels of 4-75% in air. Hydrogen should only be produced in a well-ventilated area, and calculations should be performed to determine the maximum possible flow rate vs. the air flow in the area. Hydrogen can also embrittle metals over time, and materials of construction should be selected and inspected based on exposure.

4. Quality Control and Quality Assurance Section

TBD.
Diagnostics
Error Analysis

5. Reference Section

1. http://www.energy.kth.se/compedu/webcompedu/S4_Combustion/B1_Combustion_Basics/C1_Introduction_to_Combustion/ID35_files/Lower_calorific_value.htm
2. https://h2tools.org/hyarc/calculator-tools/lower-and-higher-heating-values-fuels
3. SOCTESQA Deliverable Report D.7.2– Liaison Interim Report – 16.11.2015 – Version 1 – 5.