CATHODE OPTIMIZING SOLUTION

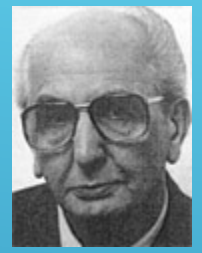
OPTIMIZE YOUR CHLOR - ALKALI MEMBRANE CELL

By Dino DiFranco

Electrode Solutions

About Me: (Continued)

- Joined ELTECH Systems / De Nora for 20 years (**Anode Focused**)
  - ➢ These companies commercialized Henri Beer's historic 1968 Anode invention which is a thermally applied mixed metal oxide on titanium.



- Henri Beer's invention of using metal oxides as an anode in an oxidizing environment delivers exceptional performance and can deliver 25+ years of service without appreciable voltage escalation.

  - ➢ While it can also function as a cathode, this technology is not optimum for cathodes which are in a reducing environment. Limitations include:
    - Voltage escalation
    - Poor adhesion
    - High wear rate
    - Limited lifetime
    - Require Polarization
    - Poor substrate protection
    - High cost

Cracks and Pores in a Thermally Applied Coating

I believe there is room to improve chlor-alkali cathodes and this is one of the reasons I started Electrode Solutions.

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IN-SITU CATHODE ACTIVATION

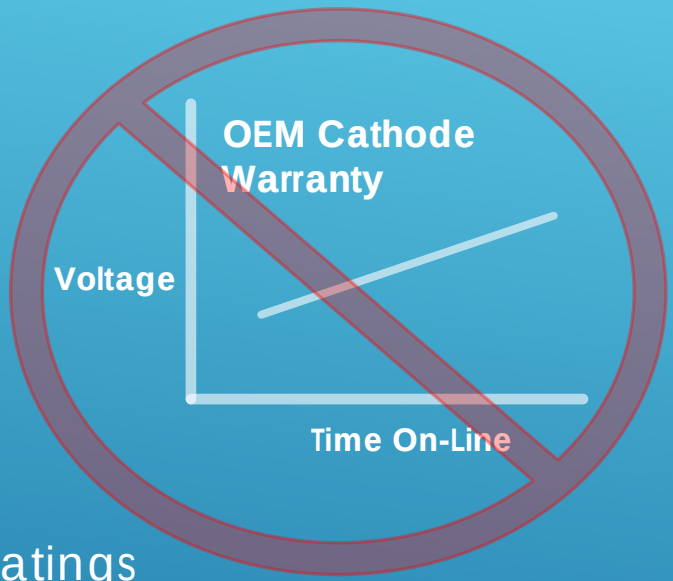
BENEFITS

- No Cathode Recoating
  - ✓ No cell dis-assembly
  - ✓ No shipping of cathodes
  - ✓ No spare cathode requirements (Idle capital)
  - ✓ No cathode distortion or thinning from recoating
  - ✓ No cathode warranty constraints / concerns
  - ✓ No large capital expense for recoating

- Operate at the **LOWEST ENERGY CONSUMPTION**
  - ✓ Activate all areas capable of hydrogen evolution
  - ✓ No voltage escalation (consistent cell room performance)
  - ✓ Immediate recovery from upsets

- MUCH LESS expensive and BETTER than OEM supplied cathode coatings

- Possible improvement for the membrane
  - ✓ Equilibrate the current density across the membrane surface
  - ✓ Less heating at the membrane surface **= Higher Efficiency**
  - ✓ Less hydrogen on the membrane **= Lower H_2 in Cl_2**



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IN-SITU CATHODE ACTIVATION – History

- Some OEM's have promoted in-situ activation in the past (CEC, ELTECH, etc).
- I promoted a product called VRS (Voltage Reduction Solution) for ELTECH in the early 2000's.
- Many customers used it in their cell rooms
  - Voltage reduction was observed using VRS (Technical success)
  - Economics of using VRS were not satisfactory (Economic failure)

VRS was too expensive but it demonstrated the promise of a better cathode via in-situ activation.

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IN-SITU CATHODE ACTIVATION – TODAY

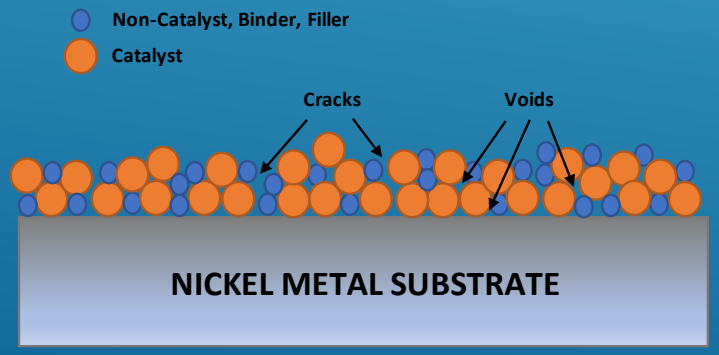
CATHODE OPTIMIZING SOLUTION (COS) was developed to deliver optimized cathode performance at an economic price.

COS is added in-situ to the catholyte and immediately activates all surfaces capable of hydrogen evolution.

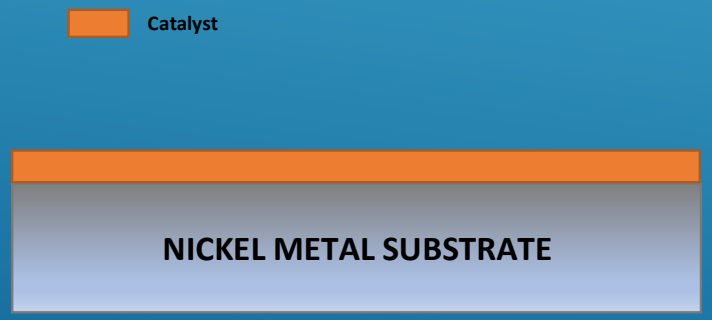
- Surfaces previously activated are renewed

COS is economical enough that it is continuously added to maintain the lowest energy consumption and achieve a stable cathode performance.

Unlike thermally applied coatings provided by OEM's, COS will seal off the underlying nickel and protect the nickel substrate during power outages.



Oxide Coating



COS Coating

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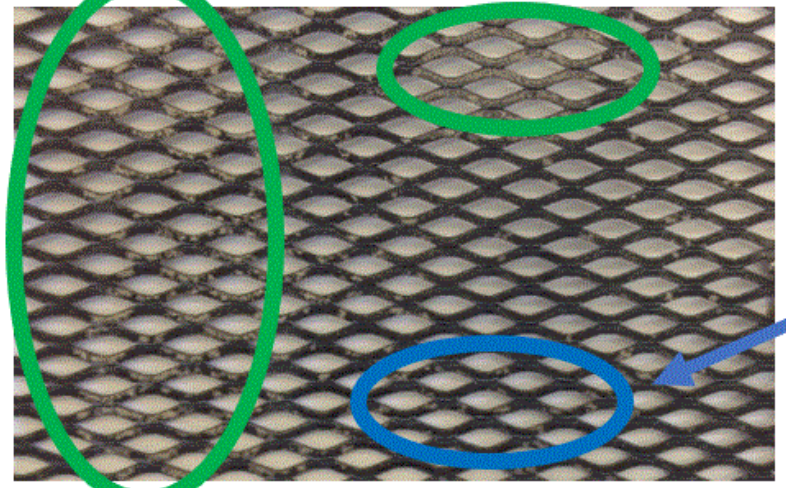
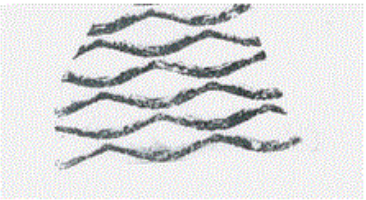
"Greenish" Stains on OEM Supplied Oxide Coating



"Non-Uniform" Appearance



Tape test result showing the adhesion of the Oxide Coating is compromised.

To avoid voltage escalation, the coating must protect the underlying nickel and be adherent. This is especially important during outages.

COS is adherent to the nickel substrate and protects it.

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Porous OEM Cathode Coating allows corrosion and corrosion products (greenish color) to migrate to the surface.

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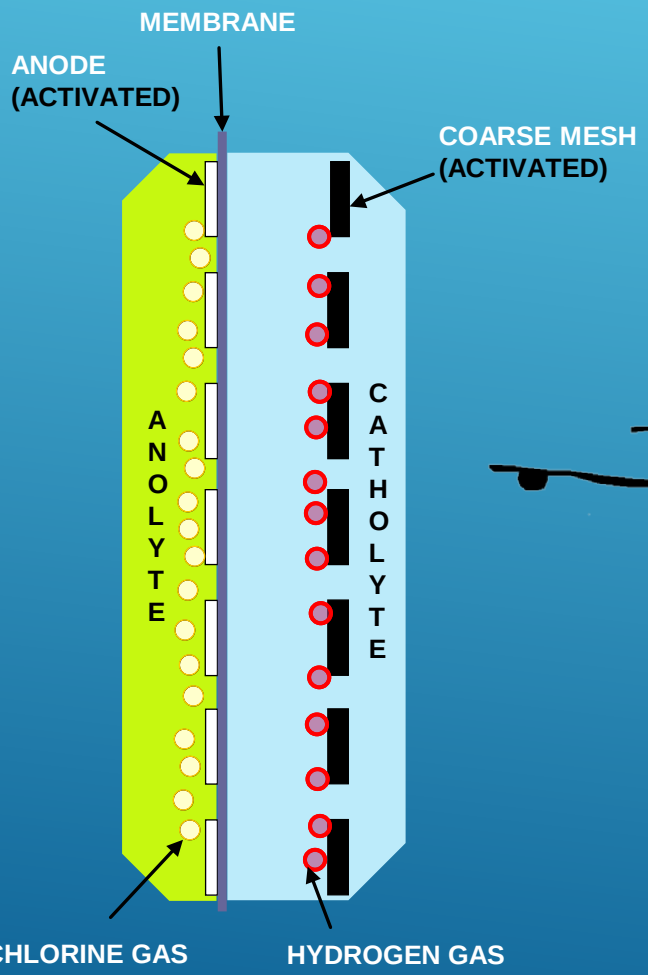
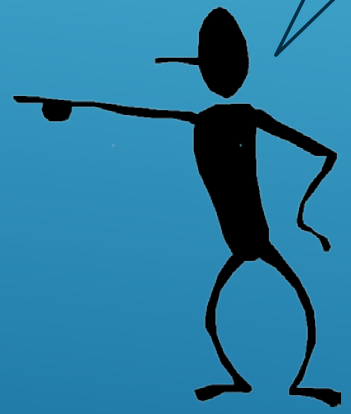
FIXED GAP CHLOR-ALKALI MEMBRANE CELL





EARLY CHLOR-ALKALI MEMBRANE CELLS WERE DESIGNED WITH A FIXED GAP BETWEEN THE CATHODE AND THE MEMBRANE TO PREVENT MEMBRANE DAMAGE. THESE CELLS ARE REFERRED TO AS “FIXED GAP” CELLS.

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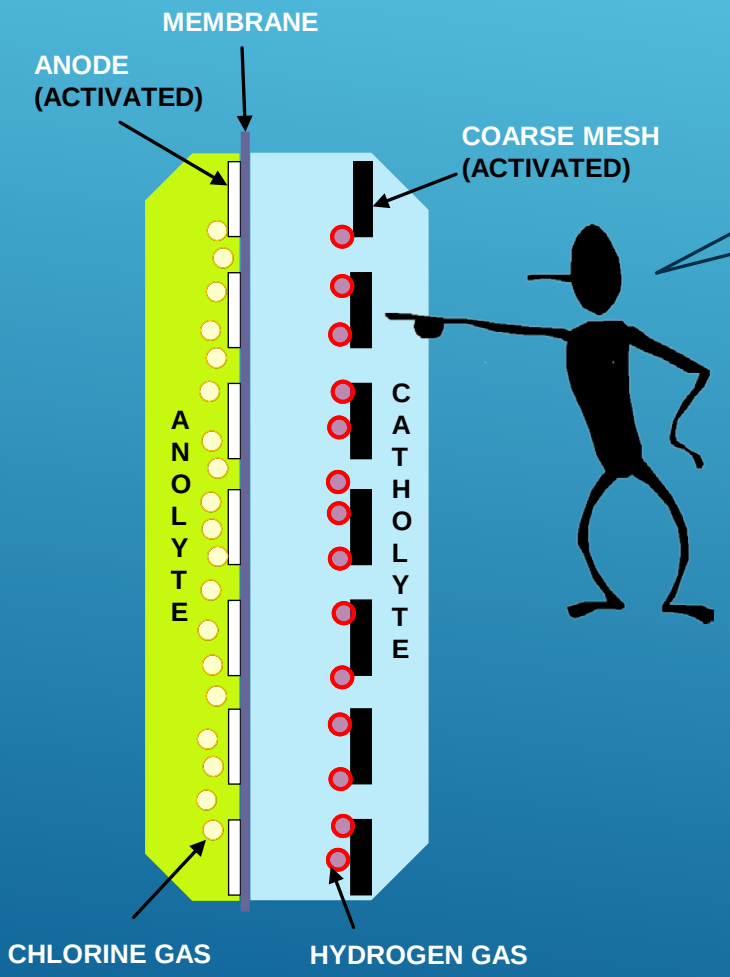
FIXED GAP CHLOR-ALKALI MEMBRANE CELL



IN A FIXED GAP CELL, THE HYDROGEN GAS IS EVOLVED ON THE ACTIVATED COARSE MESH AS SHOWN HERE.

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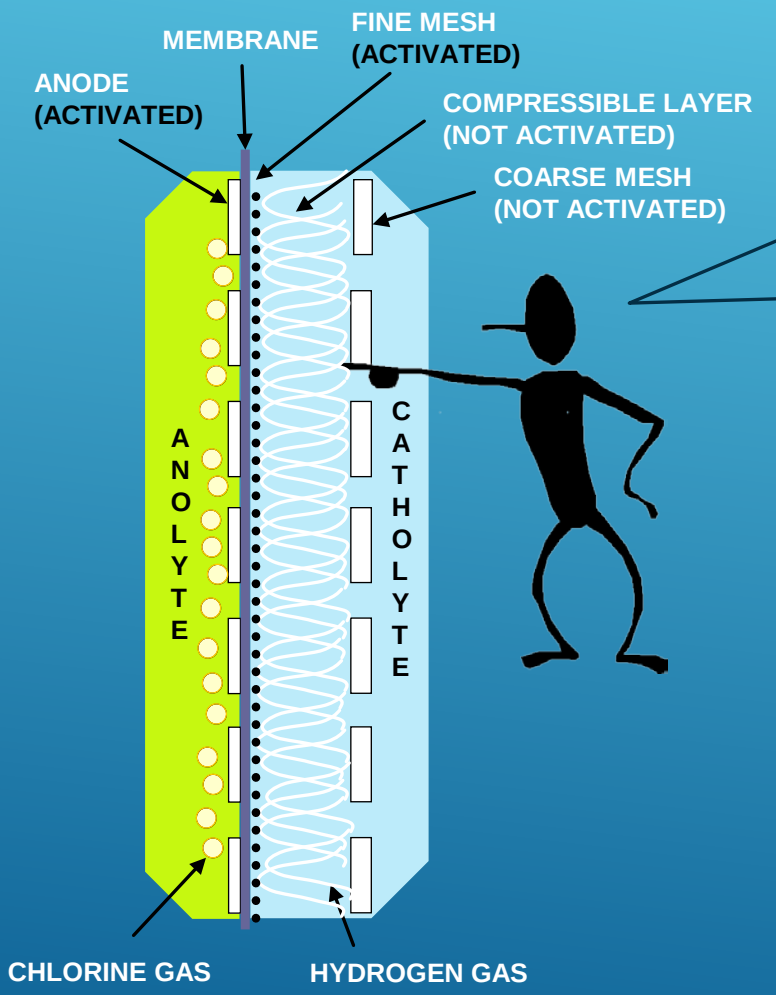
ZERO GAP CHLOR-ALKALI MEMBRANE CELL



NEWER CELL DESIGNS AND/OR RETROFITS OF OLDER CELLS INCORPORATE A ZERO GAP DESIGN WHEREIN A COMPRESSIBLE LAYER IS PLACED BETWEEN THE COARSE MESH AND A FINE SCREEN.

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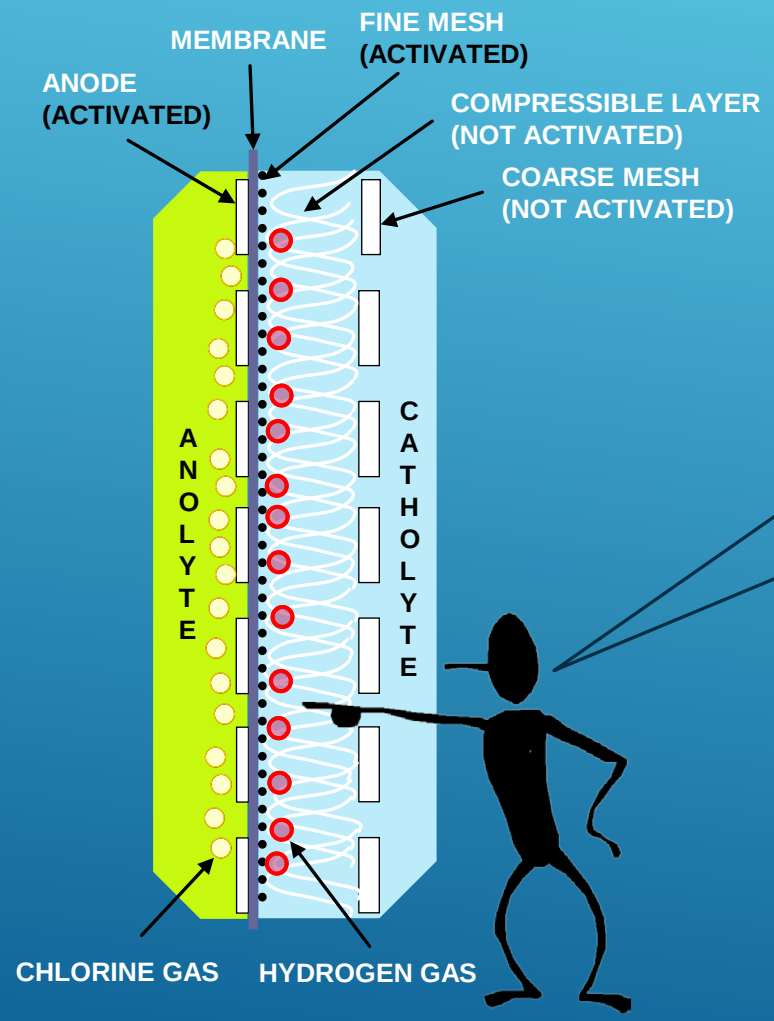
ZERO GAP CHLOR-ALKALI MEMBRANE CELL



IN A ZERO GAP CELL, THE FINE MESH IS ACTIVATED AND THE HYDROGEN GAS IS EVOLVED ON THE FINE MESH ONLY.

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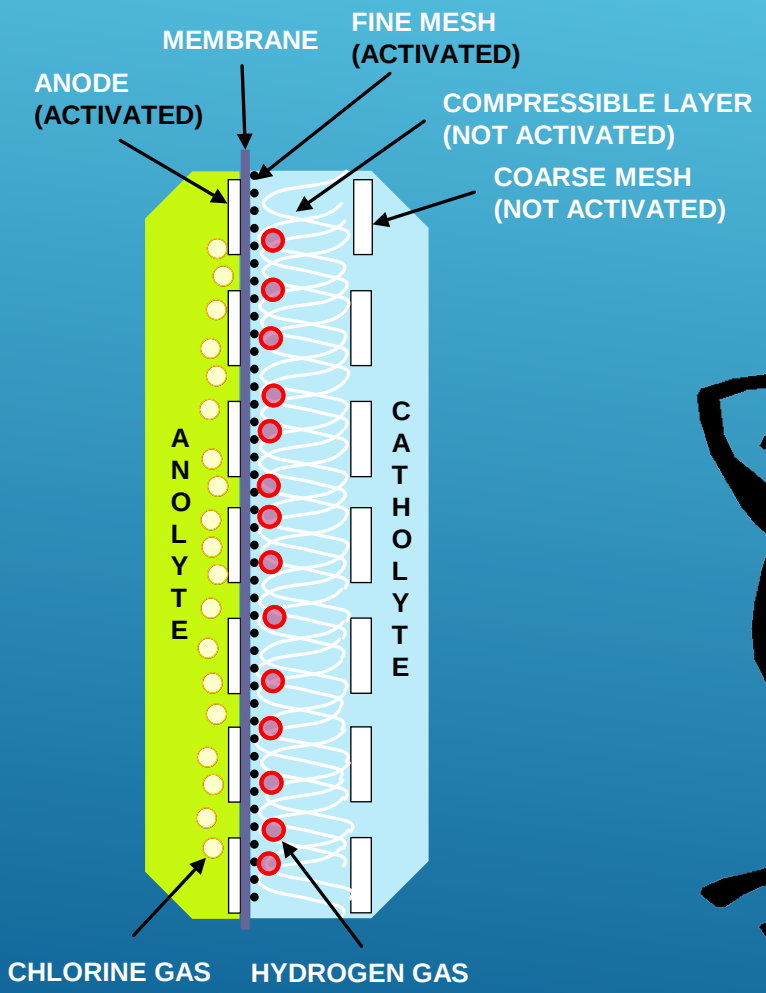
ZERO GAP CHLOR-ALKALI MEMBRANE CELL



MORE THAN 2/3 rds OF THE AVAILABLE CATHODE SURFACE AREA IS **NOT ACTIVATED** IN PRESENT DAY ZERO GAP CELLS.

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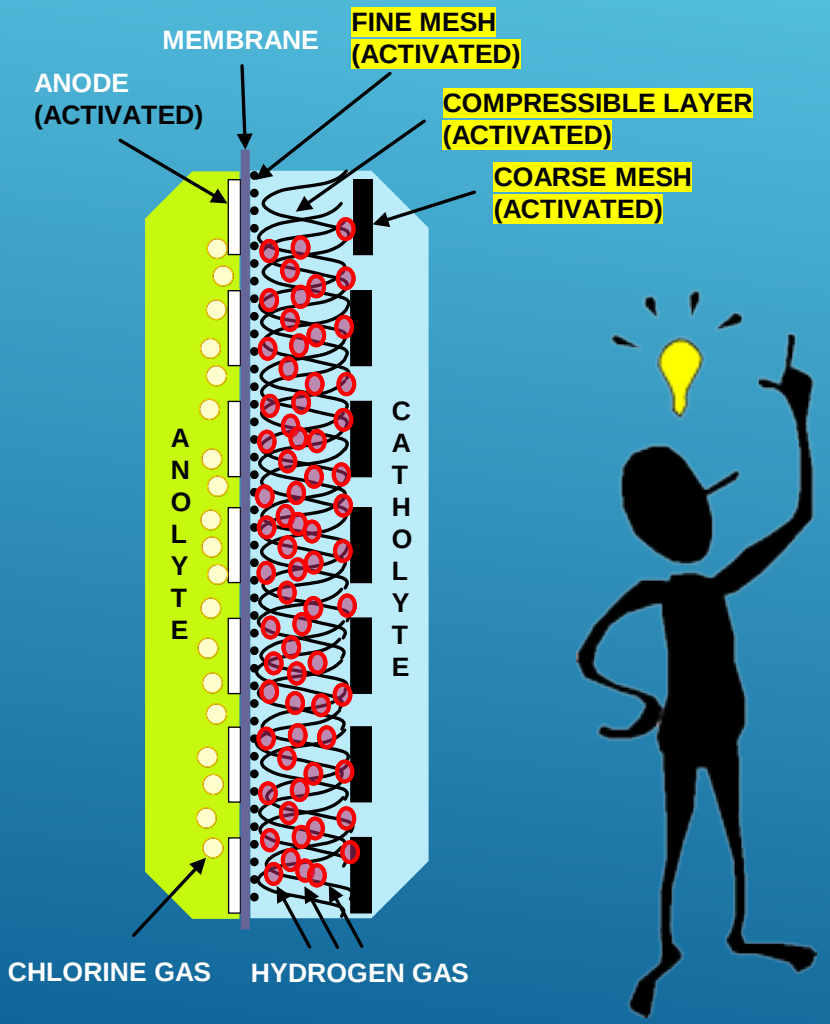
ZERO GAP CHLOR-ALKALI MEMBRANE CELL BY ELECTRODE SOLUTIONS



AFTER THE ADDITION OF
CATHODE OPTIMIZING SOLUTION
FROM ELECTRODE SOLUTIONS, ALL SURFACES IN THE CATHOLYTE ARE ACTIVATED AND EVOLVING HYDROGEN GAS, AND THE CELL VOLTAGE IS **REDUCED!**

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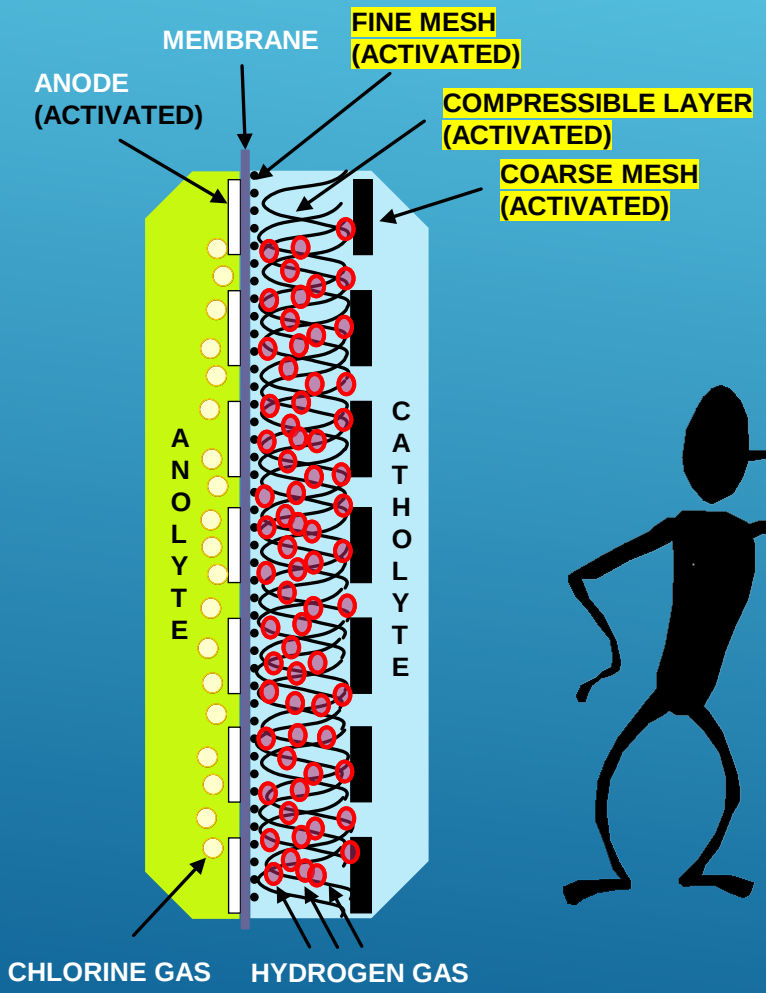
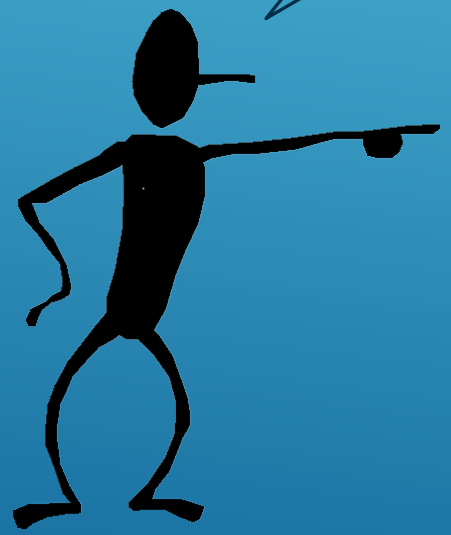
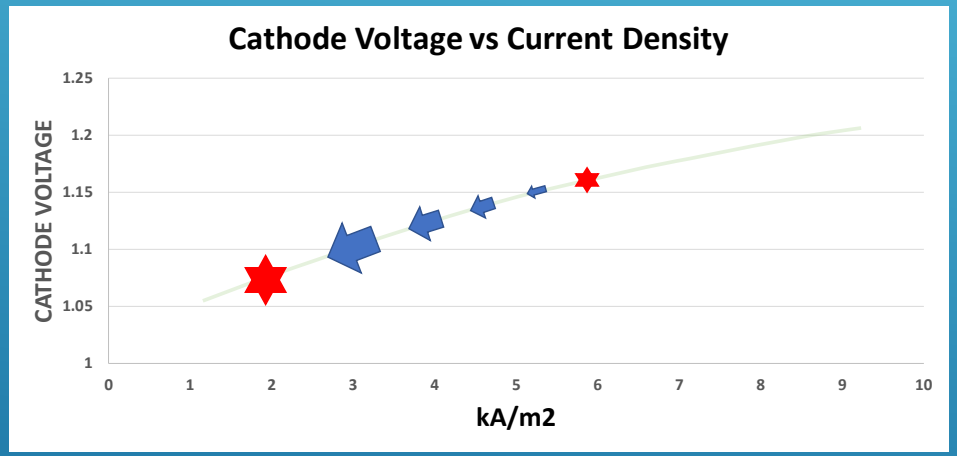
ZERO GAP CHLOR-ALKALI MEMBRANE CELL BY ELECTRODE SOLUTIONS





CATHODE OPTIMIZING SOLUTION

OPTIMIZES THE CATHODE OPERATION. PREVIOUSLY UNACTIVATED SURFACES ARE ACTIVATED AND PREVIOUSLY ACTIVATED SURFACES ARE RENEWED. THE CATHODE CURRENT DENSITY IS LOWERED.



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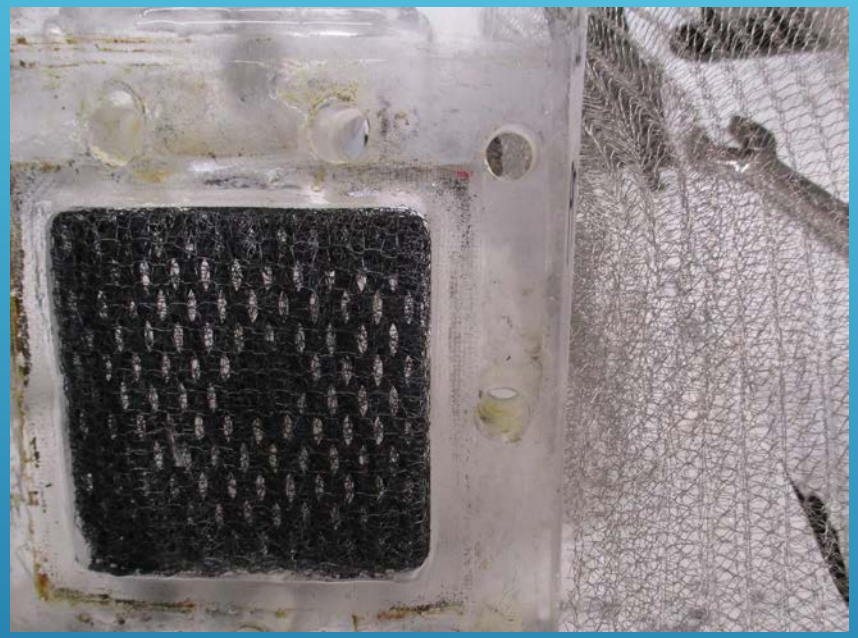
COS LAB PHOTOS

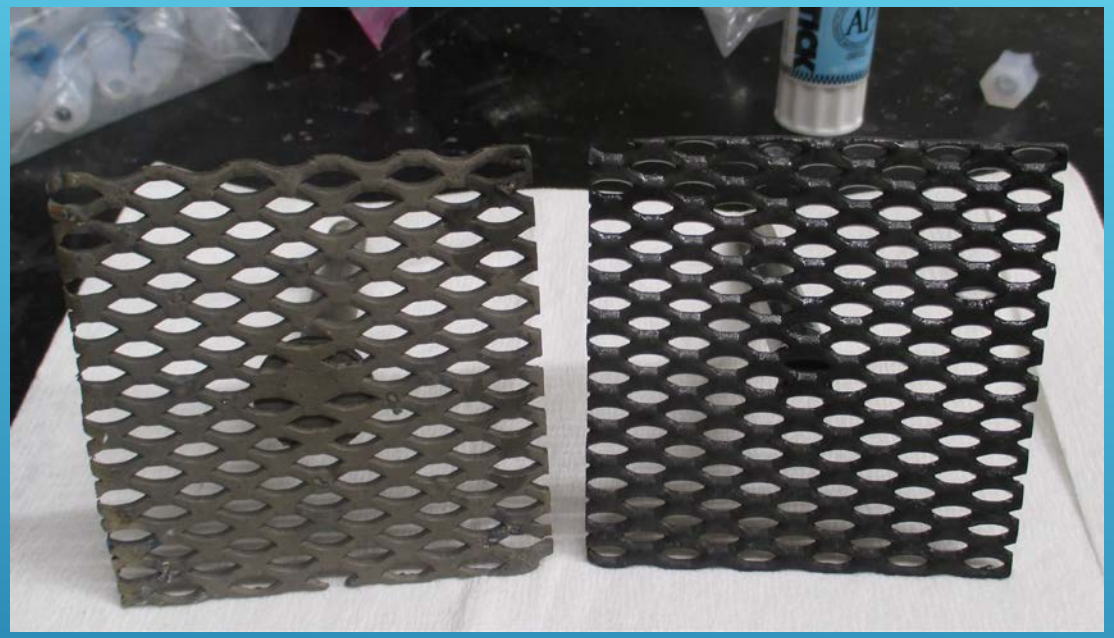
Photos taken after adding COS to a zero gap cathode constructed with uncoated nickel components.

Showing COS deposited on **ALL** cathode surfaces.



Showing COS deposited on cushion layer and current collector.

Bare nickel cushion layer



Bare nickel current collector

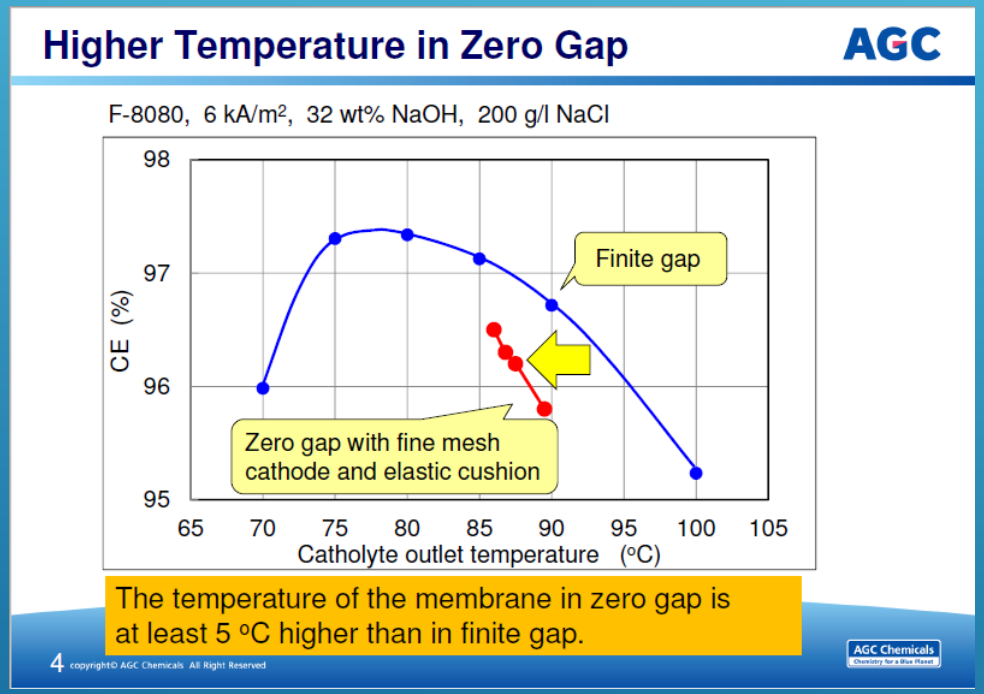
Showing COS deposited on current collector

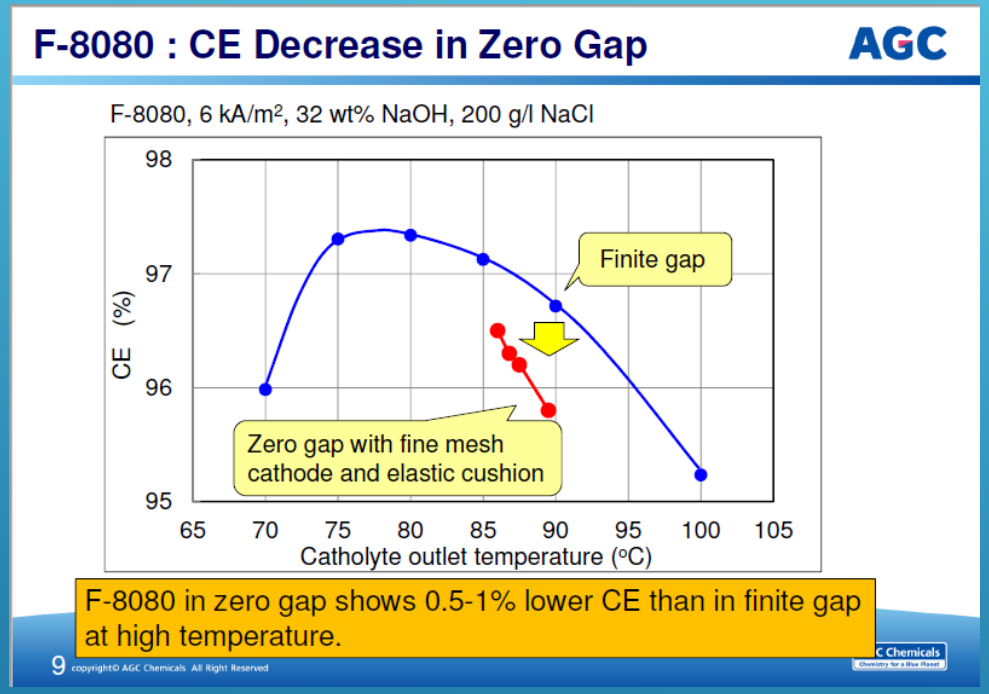
COS FIELD DATA

OTHER BENEFITS OF A CATALYZED CUSHION LAYER

OEM supplied catalyzed fine mesh layers increase the temperature of the membrane by at least 5 °C according to AGC chemicals which lowers the Current Efficiency by 0.5-1%.

Catalyzing the cushion layer counters these negative effects and improves the operation.





AGC data presented at Clorosur Technical Seminar

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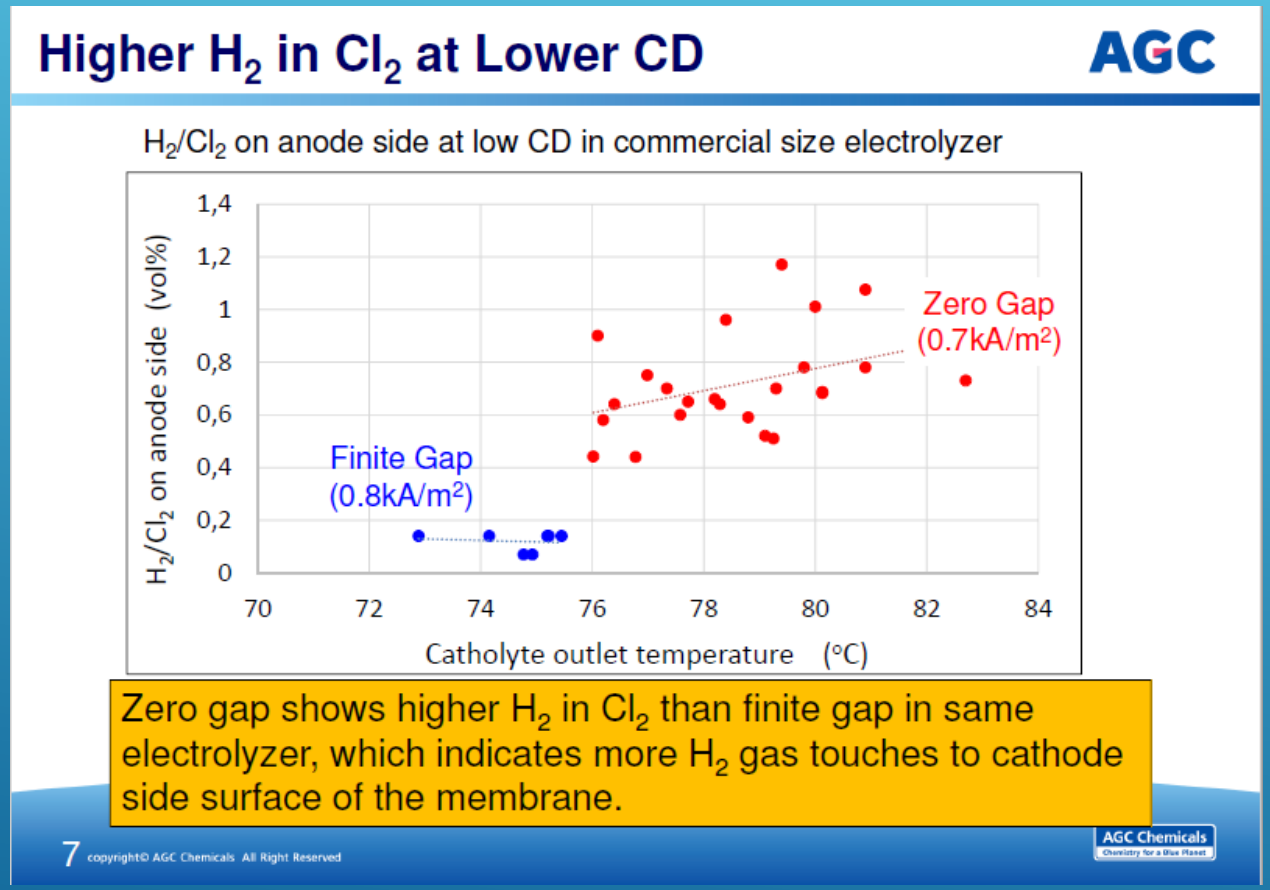
OTHER BENEFITS OF A CATALYZED CUSHION LAYER

OEM supplied catalyzed fine mesh layers increase the hydrogen in chlorine.

Catalyzing the cushion layer with COS counters this negative effect and improves the operation.



AGC data presented at Clorosur Technical Seminar

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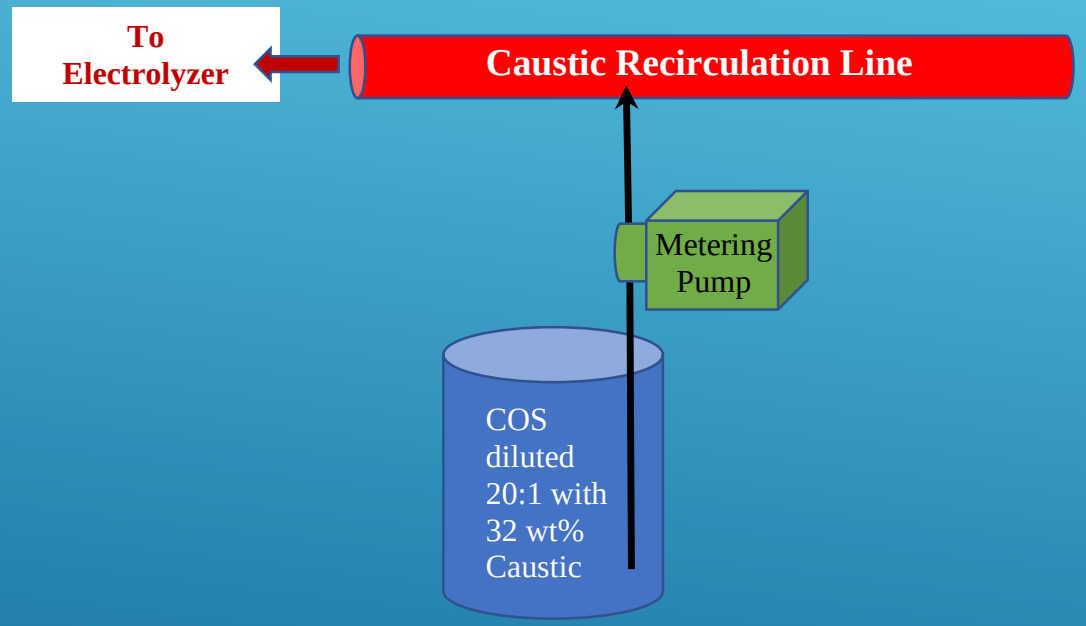
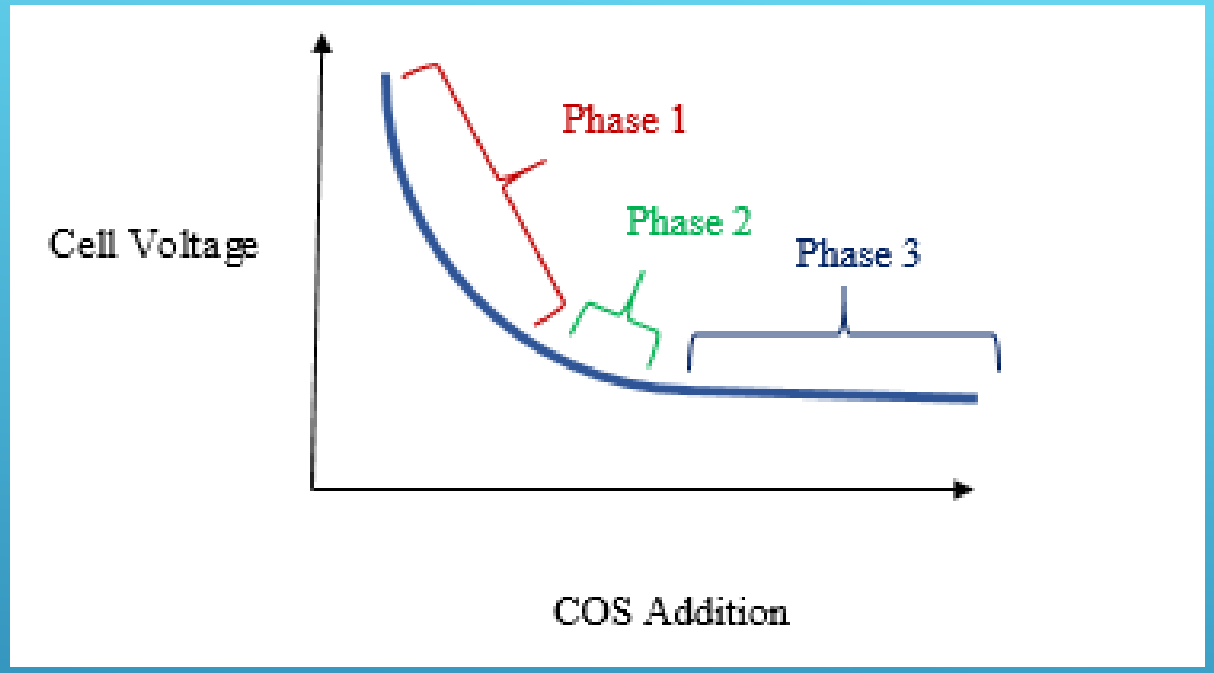
HOW TO ADD COS

Addition Setup





Phase	Finite Gap	Zero Gap
1	5-10 ml/m^2	10-15 ml/m^2
2	2-4 ml/m^2	2-5 ml/m^2
3	0.5-1.5 ml/m^2	0.5-1.5 ml/m^2-wk

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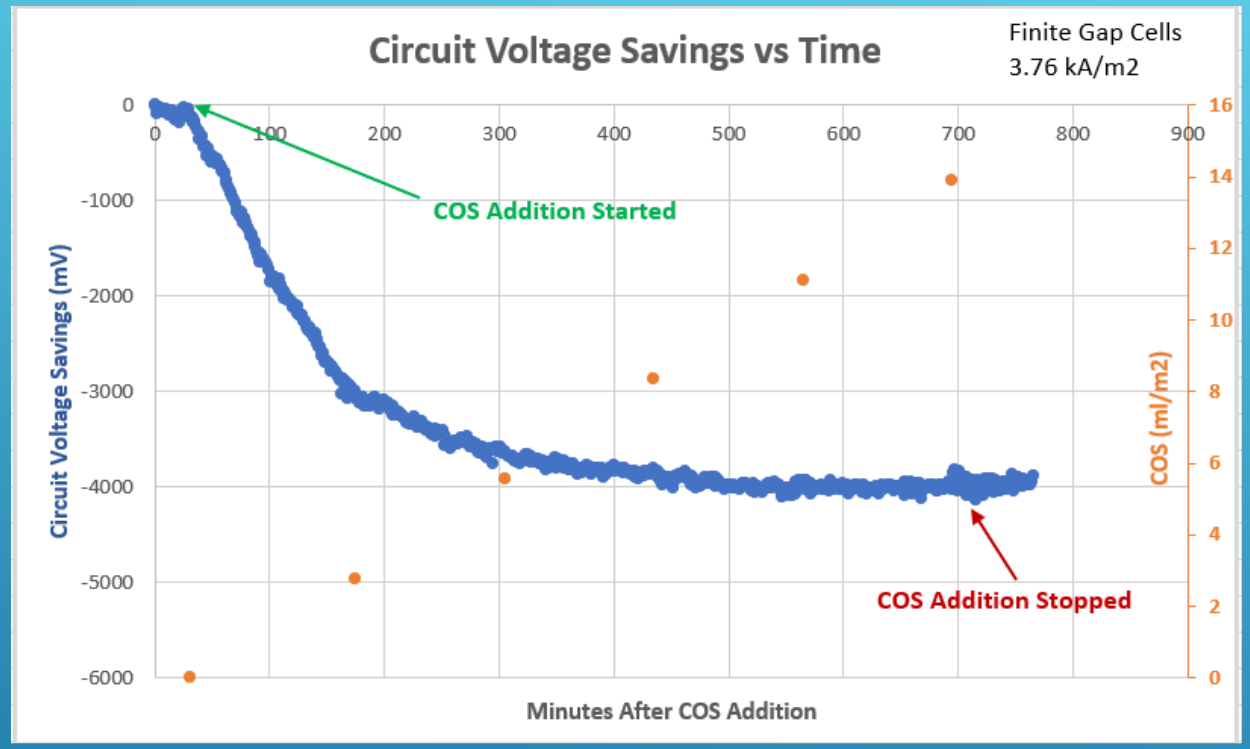
COS FIELD DATA
(ELTECH ExL 1.5 m2 Cells)



COS lowered the voltage of each cell by ~90 mV.

COS lowered the voltage on three different recently installed OEM cathode coatings by 20-30 mV.

COS Savings retained after un-protected 6 hour power outage.

Minimum Voltage at ~10 ml/m^2 of COS

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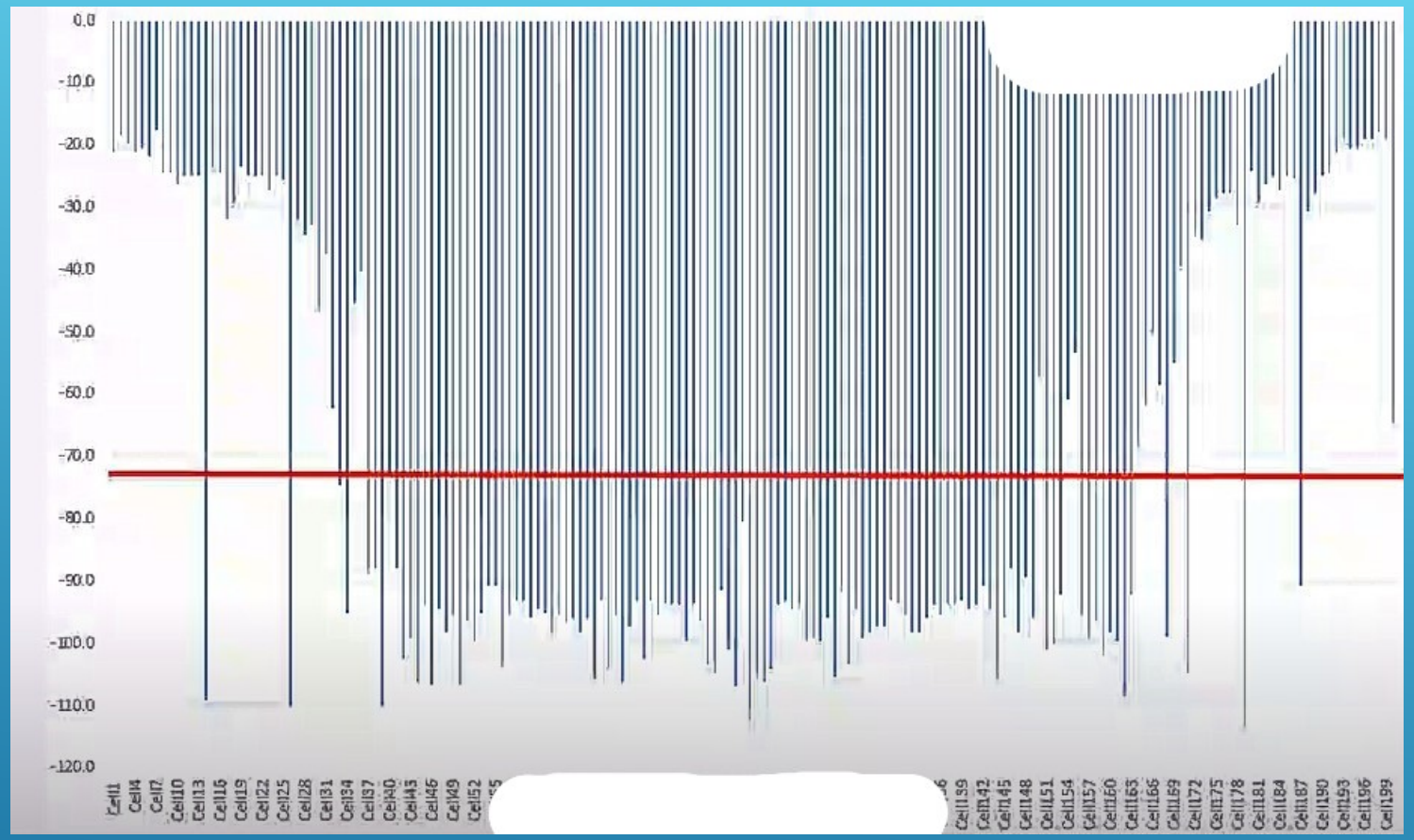
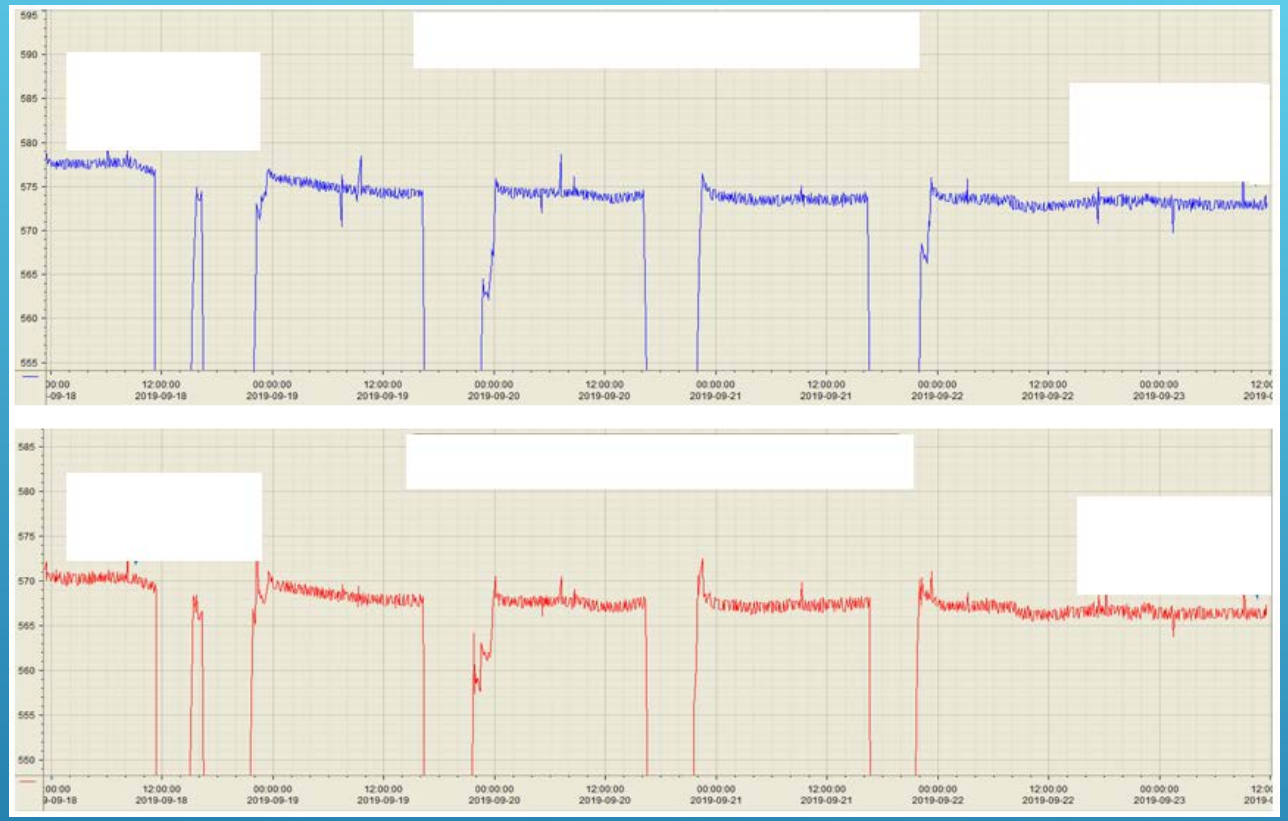
COS FIELD DATA

(Asahi Kasei Zero Gap 3.3 m^2 Cells)



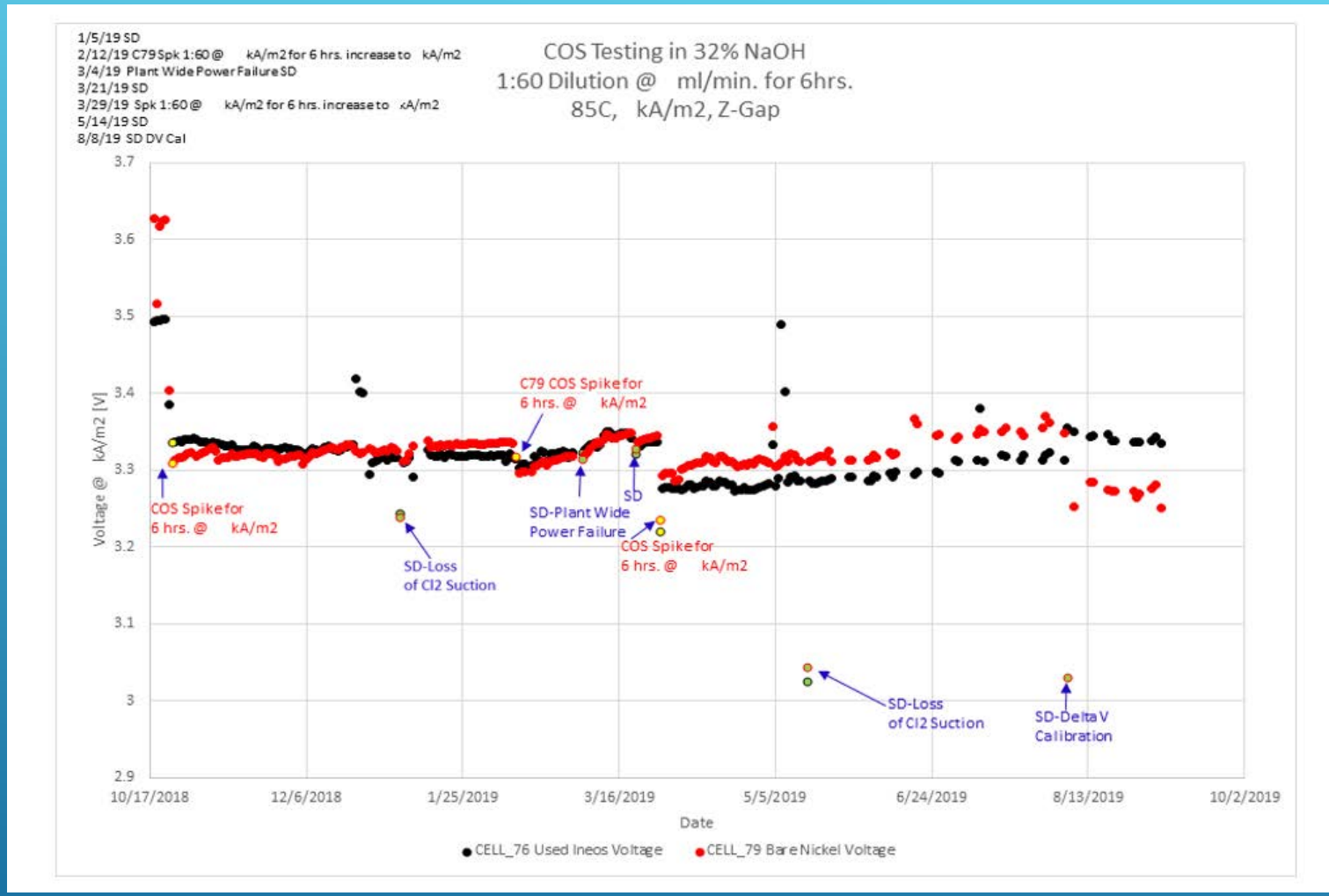
- COS corrected the voltage loss due to poor cathode polarization during power outages.
- Savings of ~20 mV on “good” cathodes and up to 115 mV on “bad” cathodes with an average savings of >70 mV.

COS FIELD DATA
(UHDE Fixed Gap 2.7 m^2 Cells)



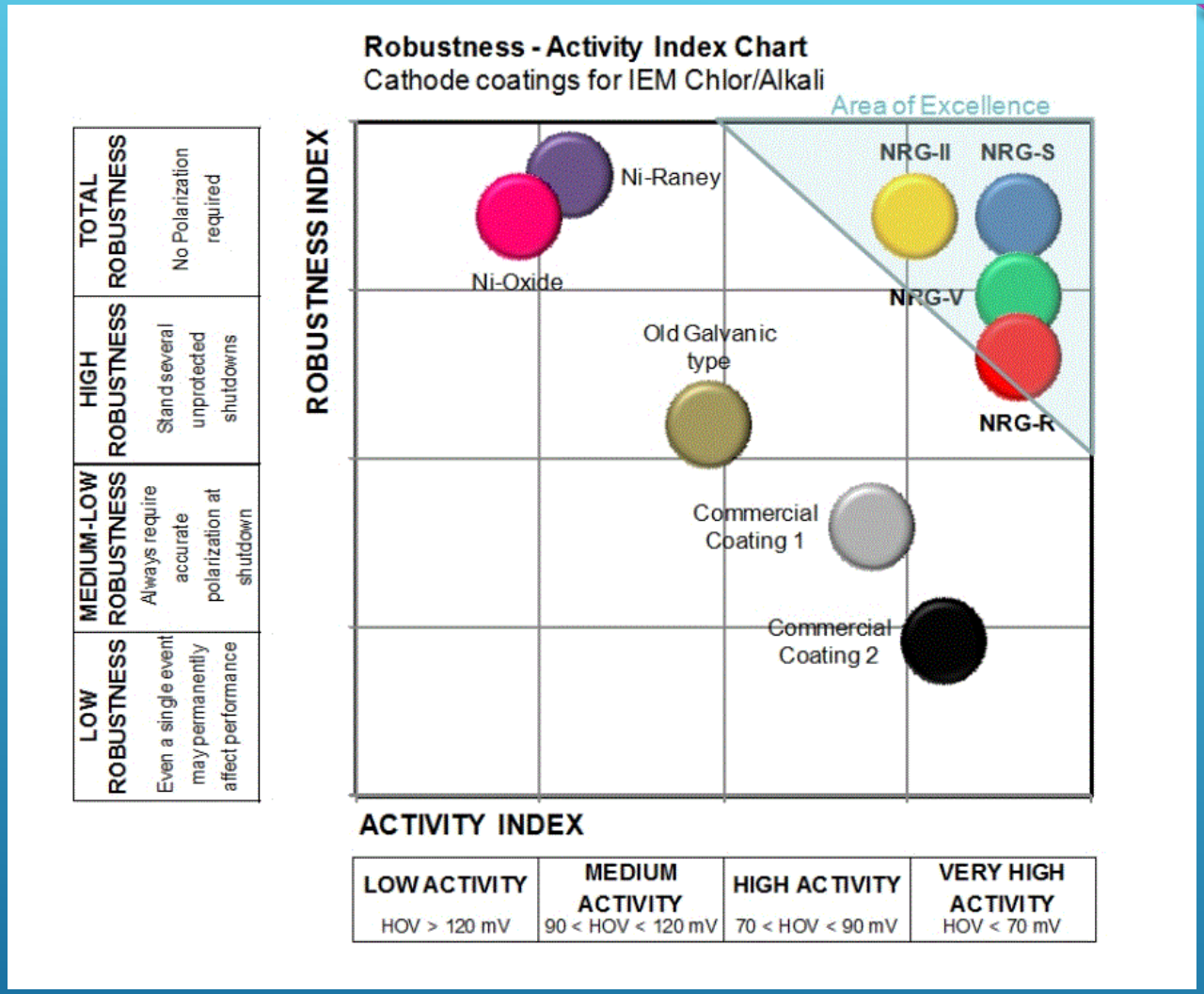
- COS lowered the voltage on good condition UHDE cathodes.
- Savings of ~30-50 mV.

COS FIELD DATA
(Long Term Data)



- COS lowered the voltage on OEM cathode coating and bare nickel cathodes.
- Long term stability.

COS



TAKEN FROM THE DE NORA WEBSITE

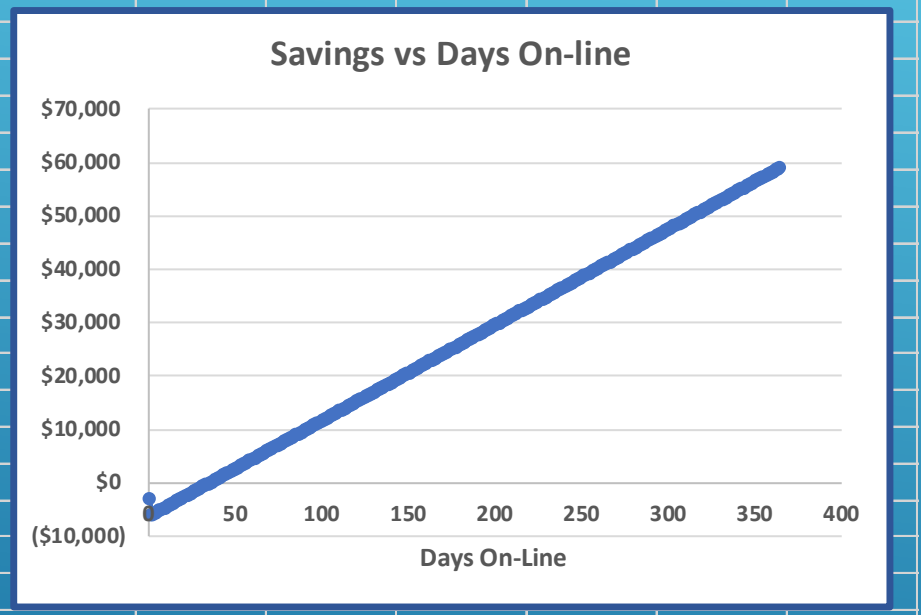
ECONOMICS

Cells in yellow can be changed

COS Savings Analysis

Electrolyzer Characteristics		
Number of Electrolyzers:	1	
Cathodes per Electrolyzer:	183	
Total # of Cathodes:	183	
M2 per Cathode:	2.72	
Total Cathode M2:	497.8	
COS Requirements		
Initial Addition:	15	ml/m2
Continuous Additions	1	ml/m2-week
COS Price:	$0.880	per ml
Initial Addition Cost	$6,570	
Continuing Addition Cost	$63	$/day
Voltage Savings		
Average Savings from COS:	0.070	Volts
Current Density	5.00	kA/m2
Power Costs	$0.055	per kWH
Rectifier efficiency	95.0	%
Savings		
Savings per day with COS	**$242.07**	$/day

+/− Electrode Solutions



ROI is 37 Days

EVEN LARGER SAVINGS
from ELIMINATION of OEM Recoating

Eliminate more than $500,000 in this example
AND
Achieve a lower voltage

OTHER POSSIBLE BENEFITS FROM COS

- Increase production or add additional cells if presently rectifier limited.
- Install longer life anodes
  - Minimize anode recoating which can harm the anode elements
  - A 2 x life anode is only marginally more costly than a 1x life anode.
- Achieve longer membrane life by improving the current uniformity across the membrane and reducing membrane overheating.
  - Lower nickel contamination of the membrane.
- Lower CO_2 footprint
- **Easy, Inexpensive on-site conversion to Zero-Gap technology**

CATHODE OPTIMIZING SOLUTION (COS):

- Eliminates Conventional Cathode Re-Coating
  - ✓ No Downtime
  - ✓ No Spare Cathodes required
  - ✓ No Crating and Shipping of Cathodes
- Recover lost Cathode Performance
- Delivers a lower voltage than OEM Cathode Coatings
  - ✓ ~30 mV savings on OEM coatings
- Protects the nickel substrate better than OEM Cathode Coatings
- Protects and activates all surfaces on the nickel cathode
- Easy and Safe to use
- Does not harm cell room components
- Does not contaminate the caustic product
- Corrects membrane over-heating observed in zero gap cells utilizing OEM zero gap cathodes.
  - Higher cell efficiency
  - Lower H_2 in Cl_2
- Very Economical to use
- Performance is mostly retained after power outages
- No warranty concerns

	OEM Coating	COS
Cost	~$1000/$m^2$	~$10/$m^2$ ✓
Stable Coating	No	Yes ✓
Requires a Cell Room Outage/Downtime to Install	Yes	No ✓
Requires Dis-assembly to install	Yes	No ✓
Requires Shipping	Yes	No ✓
Requires Cathode Spares	Yes	No ✓
Recover From Upsets	No	Yes ✓
Activate All Available Cathode Area	No	Yes ✓
Require Polarization to Protect Coating	Yes	No ✓
Adequately Protects the Nickel Substrate	No	Yes ✓
Contaminates the Caustic Product	Yes	No ✓
Removeable via Tape or a Water Hose	Yes	No ✓
Delivers the Lowest Energy Consumption	No	Yes ✓
Corrects Membrane Over-Heating in Zero Gap Cells	No	Yes ✓
Warranty Requirements	Yes	No ✓

Even if an OEM offers **FREE CATHODE COATING**, you are still better served with **COS** from Electrode Solutions.

OTHER OFFERINGS

- ON-SITE ANODE RECOATING
- ANODE RECOATING BY OLIN (USA)