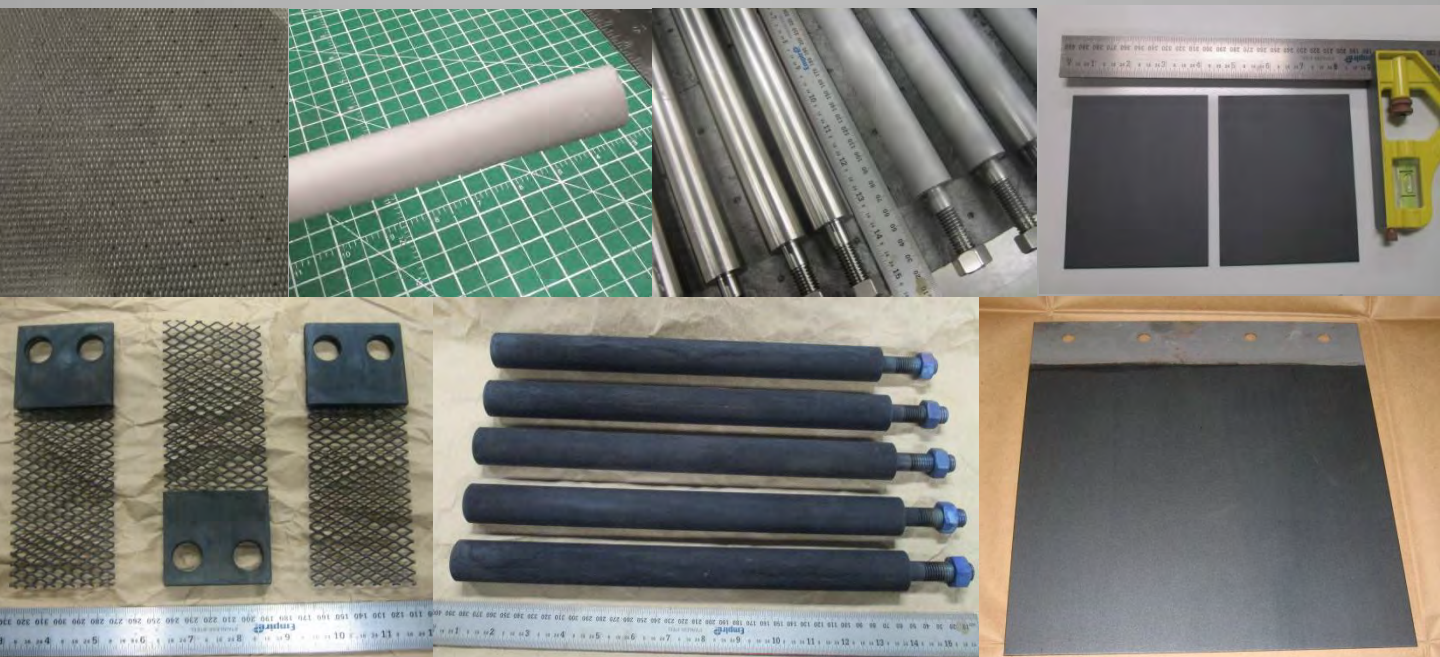




# GET TO KNOW: MIXED METAL OXIDE (MMO) ANODES FOR **OXYGEN** EVOLUTION

by *François Cardarelli*





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The technical information brochure should be used in conjunction with safety data sheets (SDS). It does not replace them. The information given is based on our knowledge of these products, at the time of publication. It is given in good faith.

The attention of the user is drawn to the possible risks incurred by using the product for any other purpose other than that for which it was intended. This does not in any way excuse the user from knowing and applying all the regulations governing his activity. It is the sole responsibility of the user to take all precautions required in handling the product. The aim of the mandatory regulations mentioned is to help the user to fulfill his obligations regarding the use of hazardous products.



# CHOOSE THE RIGHT METAL SUBSTRATE

- C.P. TITANIUM GRADES 1 AND 2 (ASTM B265)**
  - Cheaper and the most versatile
  - Plethora of mill products available
- TITANIUM Ti-0.15Pd GRADES 7 AND 11 (ASTM B265)**
  - Enhanced corrosion resistance
  - Higher cost related to its palladium content
  - End-of-Life anodes with a high scrap value
- NIOBIUM AND ITS ALLOYS**
  - Expensive and slightly enhanced performances vs. Ti-0.15Pd
  - The fast air oxidation poses challenges during fabrication
  - Excellent resistance to H<sub>2</sub> embrittlement during reversals
- TANTALUM**
  - Prohibitive but tantalum-coated metals an alternative
  - Longest service life at high current densities
  - It competes with bulk and electroplated platinum anodes



## CORROSION RESISTANCE | COST



# CHOOSE THE RIGHT CATALYST & LOADING

## ELECTRO-CATALYSTS:

- Iridium-coated ( $\text{IrO}_2$ )
- Ruthenium-coated ( $\text{RuO}_2$ )
- Platinized ( $\text{PtO}_x$ )

## PROTECTIVE LAYER (metal oxides with valve action):

- Titanium dioxide ( $\text{TiO}_2$ )
- Niobium pentoxide ( $\text{Nb}_2\text{O}_5$ )
- Tantalum pentoxide ( $\text{Ta}_2\text{O}_5$ )
- Zirconium dioxide ( $\text{ZrO}_2$ )

- Low overpotential for the oxygen gas evolution reaction (OER)
- Service life exceeding several millions of Ampere-hour per square meter ( $\text{MAh/m}^2$ )
- Consumption rates lower than few mg per A-year
- Catalysts loadings, thicknesses, and formulations remain proprietary among anodes manufacturers

**LOW  $\text{O}_2$  OVERPOTENTIAL | LONG  
SERVICE LIFE**



# DESIGNATIONS & COMBINATIONS

**EMMO – IRO – TI2 – LS**

## ELECTROCATALYST

- IRO**: IrO<sub>2</sub>-based
- RUO**: RuO<sub>2</sub>-based
- PTO**: PtO<sub>x</sub>-based
- OTHERS**

## BASE METAL

- TI2**: Titanium Gr. 2
- TI7**: Titanium Gr. 7
- NB**: Niobium
- TA**: Tantalum

## CATALYST LOADING

- LS**: Low service
- MS**: Moderate
- HS**: High service
- HD**: Heavy duty

**MIXED METAL OXIDES (MMO) ANODES FORMULATIONS & CONFIGURATIONS**

ELECTRO-CATALYST(S) / METAL SUBSTRATE(S)	TITANIUM & TITANIUM ALLOYS	ZIRCONIUM & ZIRCONIUM ALLOYS (*)	NIOBIUM & NIOBIUM ALLOYS (*)	TANTALUM & TANTALUM ALLOYS (*)
<b>IRIDIUM-COATED</b> (Ir, IrO <sub>2</sub> )	Plates, sheets, meshes, strips, wires, rods, disks, bars, tubes anodes	Plates, sheets, strips, wires, rods, disks, tubes anodes	Plates, sheets, strips, wires, rods, disks anodes	Plates, sheets, strips, wires, rods anodes
<b>RUTHENIUM-COATED</b> (Ru, RuO <sub>2</sub> )	Plates, sheets, meshes, strips, wires, rods, disks, bars, tubes anodes	Plates, sheets, strips, wires, rods, disks, tubes anodes	Plates, sheets, strips, wires, rods, disks anodes	Plates, sheets, strips, wires, rods anodes
<b>IRIDIUM &amp; RUTHENIUM-COATED</b> (IrO <sub>2</sub> , RuO <sub>2</sub> )	Plates, sheets, meshes, strips, wires, rods, disks, bars, tubes anodes	Plates, sheets, strips, wires, rods, disks, tubes anodes	Plates, sheets, strips, wires, rods, disks anodes	Plates, sheets, strips, wires, rods anodes
<b>LEAD DIOXIDE COATED</b> (PbO <sub>2</sub> & PbO <sub>2</sub> -IrO <sub>2</sub> )	Meshes, strips, wires, rods, bars	Meshes, strips, wires, rods, bars	Meshes, strips, wires, rods, bars	Meshes, strips, wires, rods, bars
<b>MANGANESE DIOXIDE COATED</b> (MnO <sub>2</sub> & MnO <sub>2</sub> -IrO <sub>2</sub> )	Plates, sheets, meshes, strips, wires, rods, disks, bars	Plates, sheets, strips, wires, rods, disks, tubes anodes	Plates, sheets, strips, wires, rods, disks anodes	Plates, sheets, strips, wires, rods anodes
<b>PLATINIZED</b> (Pt, PtO <sub>x</sub> )	Plates, sheets, meshes, strips, wires, rods, disks, bars, tubes anodes	Plates, sheets, strips, wires, rods, disks, tubes anodes	Plates, sheets, strips, wires, rods, disks anodes	Plates, sheets, strips, wires, rods anodes
<b>TIN DIOXIDE COATED</b> (IrO <sub>2</sub> -SnO <sub>2</sub> , RuO <sub>2</sub> -SnO <sub>2</sub> , Ta <sub>2</sub> O <sub>5</sub> -SnO <sub>2</sub> )	Plates, sheets, meshes, strips, wires, rods, disks, bars, tubes anodes	Plates, sheets, strips, wires, rods, disks, tubes anodes	Plates, sheets, strips, wires, rods, disks anodes	Plates, sheets, strips, wires, rods anodes
<b>CERIUM DIOXIDE COATED</b> (IrO <sub>2</sub> -CeOx, RuO <sub>2</sub> -CeOx, Ta <sub>2</sub> O <sub>5</sub> -CeOx, IrO <sub>2</sub> -SnO <sub>2</sub> -CeOx)	Plates, sheets, meshes, strips, wires, rods, disks, bars, tubes anodes	Plates, sheets, strips, wires, rods, disks, tubes anodes	Plates, sheets, strips, wires, rods, disks anodes	Plates, sheets, strips, wires, rods anodes



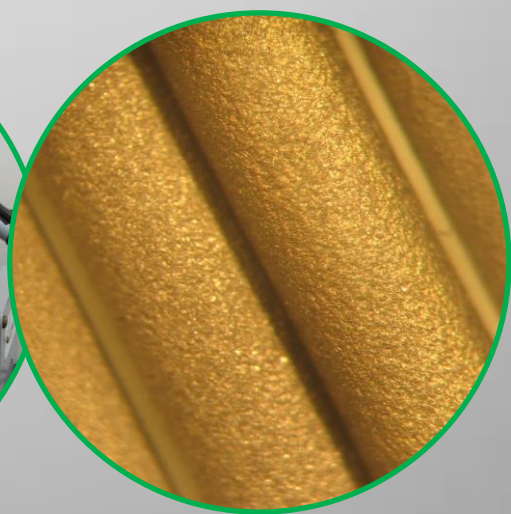
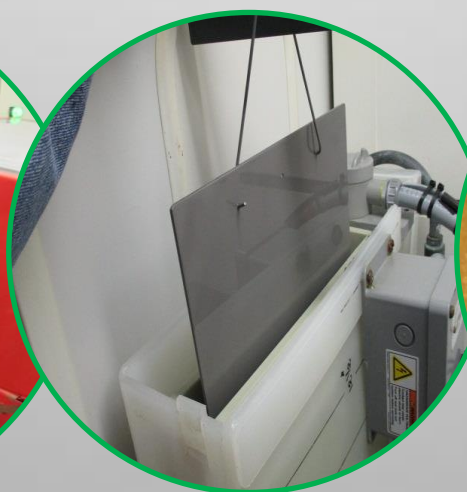
# KNOW THEIR LIMITATIONS



- **DO NOT LEAVE MMO ANODES IMMERSSED IN CORROSIVE SOLUTIONS WHEN NOT POLARIZED DURING SHUTDOWNS UNLESS CORROSION INHIBITORS ARE PRESENTS**
- **AVOID TRACES OF FLUORIDE ANIONS AND FREE HYDROFLUORIC ACID (HF)**
- **AVOID TRACES OF ORGANICS (AROMATICS, NITRO COMPOUNDS, HALOGENATED SOLVENTS)**
- **DO NOT POLARIZE A MMO AS CATHODE**
- **DO NOT USE REVERSALS EXCEPT WHEN NIOBIUM IS USED AS METAL SUBSTRATE**



# END OF LIFE MMOs REFURBISHING & RECYCLING



- Spent MMOs can be refurbished but the number of recoating is limited and depends on the residual MMO loading
- Stripping used coatings from spent Ti-0.15Pd, Nb and Ta based MMOs represents a huge cost saving
- Know the scrap value of your base metal and of the residual MMO loading before considering recycling



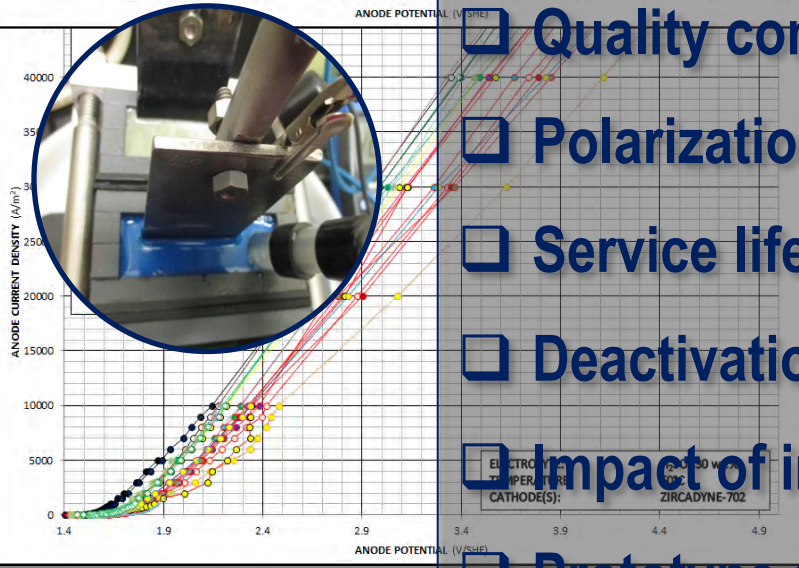
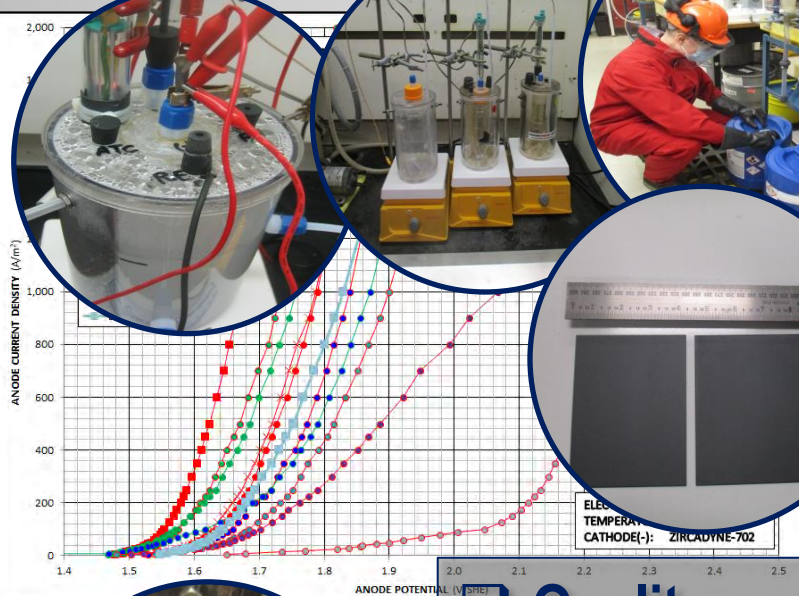
# SAFE HANDLING & PROPER INSTALLATION

- NO SHARP TOOLS AND OBJECTS
- DO NOT TOUCH THE COATING SURFACE
- NO GREASE
- WEAR NITRILE GLOVES
- TRAIN YOUR KEY PERSONNEL
- USE STANDARD OPERATING PROCEDURES
- PROTECT MMOs AGAINST MECHANICAL SHOCKS
- INSPECT REGULARLY

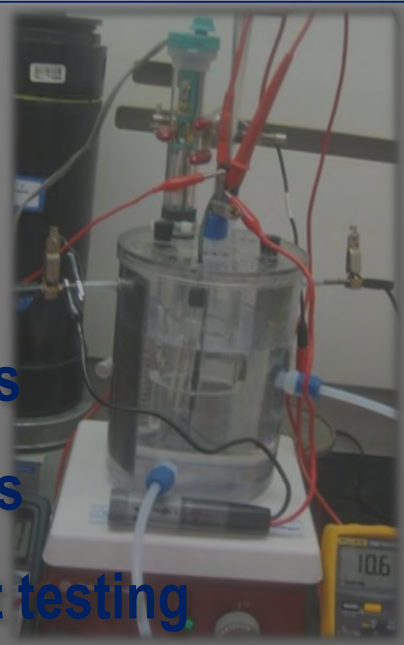




# MMOs CHARACTERIZATION & TESTING



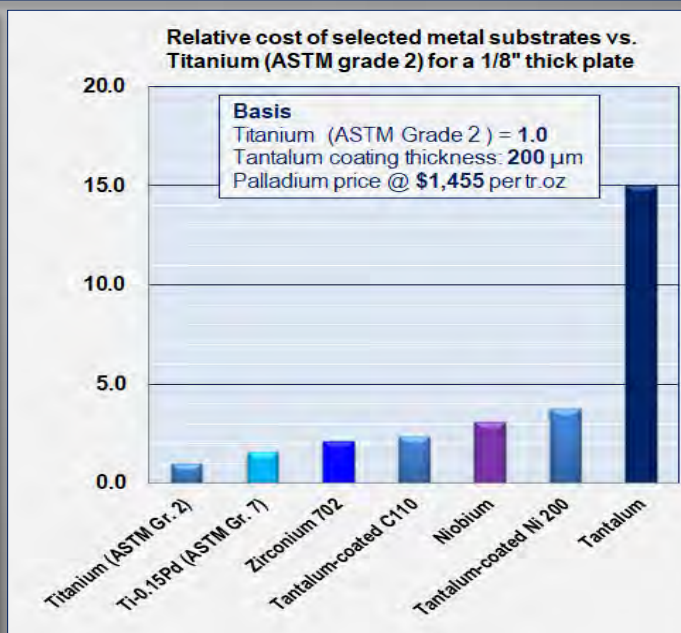
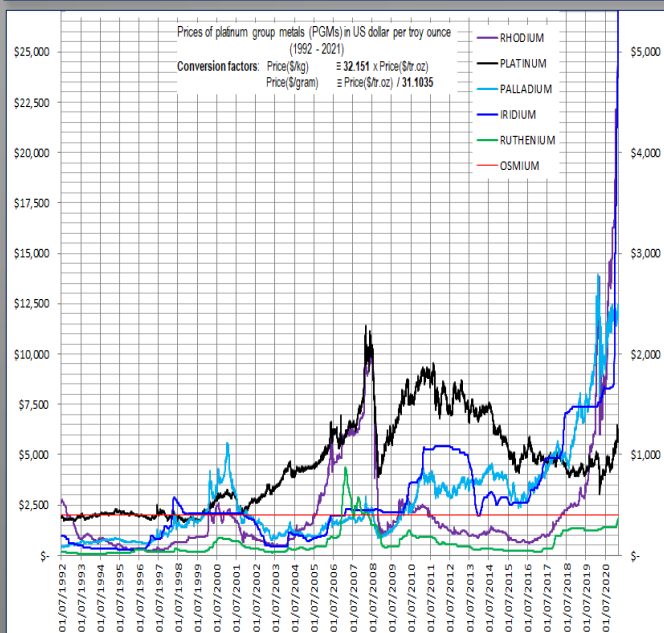
- Quality control
- Polarization plots
- Service life tests
- Deactivation modes
- Impact of impurities
- Prototype and pilot testing





# UNDERSTAND HIGH MMO'S PRICES

- ❑ Linked to the *Platinum Group Metals (PGMs)*
- ❑ Precursors are several times more expensive than the PGMs they contain!
- ❑ Impacted by shortages and geopolitical events
- ❑ Affected by the prices and the availability of titanium, niobium, and tantalum mill products
- ❑ Limited number of manufacturers worldwide

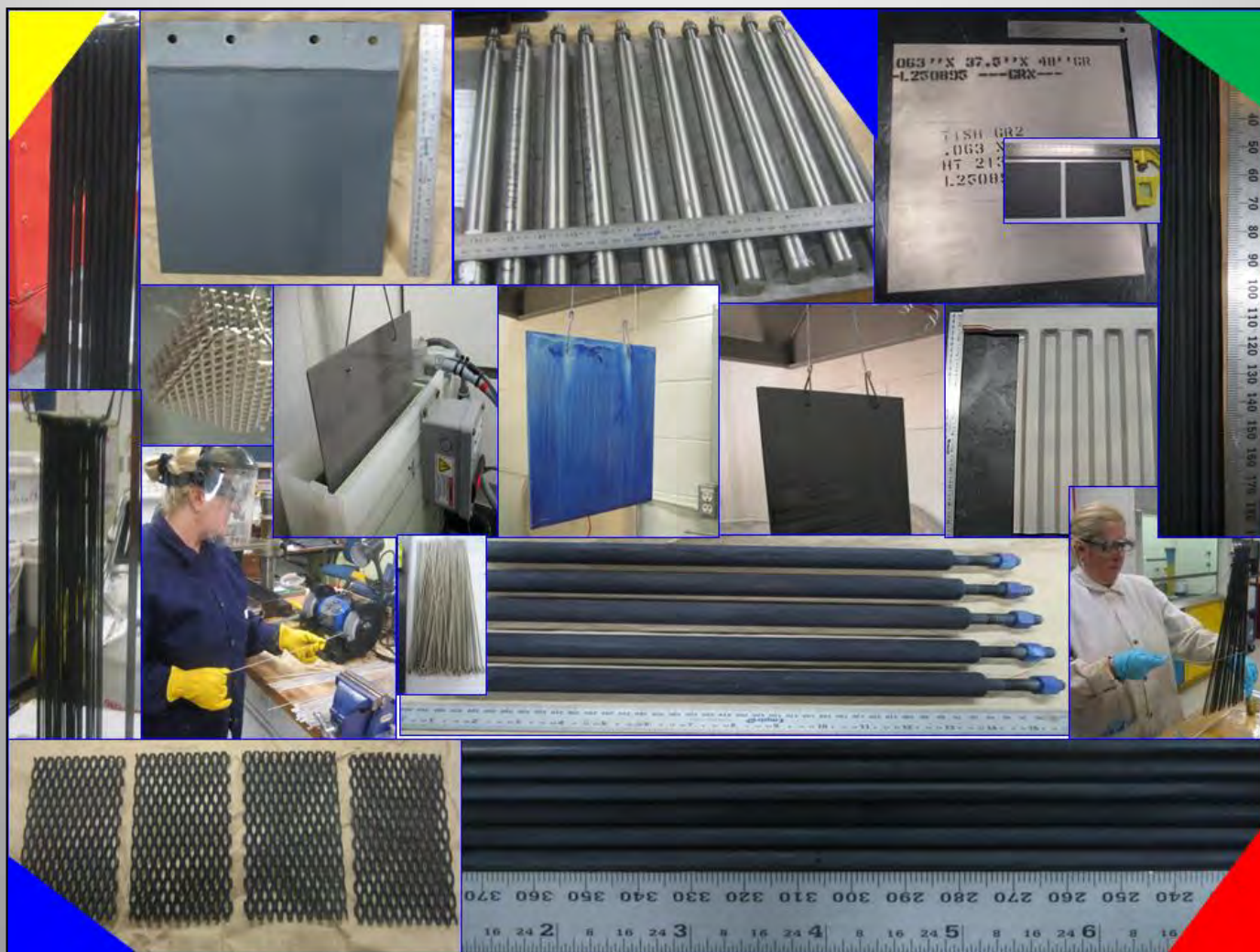




# WHAT INFO DO YOU NEED TO PROVIDE?

## □ ORDERING INFORMATION

- **SHAPE AND DIMENSIONS**
- **TYPE OF ELECTROCHEMICAL PROCESS**
  - Electrosynthesis or electro-oxidation
  - Electrowinning, electroplating or galvanizing
- **TYPE OF ANODIC PROCESS**
  - Oxygen gas evolution
  - Mixed gases evolution  $O_2$  with  $Cl_2$ ,  $I_2$  or  $Br_2$
- **TYPE OF CURRENT REGIME**
  - Direct current
  - Alternative current and reversals
  - Pulsed current
- **OPERATING CONDITIONS**
  - Electrolyte or anolyte compositions
  - Temperature
  - Anode current density
  - Overall cell voltage
  - Expected service life
- **DELETERIOUS IMPURITIES**
  - fluorides, organics, nitrites, and manganese cations
- **MECHANICAL AND THERMAL CONSTRAINS**



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