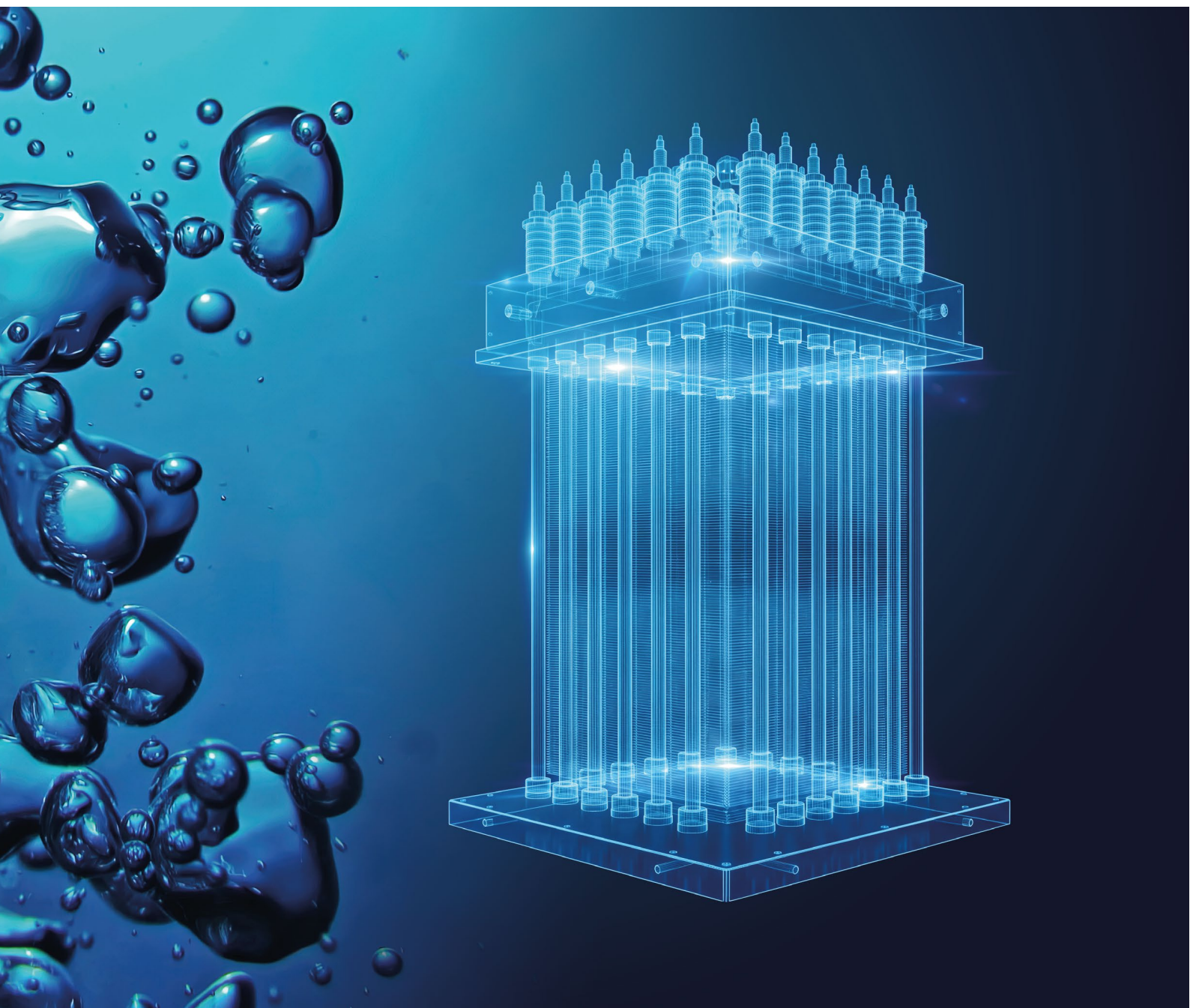




Electrocatalysts for Electrolysis

Actydon | Iridium

Actydon | Platinum

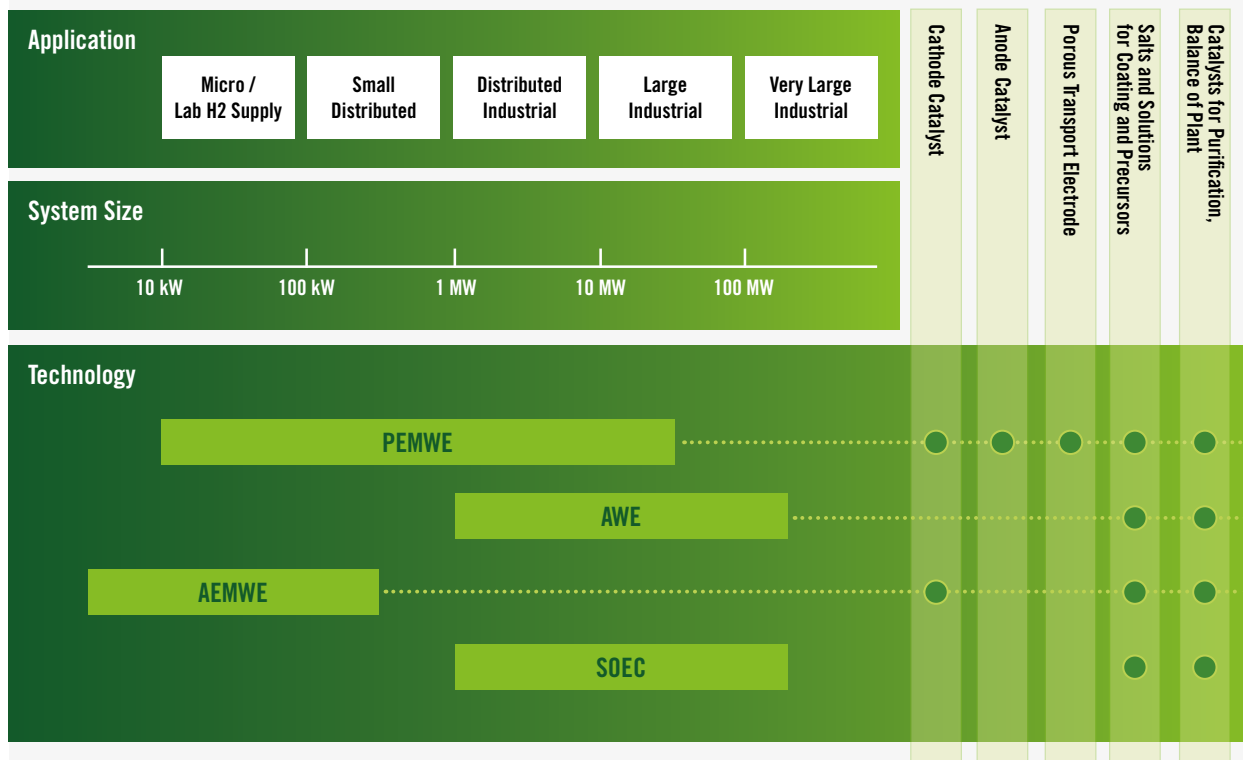
Water Electrolysis

Water electrolysis plays a pivotal role in producing green hydrogen cost-efficiently and at industrial scale, as water electrolyzers can be operated efficiently with renewable electricity.

A rapidly evolving ecosystem supports green hydrogen production at scales ranging from small, localized systems to large, centralized industrial facilities. A range of electrolyzer technologies is available to meet the requirements of different production scales and intermittent renewable energy sources.

Heraeus supports the production of hydrogen through products for a broad range of electrolyzer technologies: electrocatalysts for PEMWE (Proton Exchange Membrane Water Electrolysis) and AEMWE (Anion Exchange Membrane Water Electrolysis), precursor materials for AWE (Alkaline Water Electrolysis) electrode coatings and protective coatings for balance of plant components across all technologies, including high-temperature SOEC (Solid Oxide Electrolysis Cells).

Electrolyzer applications and technologies



PEMWE Proton Exchange Membrane Water Electrolysis

Proton Exchange Membrane Water Electrolysis is well suited for small, intermediate, and large-scale hydrogen production from intermittent renewable energy sources. The technology is widely adopted where high energy prices and land costs require highly efficient equipment with a small footprint to achieve low levelized costs of hydrogen.

Heraeus provides iridium- and ruthenium-based anode catalysts, optimized for durability and iridium thrifting at high performance. The specially adapted platinum and platinum-on-carbon cathode catalysts by Heraeus increase system durability and are modified according to customer requirements for easy application in different catalyst-coated membrane production processes.

PEMWE Anode Materials

The choice of the right anode catalyst for PEMWE defines stack performance and durability. It thus directly affects the Levelized Cost of Hydrogen at which the electrolyzer system can operate.

Heraeus offers a wide range of catalyst materials to optimize loading, processability, and operating conditions for our customers. We focus especially on the next generation of catalysts with low iridium content and high durability to support the scale-up of hydrogen production technologies.

A comprehensive product portfolio to fit your needs

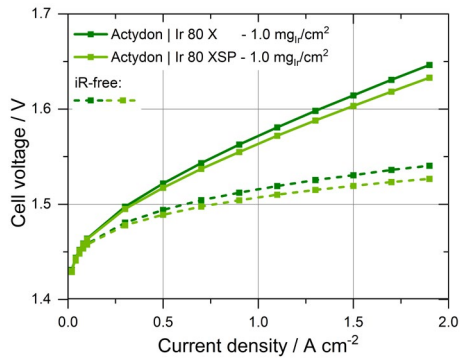
	Ir content [wt%]	Crystallite size [nm]	BET surface area [m ² /g]	Mass activity @ 1.45 V _{cell} (iR-free)[A/g _{Ir}]*
Actydon I Ir B Ir black	100	2 – 4	25 – 30	~ 55
Actydon I Ir 80 X Crystalline Ir-Oxide	79 – 83	2 – 4	> 200	~ 85
Actydon I Ir 80 XSP Crystalline Ir-Oxide	79 – 83	2 – 4	> 200	~ 85
Actydon I Ir 45 S Ir-Oxide on TiO ₂	44 – 48	n.a.	~ 100	~ 460
Actydon I Ir 65 Ru Crystalline IrRu-Mixoxide	62 – 68	3 – 4	~ 170	~ 180
Actydon I Ir 50 Ru Crystalline IrRu-Mixoxide	48 – 54	3 – 4	~ 190	~ 490
Actydon I Ir 30 Ru Crystalline IrRu-Mixoxide	31 – 37	3 – 4	~ 150	~ 880

*CCM – 80°C, p_O, 50 µm membrane, anode 1.0 mg_{catalyst}/cm² (**0.3 mg/cm²) - platinized PTL, cathode 0.3 mg_{Pt}/cm² (Actydon I Pt 40 C240) - carbon paper

Actydon I Ir 80 X and Actydon I Ir 80 XSP

Actydon I Ir 80 X and Actydon I Ir 80 XSP

(80 °C, p = ambient, C: 0.3 mg_{Pt}/cm² M: NR212/50 µm)

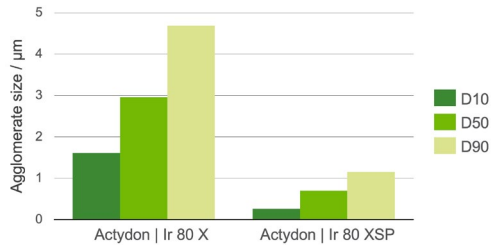


Actydon I Ir 80 X and Actydon I Ir 80 XSP, polarisation curves comparison for the materials of different particle size. The CCM level measurement are shown as raw data (solid line) and with subtracted membrane resistance (dotted lines) for better comparison of the catalyst influence

The iridium oxide catalysts Actydon I Ir 80 X and Actydon I Ir 80 XSP combine the reliable durability of iridium oxides with a very high surface area of > 200 m²/g and > 160 m²/g, respectively, resulting in high performance and activity over a wide range of loadings.

Actydon I Ir 80 X and Actydon I Ir 80 XSP

(Particle size distribution by laser diffraction in isopropanol/H₂O)

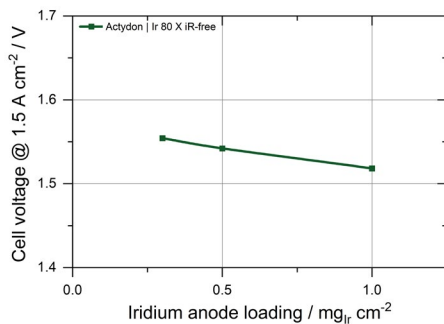


Actydon I Ir 80 X and Actydon I Ir 80 XSP. Comparison of particle size distribution measured through laser diffraction.

Actydon I Ir 80 XSP enables variable processability and flexible electrode layer designs through a controlled narrow particle size distribution.

Actydon I Ir 80 X

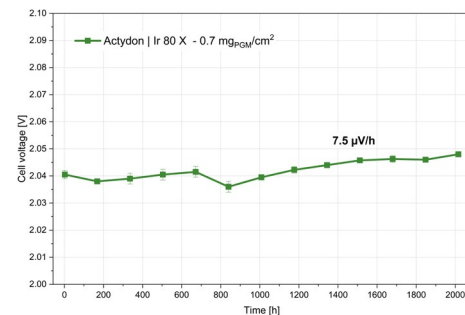
(80 °C, p = ambient, C: 0.3 mg_{Pt}/cm² M: N115/127 µm)



Actydon I Ir 80 X, HFR corrected cell voltage different anode Ir loadings from of 1 mg_{Ir}/cm² down to of 0.3 mg_{Ir}/cm².

Actydon I Ir 80 X

(65 °C, p = ambient, C: 0.3 mg_{Pt}/cm² M: N115/127 µm)

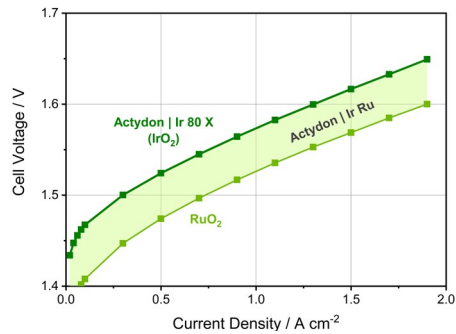


Actydon I Ir 80 X, durability plot of a > 2000 h in a „rainbow stack“ test cell configuration applying a dynamic profile of 10 min intervals @ 0.1, 2.0 and 3.0 A/cm² (80 °C, p_{amb}) with diagnostics every 168h. Degradation rate taken from the last 1000 hrs.

Actydon I Ir Ru

Actydon I Ir Ru

(80 °C, p = ambient, C: 0.3 mg_{PI}/cm² M: NR212/50 µm)



Actydon I Ir Ru polarisation curves comparison for different molar ratios for the iridium-ruthenium-mixoxides – shaded area. All materials with 1 mg_{catalyst}/cm² anode loading.

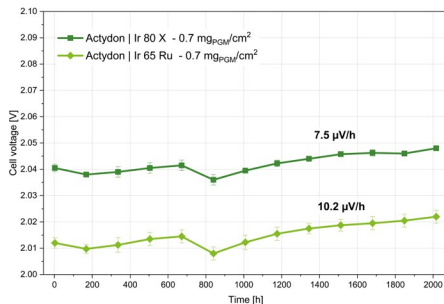
The Actydon I Ir Ru series of electrocatalysts utilizes the high OER activity of ruthenium component.

The proprietary iridium-ruthenium mixed oxide structure ensures high stability while enabling the high activity and low iridium content.

Actydon I Ir Ru is available with various ruthenium contents, enabling increased performance and significant iridium thrifting.

Actydon I Ir 65 Ru and Actydon I Ir 80 X

(65 °C, p = ambient, C: 0.3 mg_{PI}/cm² M: N115/127 µm)

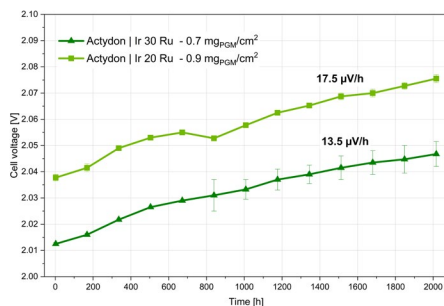


Actydon I Ir 65 Ru and Actydon I Ir 80 X, comparison of durability plot of a > 2000 h in a „rainbow stack“ test cell configuration applying a dynamic profile of 10 min intervals @ 0.1, 2.0 and 3.0 A/cm² (80 °C, p_{amb}) with diagnostics every 168h. Degradation rate taken from the last 1000 hrs.

Actydon I Ir 65 Ru shows identical high durability as the pure iridium oxide Actydon I Ir 80 X, despite higher activity and 20% lower iridium loadings, in a rainbow stack test of more than 2000 hrs.

Actydon I Ir 30 Ru and Actydon I Ir 20 Ru

(65 °C, p = ambient, C: 0.3 mg_{PI}/cm² M: N115/127 µm)



Actydon I Ir 30 Ru and Actydon I Ir 20 Ru, comparison of durability plot of a > 2000 h in a „rainbow stack“ test cell configuration at the same iridium-loading applying a dynamic profile of 10 min intervals @ 0.1, 2.0 and 3.0 A/cm² (80 °C, p_{amb}) with diagnostics every 168h. Degradation rate taken from the last 1000 hrs.

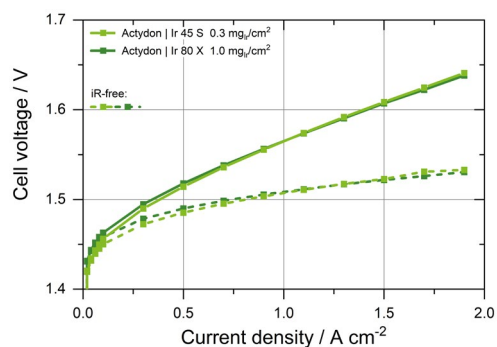
Actydon I Ir 20 Ru and Actydon I Ir 30 Ru are utilized at 0.3 mg_{PI}/cm², maintaining the performance of Actydon I Ir 80 X while using 60% less iridium per area.

Actydon I Ir 45 S

The thrifiting catalyst Actydon I Ir 45 S combines the use of a proprietary highly active iridium oxide species with a stable TiO_2 support to reduce iridium loadings to below $0.3 \text{ mg}_{\text{Ir}}/\text{cm}_2$

Actydon I Ir 45 S

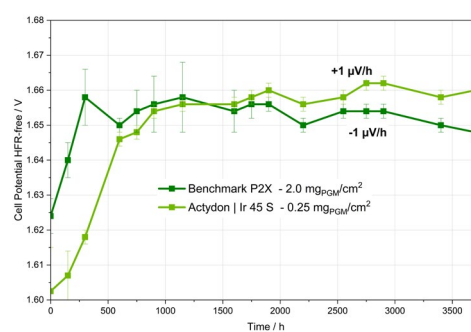
(80 °C, p = ambient, C: $0.3 \text{ mg}_{\text{Pt}}/\text{cm}^2$ M: NR212/50 μm)



Actydon I Ir 45 S and Actydon I Ir 80 X, comparison of polarisation curves at ultra low Ir loadings for Actydon I Ir 45 S. The CCM level measurement are shown as raw data (solid line) and with subtracted membrane resistance (dotted lines) for better comparison of the catalyst influence.

Actydon I Ir 45 S and Benchmark P2X*

(65 °C, p = ambient, C: $0.3 \text{ mg}_{\text{Pt}}/\text{cm}^2$ M: N117/175 μm)

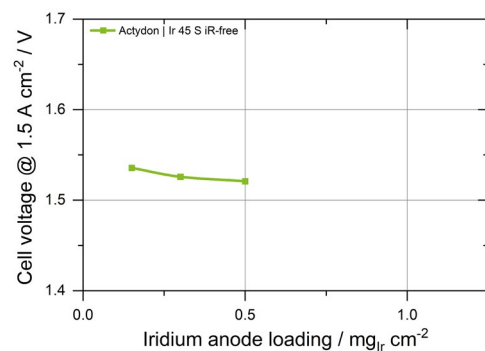


Actydon I Ir 45 S and Benchmark, comparison durability plot of a > 3500 h in a „rainbow stack“ test cell configuration applying a dynamic profile of 10 min intervals @ 0.1, 1.0 and 2.0 A/cm² (80 °C, p_{amb}) with diagnostics every 168h. Degradation rate taken from the last 2500 hrs.

*Test results from the funded project Kopernikus P2X published by Möckl et al., J. Electrochem. Soc. 169 (2022) 06450

Actydon I Ir 45 S

(80 °C, p = ambient, C: $0.3 \text{ mg}_{\text{Pt}}/\text{cm}^2$ M: N115/127 μm)



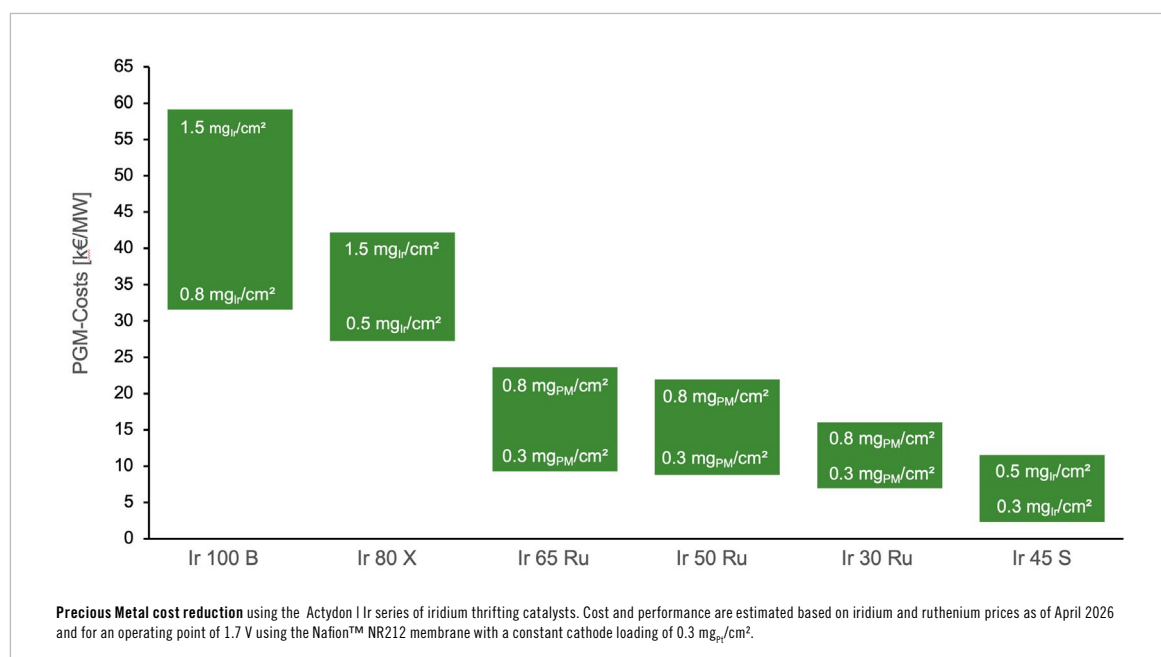
Actydon I Ir 45 S, HFR corrected cell voltage different anode Ir loadings from of $0.5 \text{ mg}_{\text{Ir}}/\text{cm}^2$ down to of $0.15 \text{ mg}_{\text{Ir}}/\text{cm}^2$.

Cost Savings with Iridium Thrifting Catalysts

Using Heraeus iridium-thrifting catalysts generates cumulative cost savings for stack manufacturers. The Actydon I Ir PEMWE anode materials enable to reduce the iridium content per area of catalyst coated membrane (CCM), simultaneously increasing the performance of the CCM in spite of the lower iridium content.

As a consequence, a stack manufacturer using the Actydon I Ir iridium-thrifting catalyst needs to use less CCM area to reach the same power and efficiency in its stacks. The cost savings of the stack manufacturer using the Actydon I Ir catalyst per MW of electrolyzer capacity are not only from using less Ir per CCM area, but by using less iridium per MW.

Additional savings are generated, as with higher power density, also less membrane, porous transport layers, and other stack components need to be used to reach the same overall power of a 1 MW stack.



PEM Water Electrolyzer Cathode Materials

Heraeus Precious Metals offers flexible solutions for PEMWE cathode catalysts. Based on customers preferences, easy-to-process platinum-on-carbon materials or high-surface-area carbon supports optimized for various loadings and cathode layer thicknesses are available.

	Description	Highlight	ECSA [m²/g _{Pt}]	Crystallite size [nm]
Actydon I Pt xx C700	20 – 60 wt% Pt on high surface area carbon	Optimized Pt surface utilization High ECSA	70 – 135	2.1 – 3.5
Actydon I Pt 50 M700	50 wt% Pt on high surface area carbon support	Optimized crystallite size for high stability	> 70	4.0 – 5.0
Actydon I Pt xx C240	20 – 50 wt% Pt on intermediate surface area carbon	Easy processability	60 – 95	2.9 – 4.1

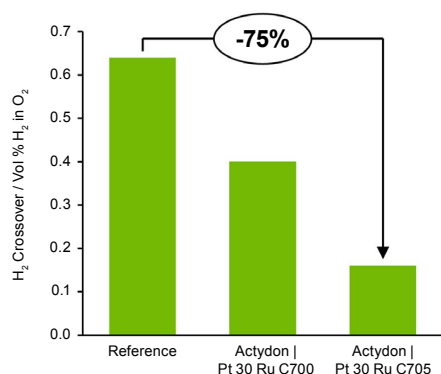
AEMWE Anion Exchange Membrane Water Electrolysis

Anion Exchange Membrane Water Electrolysis is evolving fast as an iridium- and fluorine-free technology. Available devices are currently limited to smaller sizes and used for decentralized hydrogen supply. Heraeus provides platinum- and ruthenium-containing cathode electrocatalysts that are important for the durability and efficiency of the technology. Bespoke solutions are available for a variety of different available membrane materials and electrode binders.

Cathode Materials

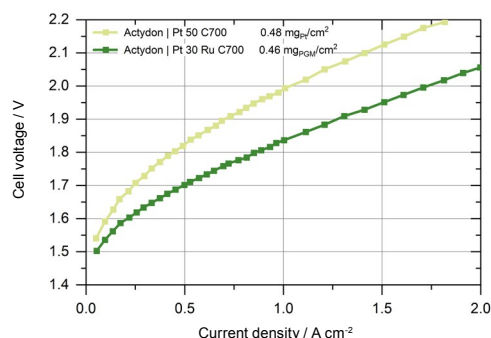
	Description	ECSA [$\text{m}^2/\text{g}_{\text{Pt}}$]	Crystallite size [nm]
Actydon I Pt 50 C700	50 wt% Pt on high surface area carbon	> 70	2.1 – 3.5
Actydon I Pt 30 Ru C700	PtRu alloy on high surface area carbon (30 wt% Pt)	~ 35	3.8 – 4.2
Actydon I Pt 30 C705	PtRu alloy on high porosity high surface area carbon (30 wt% Pt)	~ 40	3.3 – 3.6

Actydon I Pt 30 Ru C700 Actydon I Pt 30 Ru C705
(60 °C, A: NiFeOx 2 mg-NiFe/cm², M: Aemion by Ionomr)



Actydon I Pt Ru AEMWE comparison of hydrogen crossover in cells using the Actydon I Pt Ru materials as AEMWE cathodes. Data provided by Ionomr with Aemion membrane and Electrodes produced by Ionomr. Cathode with AP3-HNN0 ionomer and anode with AP3-HNN9 ionomer. 1M KOH dual feed.

Actydon I Pt 50 C700 Actydon I Pt 30 Ru C700
(80 °C, A: NiFeOx 2 mg-NiFe/cm², M: Aemion by Ionomr)



Actydon I Pt Ru AEMWE cell level measurements comparison with the Actydon I Pt materials for AEMWE cathodes. Data provided by Ionomr with Aemion membrane and Electrode produced by Ionomr: cathode and anode with AP3-HNN9 ionomer. 1M KOH dual feed.

AWE Alkaline Water Electrolysis

A large share of hydrogen is produced via alkaline water electrolysis (AWE). This mature technology can operate without a precious metal catalyst, relying instead on nickel-based materials to drive the necessary chemical reactions.

However, the use of iridium and ruthenium catalysts at the anode is still widespread in advanced alkaline electrodes. The use of precious metals increases durability and efficiency and allows for a lower turndown ratio, i.e., operation at lower minimum loads before the electrolyzer needs to be switched off. This, together with improved durability under fluctuating loads, allows for longer operating hours with variable renewable power input.

Heraeus provides precious-metal-containing solutions, salts, and metal-organic complexes used in the manufacturing of AWE electrodes.

	Cas. No.	PM	PM Range [%]	Formula	Form
Platinum Dinitrosulfato	12033-81-7	Pt	5.00 – 7.00	$\text{Pt}(\text{NO}_2)_2(\text{NH}_3)_2 \cdot \text{H}_2\text{SO}_4$	solution
Iridium Chloride	119401-96-6	Ir	50.00 – 55.00	$\text{IrCl}_4 \cdot x\text{H}_2\text{O}$	solid
Iridium Chloride - Type G	14996-61-3	Ir	50.00 – 55.00	$\text{IrCl}_3 \cdot x\text{H}_2\text{O}$	solid
Iridium Chloride	14996-61-3	Ir	52.00 – 56.00	$\text{IrCl}_3 \cdot x\text{H}_2\text{O}$	solid
Ruthenium Chloride	14898-67-0	Ru	39.00 – 42.00	$\text{RuCl}_3 \cdot x\text{H}_2\text{O}$	solid
Potassium Tetrachloroplatinate	10025-99-7	Pt	46.00 – 47.00	K_2PtCl_4	solid
Dihydrogen Hexachloroiridate	16941-92-7	Ir	20.00 – 25.00	$\text{H}_2\text{Cl}_6\text{Ir} \cdot x\text{H}_2\text{O}$	solid
Chloroplatinic Acid ,CPA'	16941-12-1	Pt	30.00 – 35.00	H_2PtCl_6	solution

CO₂ Electrolysis

CO₂ electrolysis is a state-of-the-art electrochemical method for producing CO or hydrocarbons from CO₂, green hydrogen, and renewable electricity. Different versions of the technology can employ PEM, AEM, or hybrid membranes. Depending on the end product, the technologies also differ in the choice of cathode catalyst materials. In all these applications, however, iridium- and ruthenium-based electrocatalyst solutions catalyze the anode reaction. Customized for coatability, the Heraeus PEMWE anode portfolio Actydon I Ir can be used in CO₂ electrolysis.



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