Electrochemistry, Water, Energy:

our future for a cleaner world

Ohio Fuel Cell and Hydrogen Technology Forum

Ohio State University Energy Advancement and Innovation Center
June 6th, 2025

Andrew Smeltz, PhD - Director of R&D for Americas Region

Outline

- ***A Brief History of De Nora***
- ***De Nora Today***
- ***Hydrogen Development Activities at De Nora***
- ***What's next?***

About me!

- **Born and raised in Central Ohio (Westerville)**

- **(2004) Bachelor's Degree in Chemical Engineering from Ohio University**
  - Battelle Memorial Institute R&D co-op – E-chem K_2FeO_4
  - Corrosion Engineering Lab at Ohio U.

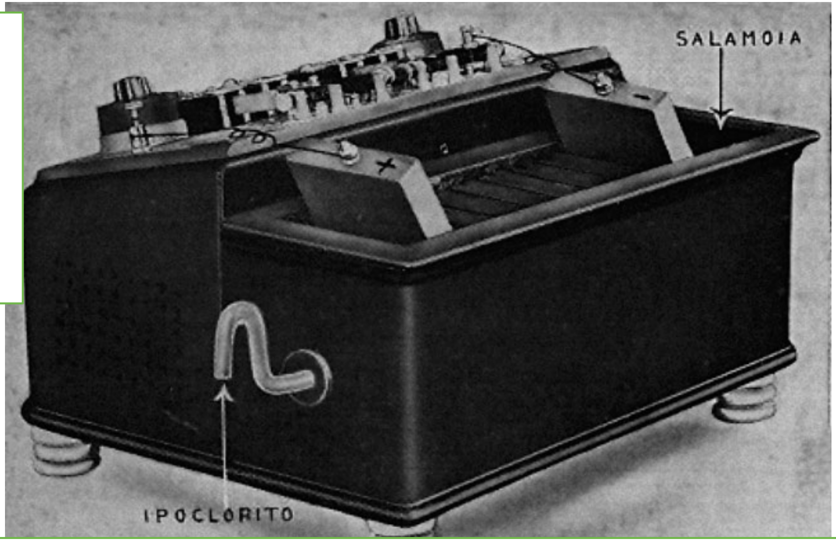
- **(2009) PhD in Chemical Engineering from Purdue University**
  - Heterogeneous Catalysis and Surface Science
    Advisors: Prof.'s Fabio H. Ribeiro and Nick Delgass
  - (2009-2011) Research Staff – Waste biomass to fuels

- **(2011-2016) United Technologies Research Center – Hartford, CT**
  - Staff Research Engineer – Physical Sciences Process Eng. Group
  - Vanadium flow batteries, elevator hybridization, fuel cell UAVs
  - Spun off company on VRB work (Largo Energy)

- **(2016-Present) De Nora Tech, LLC - Cleveland, OH**
  - Director of R&D for Americas Region
  - Energy Transition / New Applications, Core Businesses, Regional Support

In 1922, Oronzio De Nora graduates in Industrial Engineering Electrical Engineering at Milano Politecnico, then enrolls in a graduate course in electrochemistry to work on the electrolysis of alkali chlorides …

Soon after, in 1923, the history of the De Nora Group begins with Oronzio's advisor tapping him to consult on some issues at a local hypochlorite plant…



By the early 1930s, Oronzio De Nora had already produced more than a hundred hypochlorite plants and was starting to turn his attention to mercury C/A cell designs and water splitting to produce hydrogen and oxygen. Then WWII broke out…

With the war over, Oronzio De Nora is ready to test his first Hg chlor-alkali cell design. A malfunctioning plant in Lodi Italy provided the opportunity... The innovative Na-Hg decomposer was quickly adopted in both De Nora and competitor plants.

From the early 1950s until the mid-1970s, De Nora's mercury cathode cell systems spread exceptionally rapidly. At that time, 40% of the world's chlorine production is made with De Nora technologies.

From 1958 to 1965, the De Nora Group and Diamond Shamrock of Painesville, Ohio, developed a joint research program to improve the design of the C/A cell, focusing on the graphite anodes which were rapidly consumed during operation.

Fig. 1

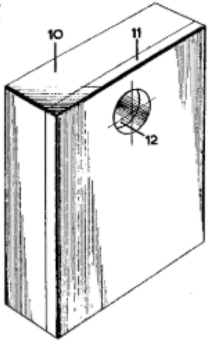
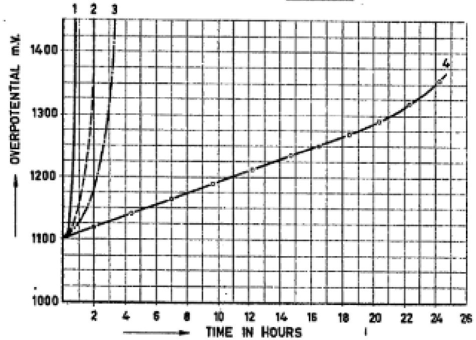


Fig. 2

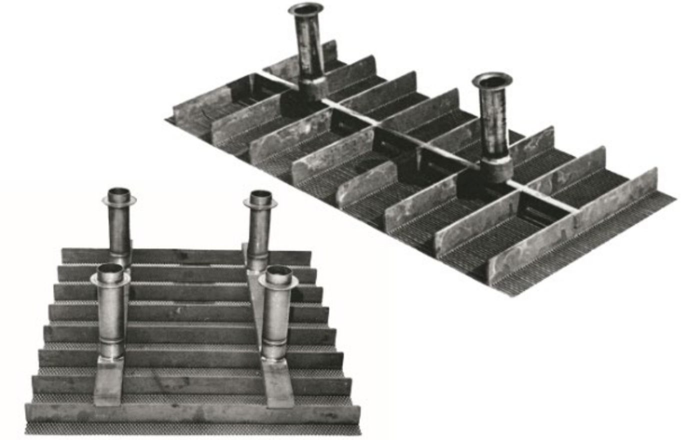


At one point, Oronzio and his brother Vittorio De Nora come across a small research laboratory in Holland also working on replacing graphite anodes for a company called Magneto Chemie.

During their experiments with titanium coated with various platinum group metals, they manage to create a dense brown coating from a resin that remains stable as an anode in chlor-alkali electrolysis and can operate at high currents without being affected by corrosion.

Oronzio De Nora's team finds a method to produce a complex oxide that includes both titanium dioxide and ruthenium dioxide by thermally breaking down a paint that contains compounds of both elements at the same time. This complex oxide shows excellent compatibility with titanium substrates, and it retains the catalytic properties for electrochemical reactions that are characteristic of pure ruthenium dioxide.

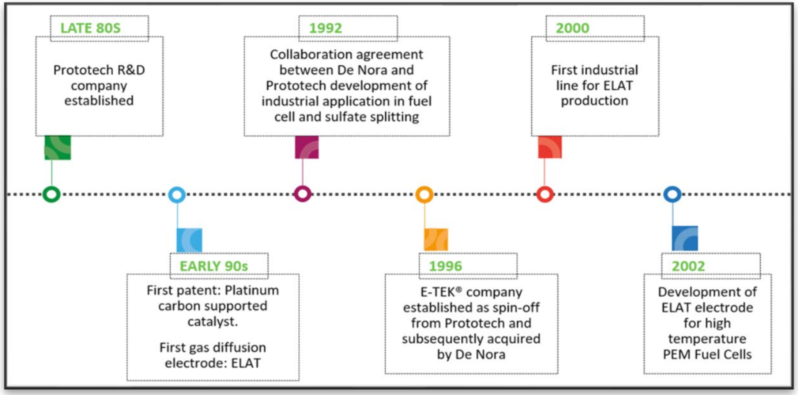
The innovative coating developed by De Nora, which is protected by the internationally recognized trademark DSA®, propels the company significantly forward in quality and transforms the previously established standards in chlor-alkali production.



- In the early 1990’s, De Nora expanded into the realm of fuel cells, eventually acquiring the company E-Tek Inc. (New Jersey)
  - First commercially available LT-PEM fuel cell catalysts, GDLs, GDEs, and MEAs Pt/C catalysts (ELAT brand name)
  - Early supplier for Co.’s Ballard Fuel Cell Systems, UTC, Chrysler
  - Became commercial reference for fuel cell R&D

- GDE and catalyst work expanded into other electrochemical applications in 2000’s
  - HT-PEM Fuel Cell GDEs
  - HCl electrolysis – Oxygen Depolarized Cathode (ODC) GDE w/ Rh_xS_y catalyst technology developed in collaboration with Northeastern University and Covestro
  - Chlor-alkali ODC technology

- Today, DN fuel cell business is limited to HT-PEM GDEs in partnership with BASF and fuel cell OEMs. The E-Tek portfolio continues to be exploited for other applications.



DE NORA

Pioneering Electrochemistry

- **1923** – **De Nora foundation**
- **1960s** – DSA® Electrodes and the Scientific Research
- **1980s** – DSA ® Diversification
- **2000 - 2011** – The Continual Improvement
- **2010 - 2011** – Acquisition of Chlorine Engineer and Permelec (MITSUI & CO.)
- **2015** – Creation of new tkUCE [1] Joint Venture (thyssenkrupp nucera)

Expanding Water Domain

- **2015** – Acquisition of STWP [2] (SEVERN TRENT WATER)
- **From 2015** – Portfolio enlargement

Entering Energy Transition

- **2017** – **Minority Investment from [3]** Blackstone
- **2020** – Launch of advanced coating for AWE
- **2021** – **Minority Investment from [4]** snam
- **2022** – Build of the new energy division; Listing on the Italian stock exchange (EURONEXT)
- **2023** – **De Nora 100th Anniversary**

[1] First Joint Venture with thyssenkrupp Uhde Chlorine Engineers (“tkUCE”) was set up in 2001, renamed tk nucera in 2022.
[2]Acquisition of Severn Trent Water Purification Technologies.
[3]Approximately 33% stake acquired from the De Nora family in April 2017.
[4]Approximately 35% stake acquired from Blackstone in January 2021.

DE NORA

€862.6m

2024 Revenues

24

Operating companies

+100

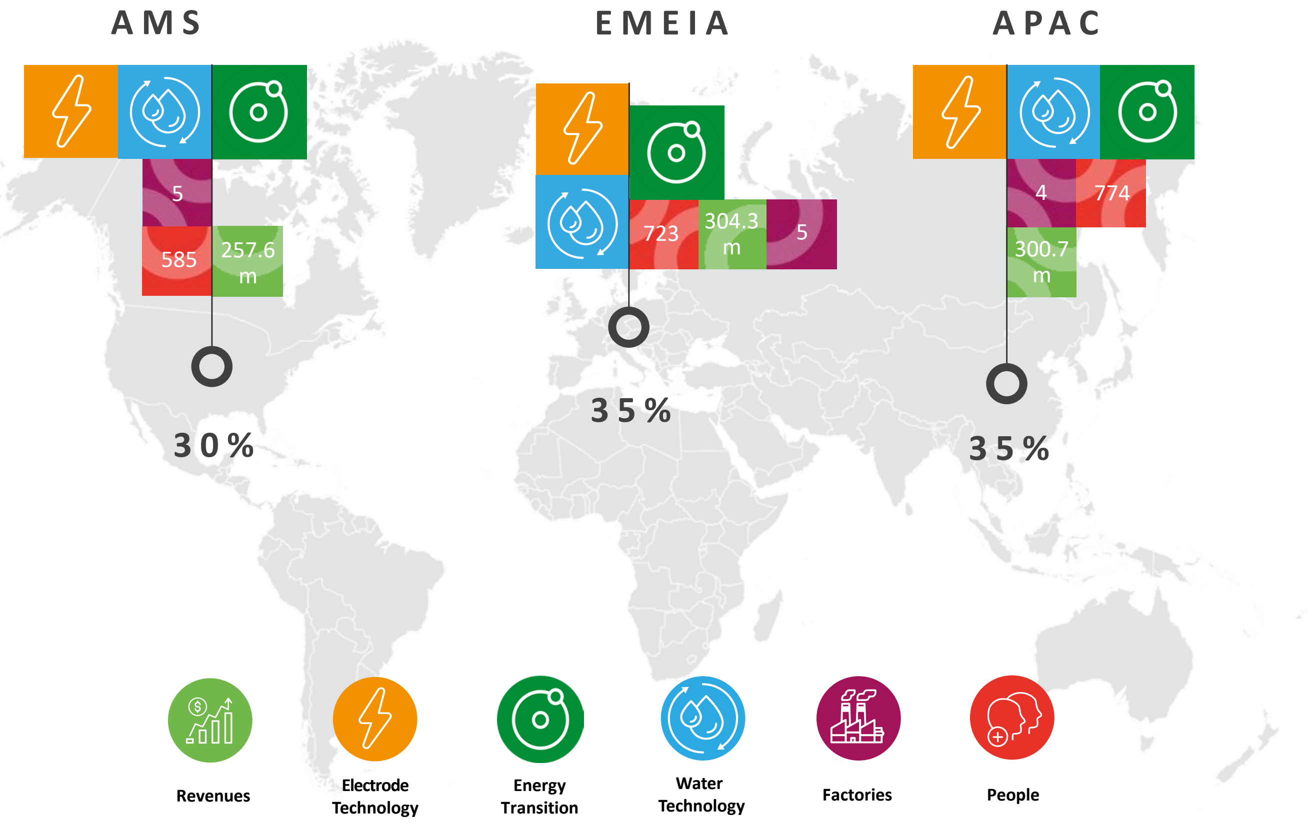
Years of Innovation

278

Patent families

2082

People



Data as of 31.12.2024

Businesses Overview

A comprehensive portfolio of mission-critical solutions and high-value-added aftermarket services.

Electrode Technologies

Energy Transition

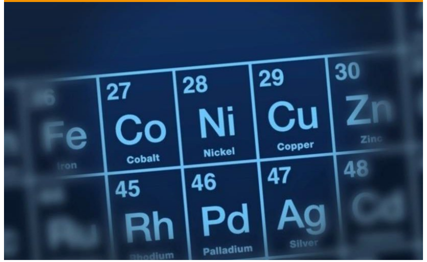
Water Technologies

APPLICATIONS

Chlor-alkali

Electronics

Metals Refining



OTHER APPLICATIONS

Pulp & paper

Steel galvanizing

Automotive Chrome plating

Plumbing & furniture Surface finishing

Steel & concrete Corrosion protection

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APPLICATIONS

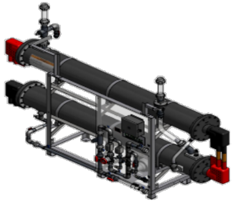
Pools

Municipal

Industrial

PORTFOLIO – main brands

Electrodes for pool chlorinators



ClorTec® On-Site Hypochlorite Generator

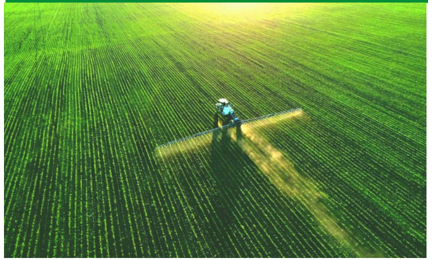
Capital Controls® Ozone Generator

CECHLO® On-Site Generator

MAIN APPLICATIONS

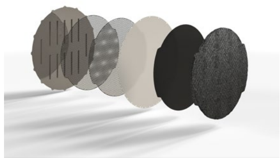
Energy storage

Green Chemicals

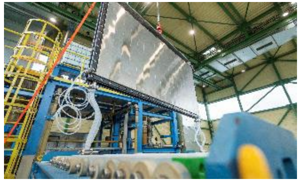


Mobility

PORTFOLIO

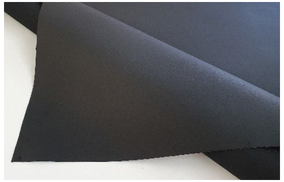


Electrodes for Alkaline Water Electrolysis (AWE)



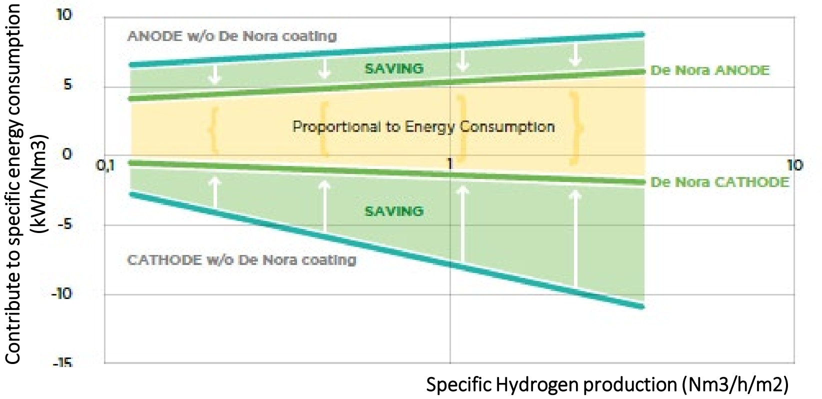
Cells

Dragonfly® system



Gas Diffusion Electrodes

Premium performance to deliver lower Levelized Cost of Hydrogen (LCOH)



De Nora's Electrodes allow a **reduced specific energy consumption (kWh/kg) at any current density**

High current densities result in a **higher H_2 production rate**

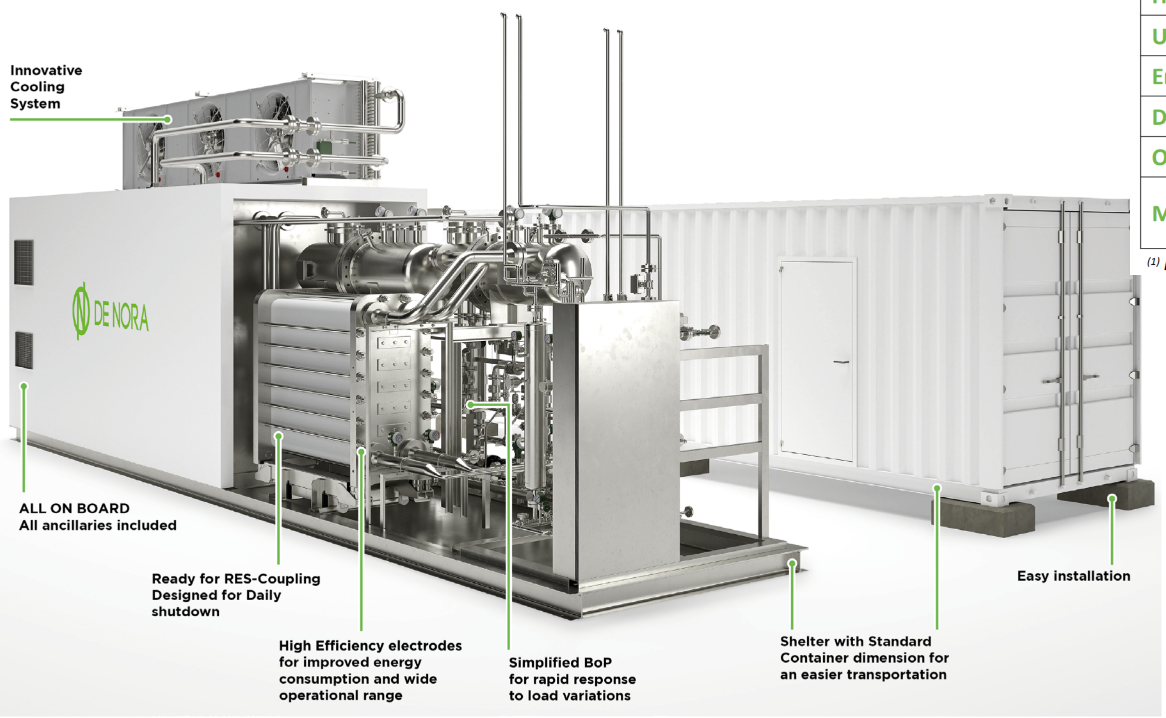
Diversified offer addressing all AWE technology and application needs

- ATMOSPHERIC AWE ELECTROLYZERS
- PRESSURIZED AWE ELECTROLYZERS
- RENEWABLE SOURCE OPERATION
- CONTINOUS OPERATION

DRAGONFLY® - ALKALINE ELECTROLYZER FOR HYDROGEN

PROCESS SHELTER

ELECTRO-INSTRUMENTAL SHELTER



MODULE POWER	MW	1.0	7.5
Number of stacks	-	1	4
H_2 production	Nm^3/h	≈200	1500
Unit flexibility	%	20-100%	
Energy consumption [(1)]	kWh/kg H_2	< 57	
Design Pressure	bar	30	
Operating temperature	°C	<90	
Module dimensions	-	1x40' + 1x30' shelter	3x40' + 2x20' shelter

[(1)] *Expected @ full load, complete system; lower Energy consumption discussed on project basis*

High capacity
High current density, reduced footprint

High-efficiency electrodes
Reduced power consumption

Reduced Stack dimension
Cooling through special design bipolar plates

Reduced footprint
MW/m^2

Optimized transportation costs
use of standard size containers

Minimized installation costs
plug and play – all utilities on board

Customizable Offer
utilities on board

Investing in innovation and manufacturing capacity

DE NORA

Funded by the European Union
NextGenerationEU

Greenfield project
Italy – Cernusco sul Naviglio
25,000 sqm
Construction started in H1 2024

R&D and Industrial Deployment

Products:

Capacity: 2GW
technologies to generate
Green Hydrogen

Financing
Eligible for €63 m IPCEI funds
Already Approved €32 m by Ita Gov.

ESG Profile
- PV solar panels / Geothermal Energy
- Smart Factory
- High Energy Efficiency
- New Job Opportunities
- Industrial Area Requalification

SELECTION OF PROJECTS IN BACKLOG

NEOM, Saudi Arabia,
Largest H_2 Project Globally
part of > **2 GW** tot project
Green H_2 to Green Ammonia

Green Steel project, Sweden
the 1° large-scale green steel plant in the EU
700+ MW
Green H_2 as alternative to coke

Dragonfly® electrolyzer- Projects

HyTecHeat
Eu Project with Snam e Tenova
1MW low carbon H_2 for steel production
Funded by EU " Horizon Europe"

CRAVE H_2
Crete-Aegean Hydrogen Valley (Crete)
4 MW - 500 tons/y of Green H_2
co-funded by the EU Commission and the Clean H2 Partn.

ENERGY TRANSITION
DE NORA TECH INNOVATION CENTER (IC)

De Nora Tech Innovation Center
New 10,000 Sq. ft add-on to Tin Man Rd. Facility in Mentor, OH

- Pilot-scale coating line for Ni-based products for AWE/AEM Water Electrolysis and membrane Chlor-Alkali
- GDE coating capability for various applications e.g. water electrolysis, hydrogen purification, flow batteries, CO_2/CO conversion, salt conversion

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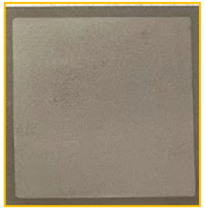
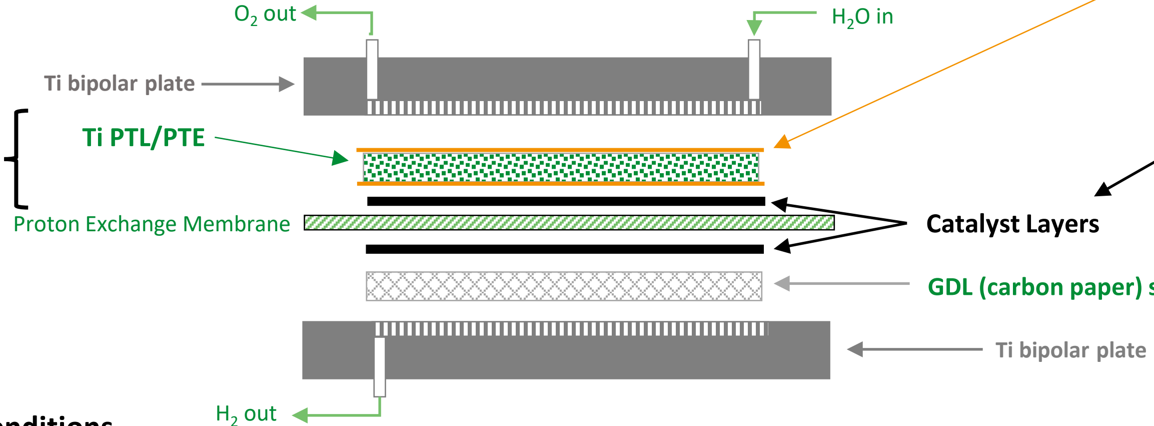
Adv. PTL designs and ultra-low PGM protective coatings



Anode Electrode



Cathode Electrode

Typical Operating Conditions

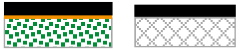
Temperature – 50-80 °C

Current Density – 2-3 A/cm^2

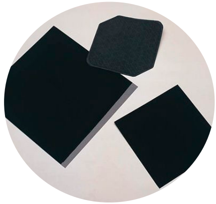
Voltage – 1.7-1.9 V, highly dependent on membrane thickness

Degradation – <5 µV/h

CCM
Catalyst coated Membranes



CCS: PTE/**GDE**
Catalyst coated onto PTL/GDL



DEPT. OF ENERGY PROJECT TO DEVELOP PTL DEVELOPMENT PROJECT

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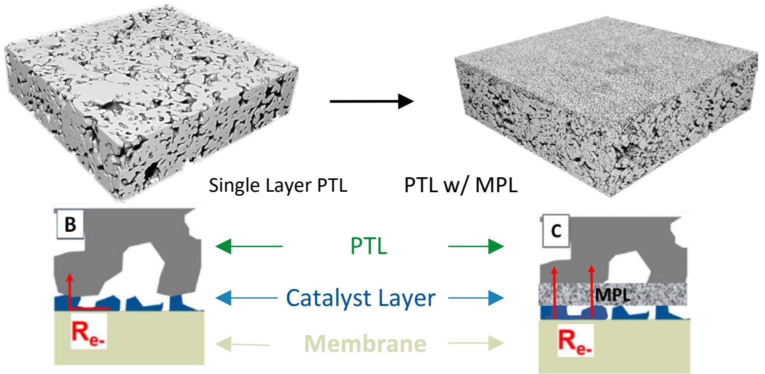
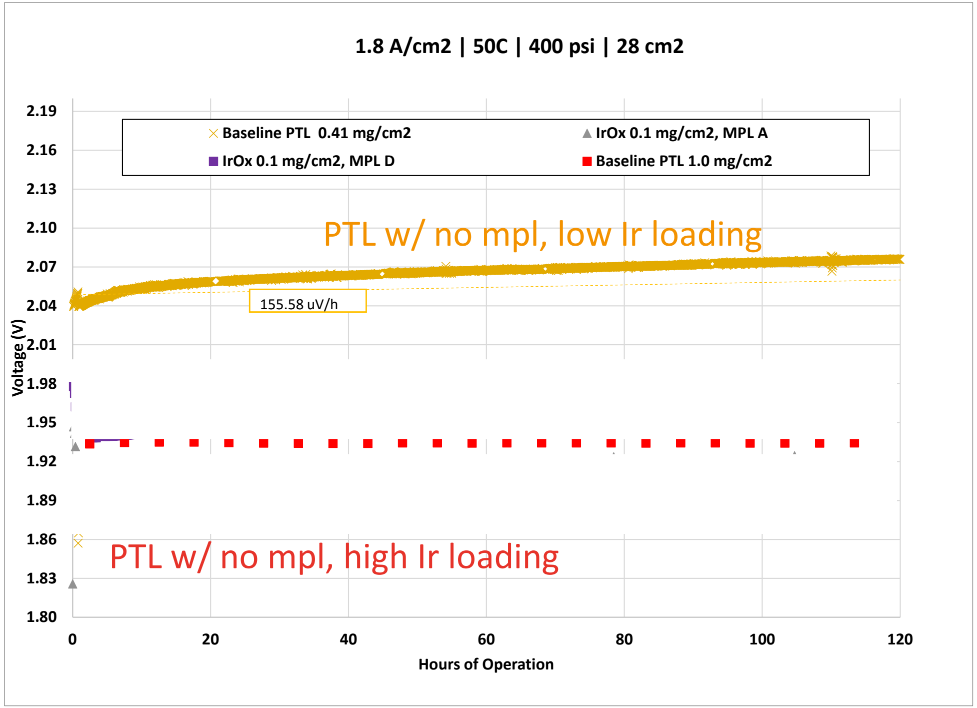
Team:	nel	DE NORA	NREL National Renewable Energy Laboratory	Oak Ridge National Laboratory	UCI University of California, Irvine	U.S. Department of Energy
(Role)	(Lead, Stack OEM)	(PTL Supplier)	(QA/QC Techniques)	(Rapid PTL Prototyping)	(PTL Characterization)	



- State-of-art single layer PTLs struggle with low loadings due to poor contact with the catalyst layer
- Bi-layered PTLs designs can improve performance of low Ir loadings by increasing contact points without increasing mass transport losses



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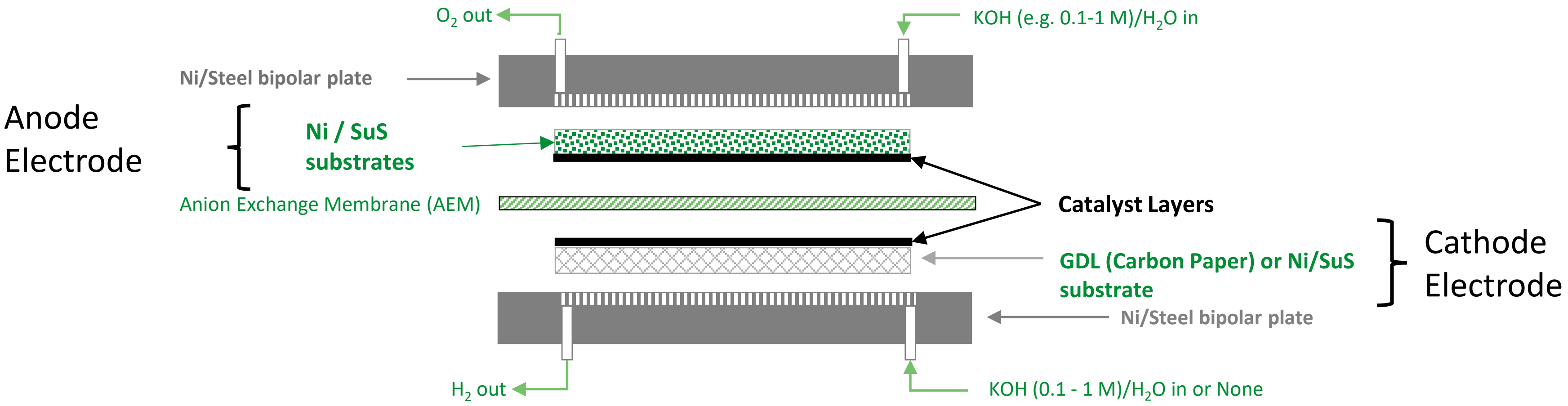

Typical Operating Conditions

Temperature – 50-70 °C

Current Density – ≥1 A/cm^2

Voltage – 1.6-2.0 V, highly dependent on membrane thickness/electrodes

Degradation – Membrane driven, goal is to be on par w/ PEM (<5 µV/h)

AEM WE Electrode Configurations

Catalyst coated substrates (CCS) are the predominate configuration used (vs CCM)

Anode Electrode – Non-PGM e.g. CoO_x, $NiCoO_x$, $NiFeO_x$, etc. - DSA® or powder catalysts

Cathode Electrode – ≤ 0.5 mg/cm^2 PGM, non-PGM - DSA® or powder catalysts

AEM ELECTROLYSIS DEPT. OF ENERGY PROJECTS

U.S. DEPARTMENT of ENERGY

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Versogen
The Hydrogen Generation.

Anode and Interface Design for Stable High-Performance Electrolyzers Without Supporting Electrolyte

Partners: UC-Berkely (lead), University of Delaware, Versogen
Total Funding amount: 6.6 million USD
Goal: Improve electrode durability for "KOH-free" AEM electrolyzers. Catalyst coatings and ionomer additives will be used to improve durability and maintain performance.

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1. Design and optimize catalyst and electrode technologies for very low or no KOH fed AEM electrolyzer
2. Anodic substrate selection and development
3. Scale-up (100 cm^2 active area) down-selected anode for Versogen stack (250 kW)

H_2 POWER to HYDROGEN

Advanced Electrolysis Cell Components Designed for Assembly

Partners: Power to Hydrogen (lead), Carnegie Mellon University, Bettergy Corp, Florida A&M University, RE:Build Manufacturing, Ohio Fuel Cell and Hydrogen Coalition, Lorain County Community College
Total Funding amount: 4.7 million USD
Goal: Further develop and scale-up a proven AEM-based alkaline electrolyzer cell design and components that meet DOE performance and cost targets.

1. Increase MRL of De Nora AEM anode and cathode electrodes through pilot manufacturing scale up and demonstration activities at DNT Innovation Center (IC)
2. Validate performance of pilot-scale electrodes at Power to Hydrogen with their innovative AEM alkaline electrolyzer design
3. Demonstrate manufacturing rate capabilities for electrodes at IC

Thank you! Grazie Mille!