Magnesium Extraction From Magnesium Oxide Using Solid Oxide Membrane Process

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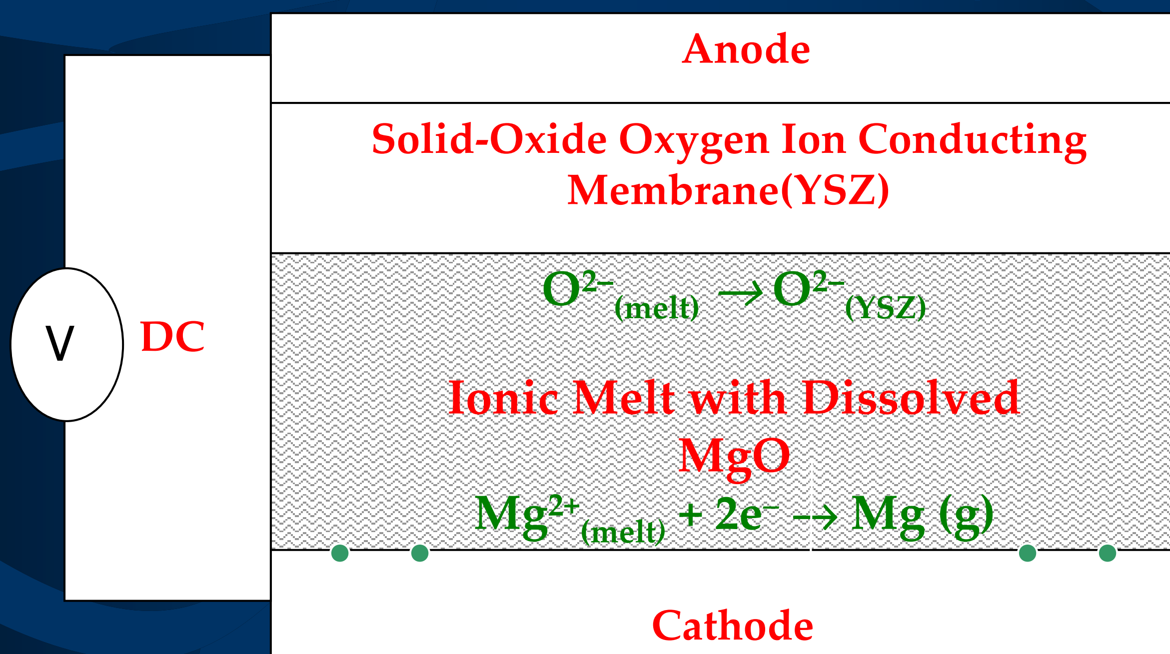
Solid Oxide Membrane (SOM) Process for Magnesium Production-Leading to Magnesiothermic Production of Other Metals

$O^{2-} \rightarrow \frac{1}{2} O_2(g) + 2e$

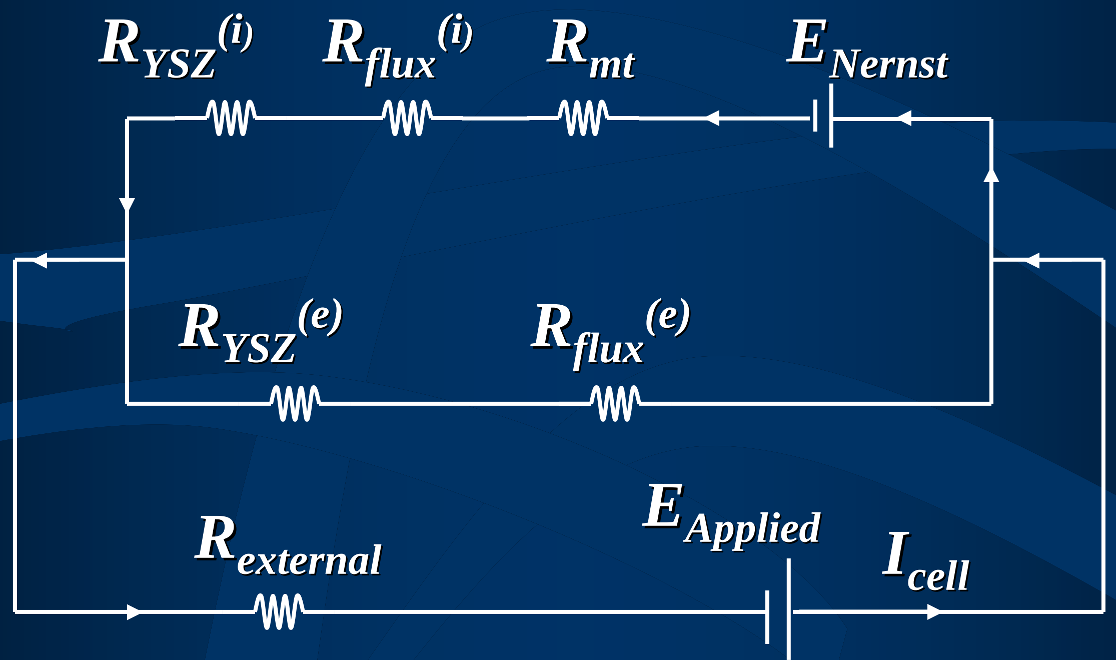
$H_2(g) + O^{2-}_{(YSZ)} \rightarrow H_2O(g) + 2e^-$

$CO(g) + O^{2-}_{YSZ} \rightarrow CO_2(g) + 2e^-$



$Mg(g) + MeO = Me + MgO(s)$

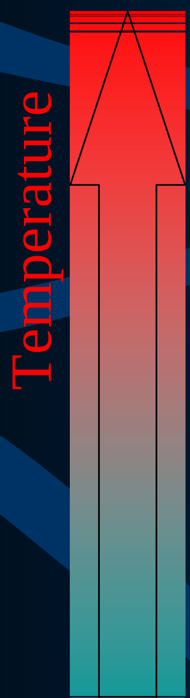
Equivalent Circuit of SOM Cell

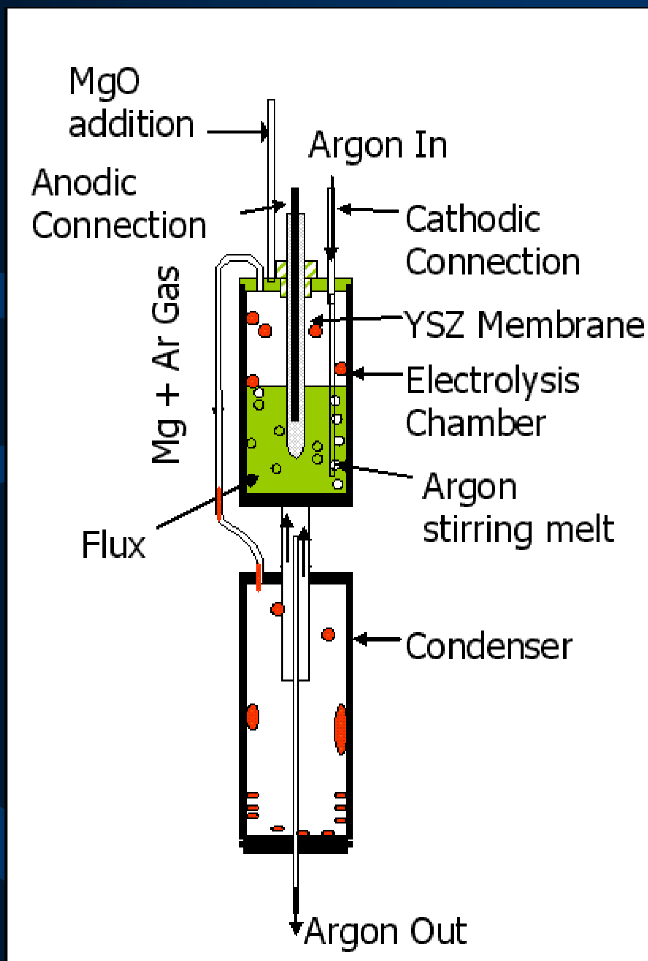


$$R_{total} = R_{YSZ}^{(i)} + R_{flux}^{(i)} + R_{external} + R_{mt}$$

$$E_{Applied} - I_{cell}R_{Total} = E_{Nernst} = (RT/4F) \ln (P_{O_2}{}^{a}/P_{O_2}{}^{c})$$

Vertical Cross Section of the SOM Cell



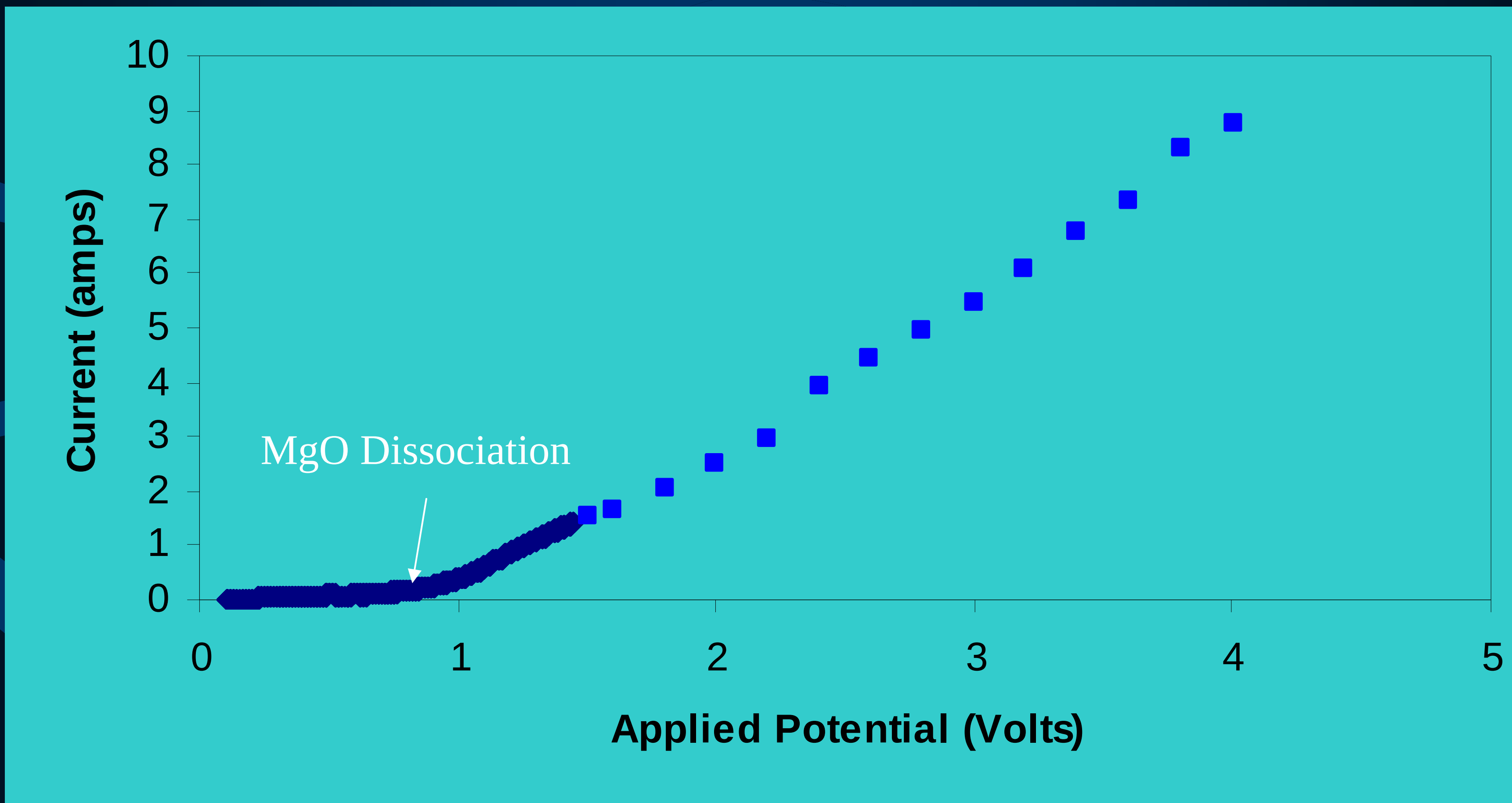


Experimental Setup

1 cm

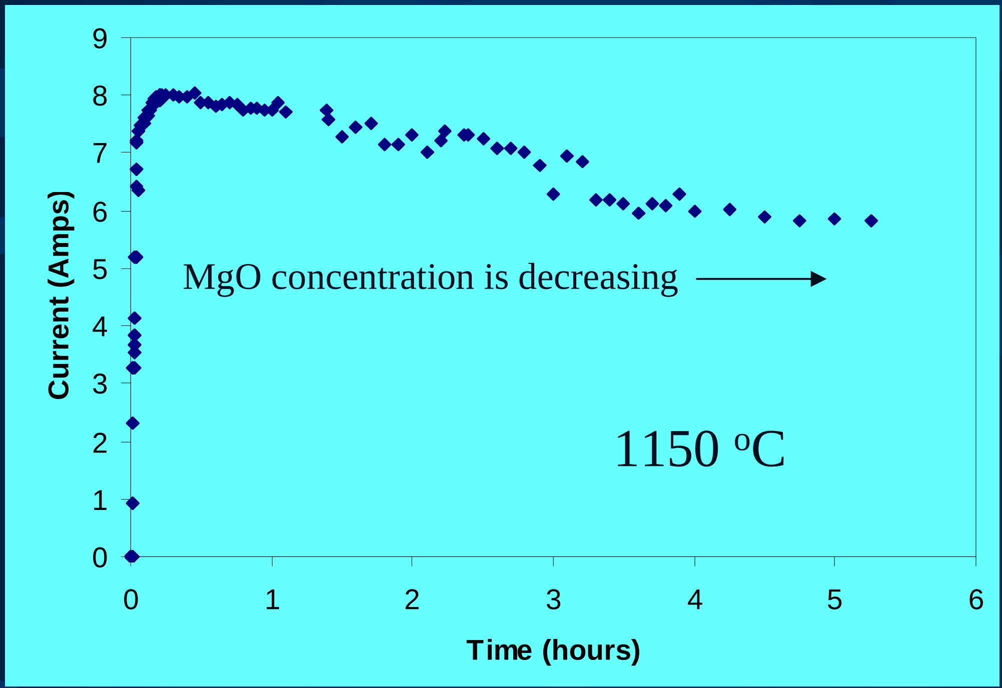
3 cm

Potentiodynamic Sweep at $1300^{0}C$

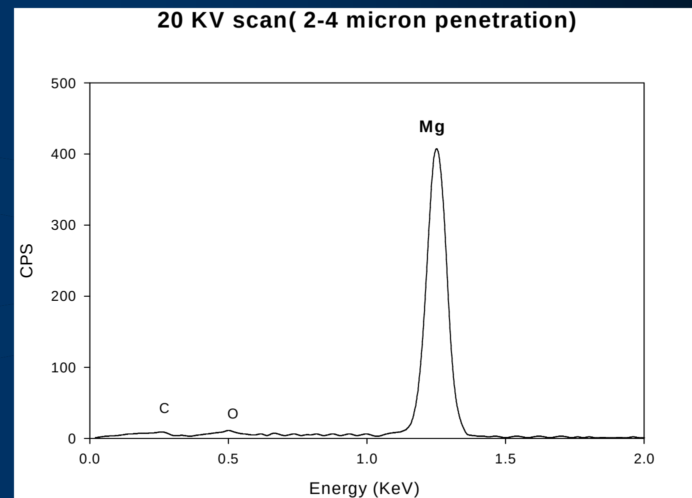


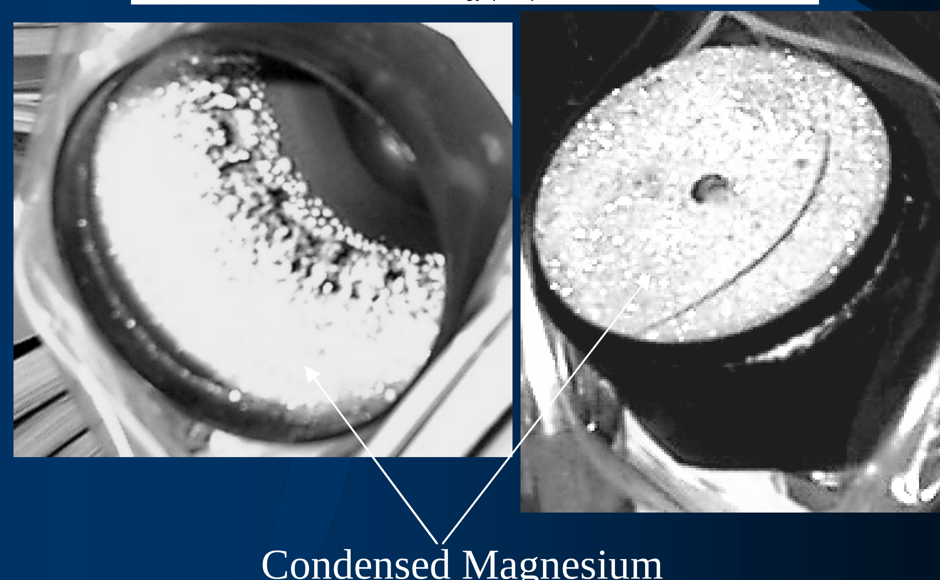
SOM Electrolysis of MgO

Potentiostatic Hold at 4.0 Volts

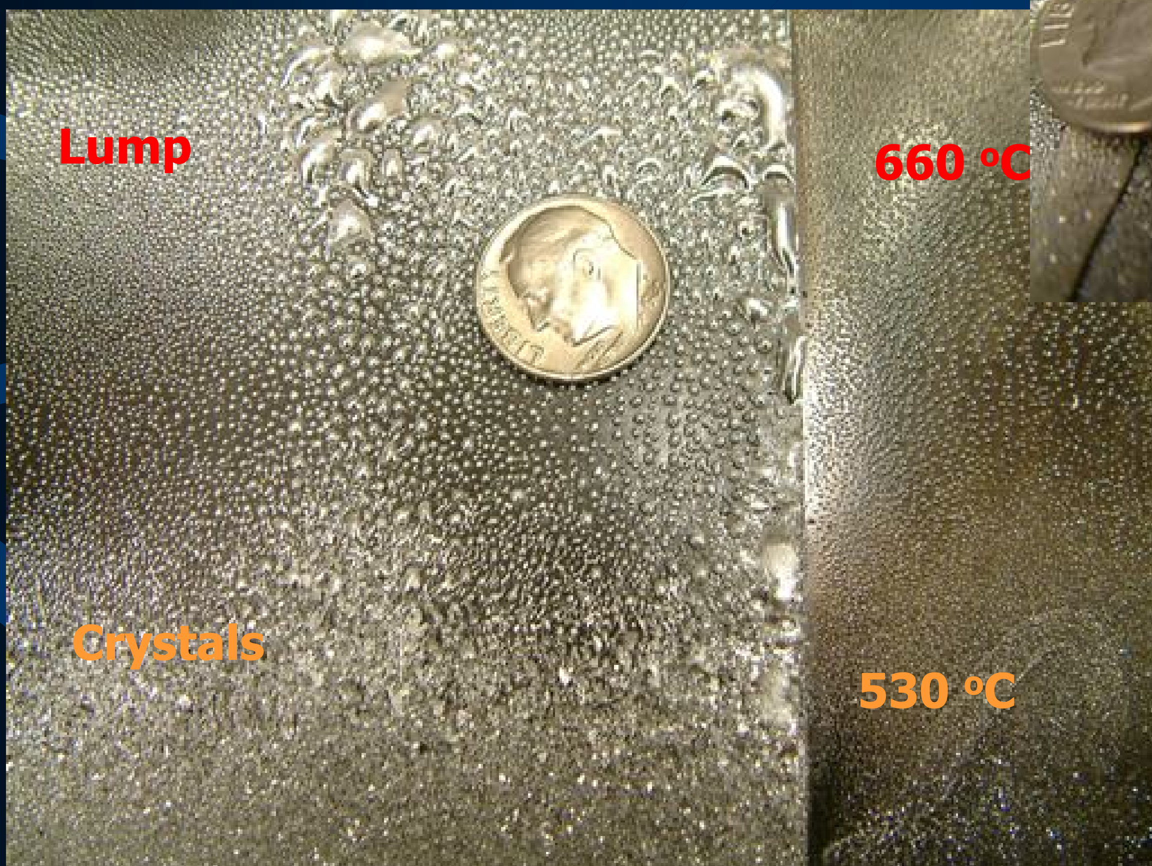


SOM Electrolysis of MgO

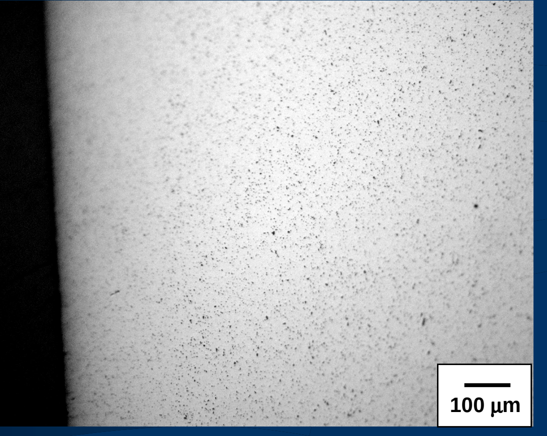




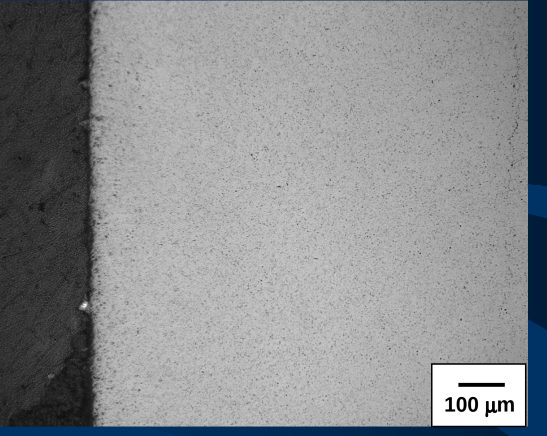
Morphology of Magnesium Deposit



Stability of Membrane



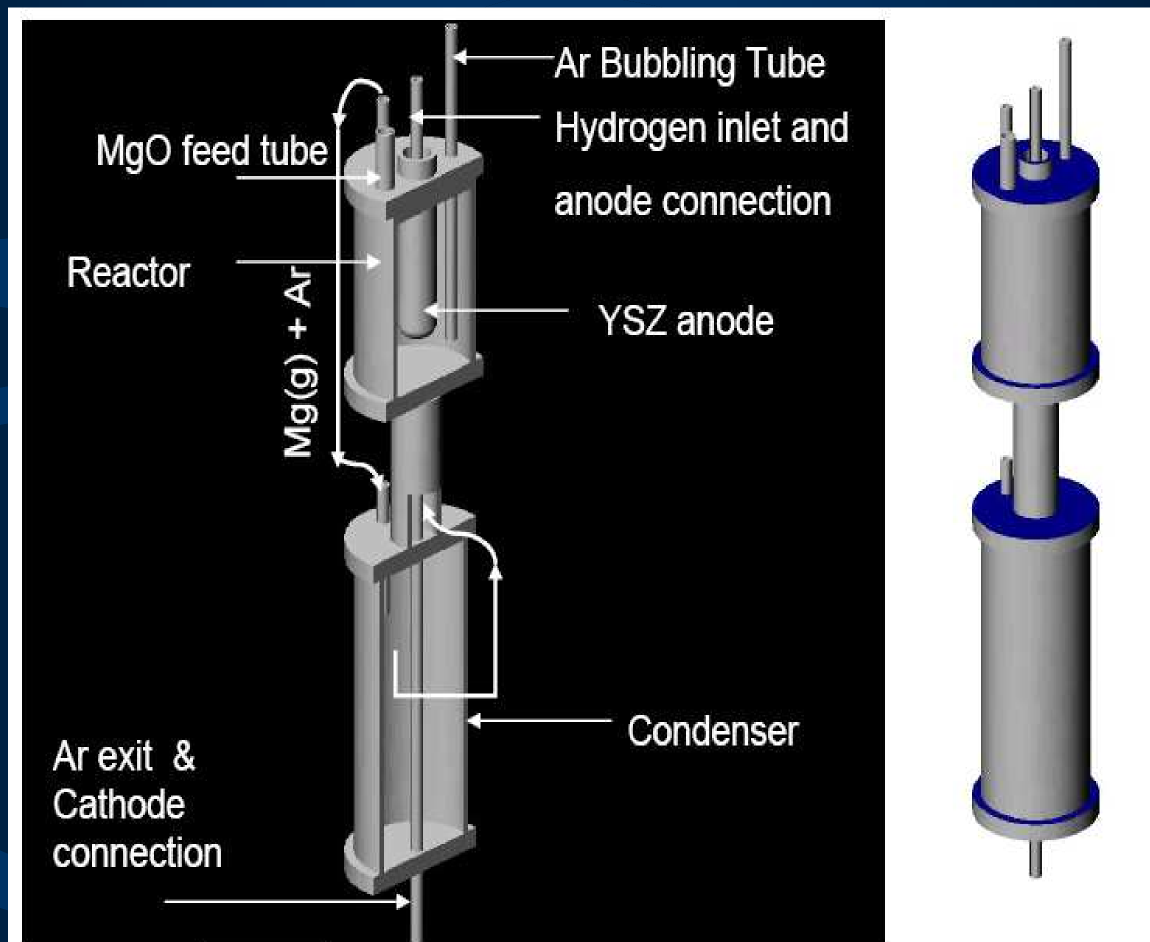
a) As Received



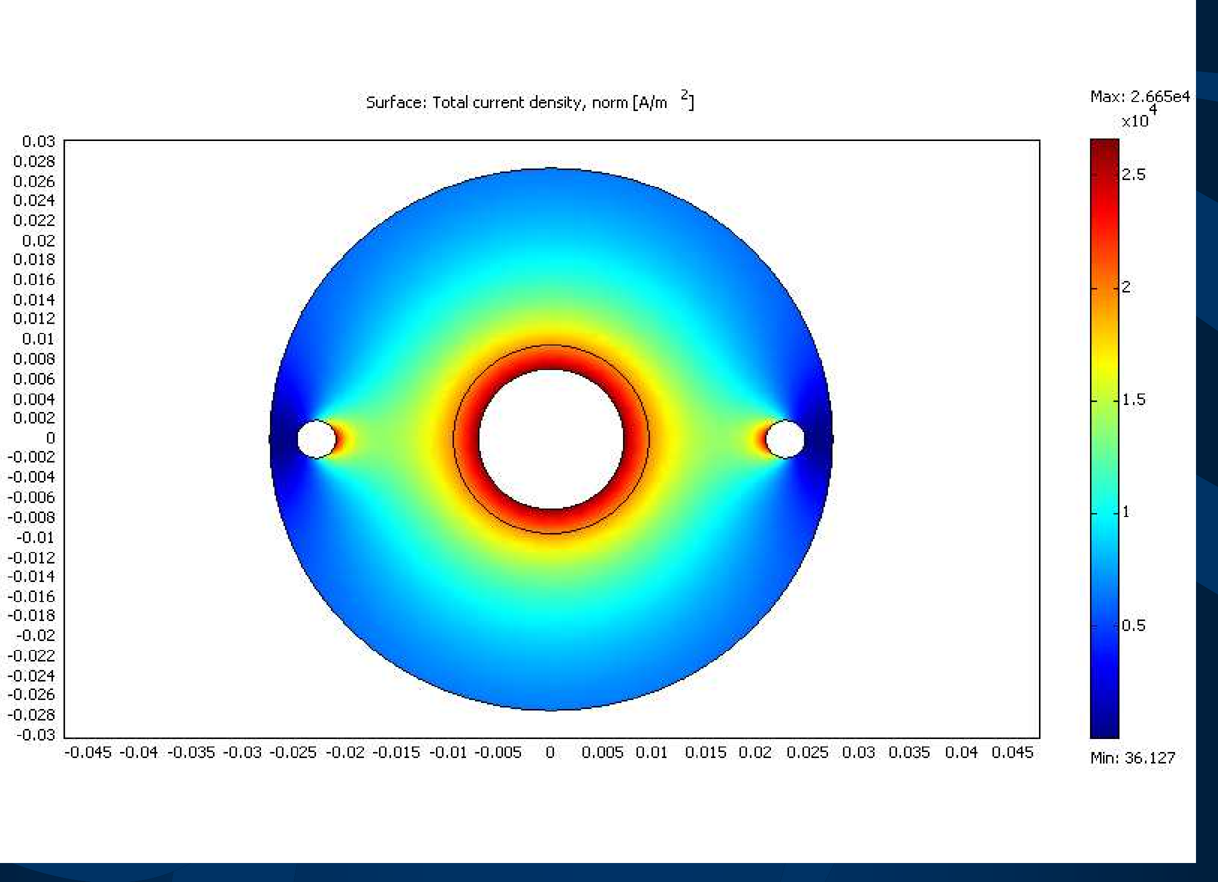
b) After Experiment

- Membrane virtually unaffected after the 20 hour experiment
- Selection of flux is critical to the process
- The operating life of Zirconia membrane will dominate overall cost of the process

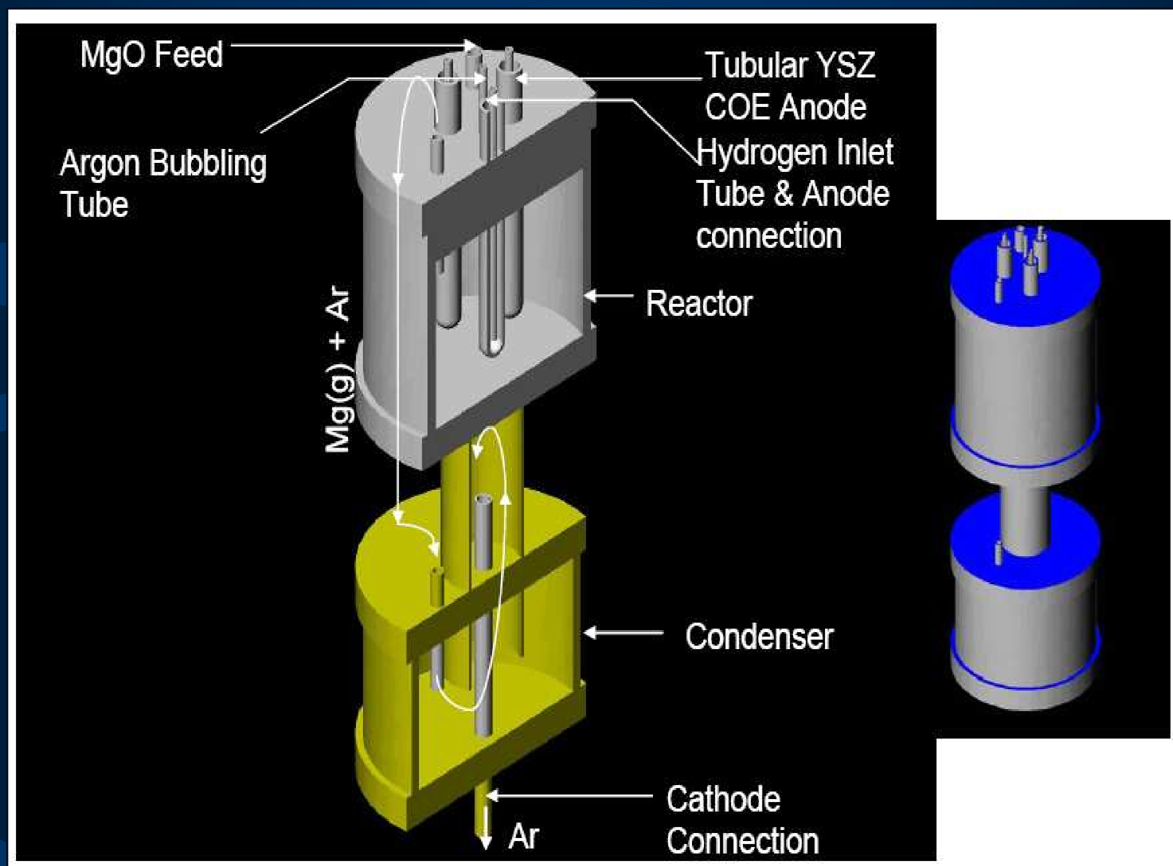
SOM design with single tube arrangement (100-200 g/day)



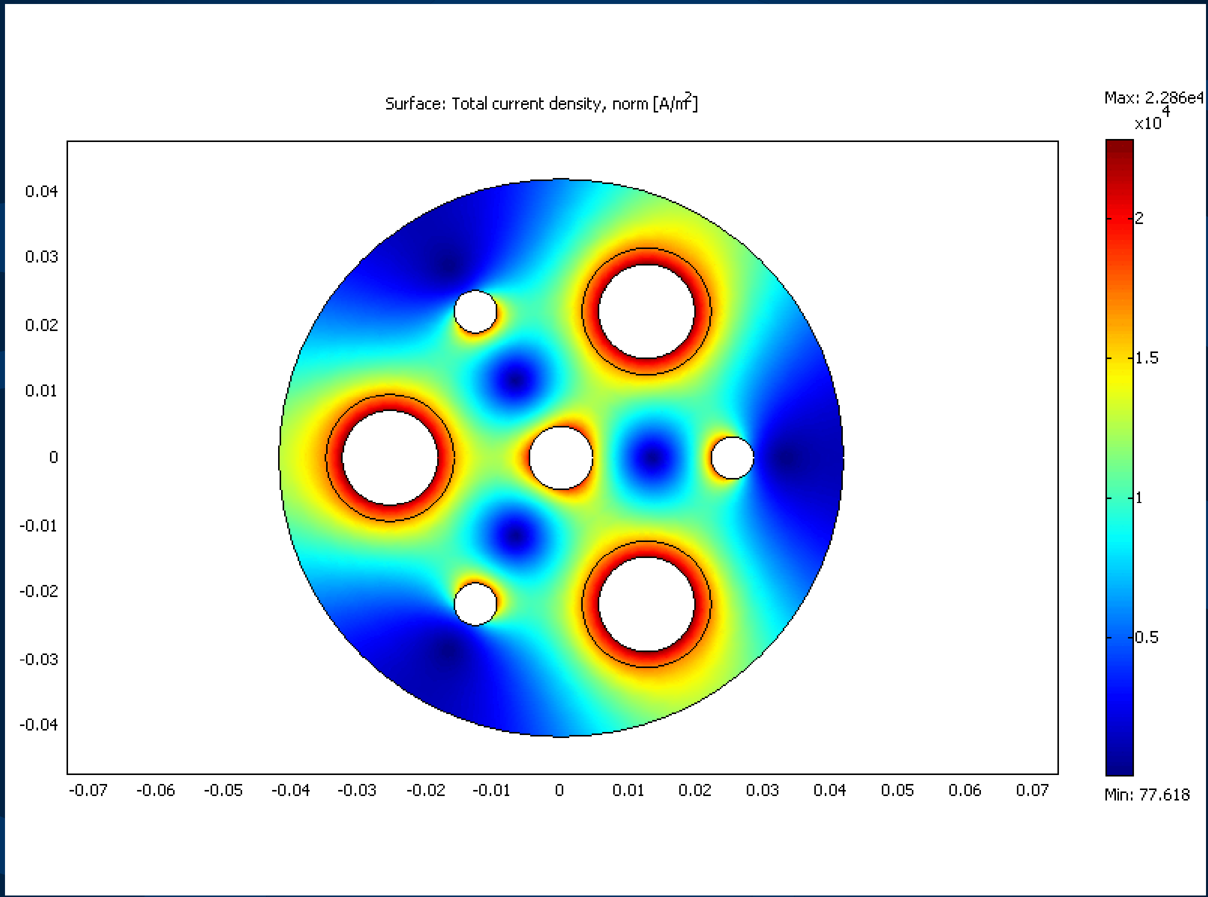
Cylinder Geometry 1-tube Model Current Density



SOM Design With Triple Tube Arrangement (0.5-1kg/day)



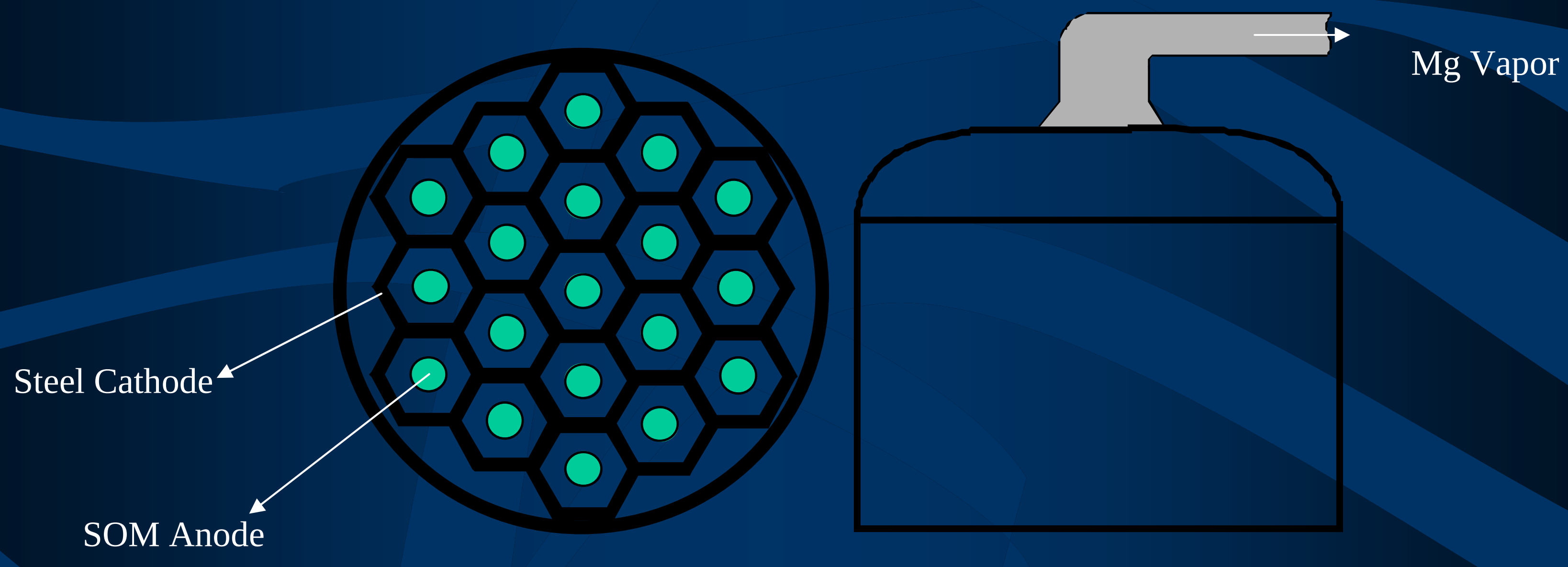
Cylinder Geometry 3-tube Model Current Density



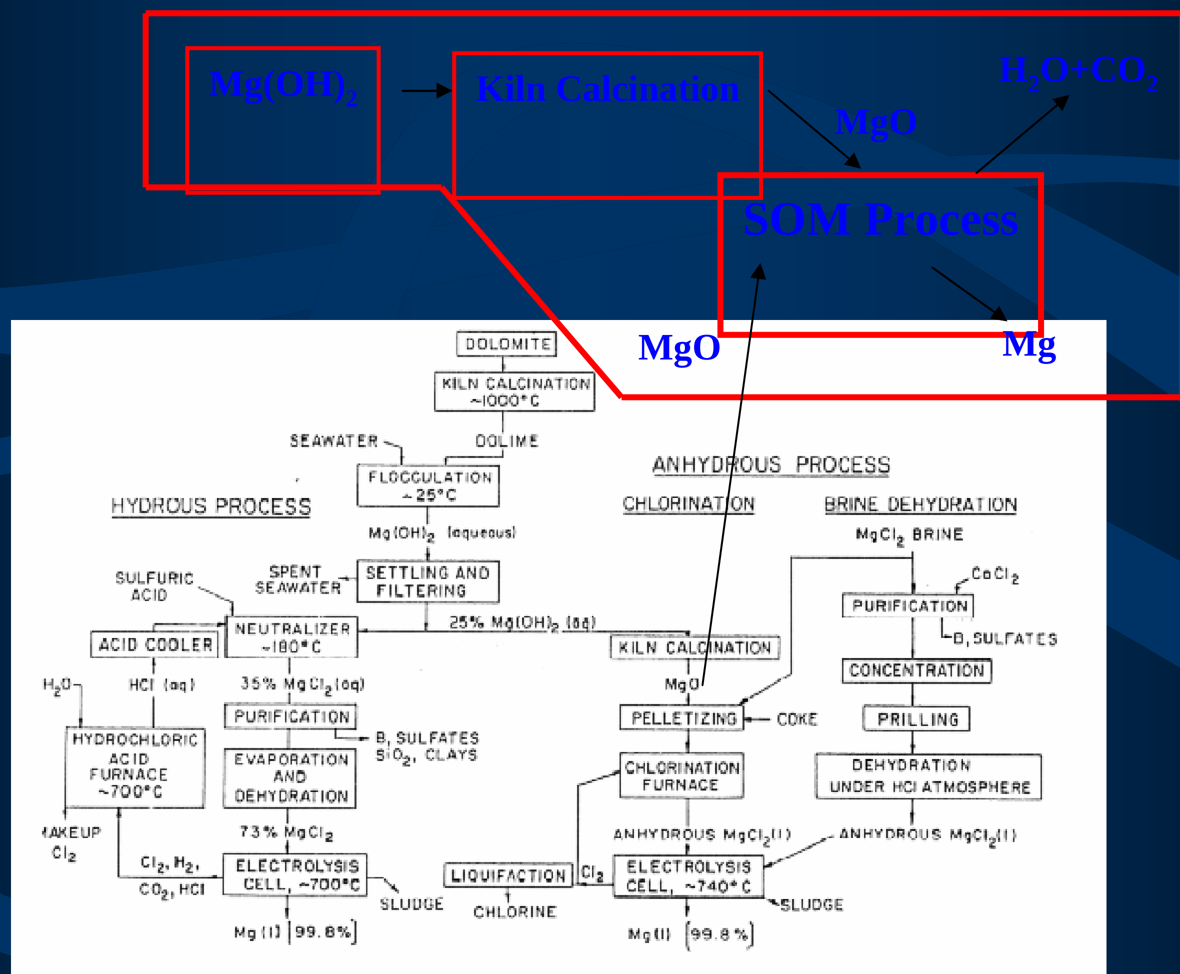
SOM Reactor Design for Mg Production

Specifications	**100-200 g/day**	**0.5-1 Kg/day**
Anode Structure	Tubular COE	Tubular COE
No of Anodes	1	3
Total active anode length (cm)	5	15
Active Anode Area(cm^2)	30.4	91.2
Crucible ID (cm)	5.461	15.24
Active Cathode Area (cm^2)	130.7	364.8
Minimum Anode-Cathode Separation Distance (cm)	1.778	4.12
Electrolyte Capacity (g)	464	3613

Top and Side Views of the Possible Scale-up Version of the SOM Electrolytic Cell.



Comparison of the SOM Process Versus State-of-the-art Process for Electrolytic Production of Magnesium



SOM Cell Physical Parameters

Output	SOM (2 MT/day)	$MgCl_2$ (1-4 MT/day)
Feed Material	MgO	$MgCl_2$
Anode Structure	Tubular YSZ	Graphite Plate
By-Product Anode Gas	(CO, H_2O or O_2)	Chlorine and Chlorinated hydrocarbons
Number of Anodes	37	Not Available
Working Length	100 cm	100-120 cm
Anode Tube Diameter	16 cm	Not Applicable
Anode Area	185,900 cm^2	Not Available
Heat Anode Life/Consumption	3-6 months	0.5-100 kg/MT
Cathode	Plate Steel	Plate Steel
Anode-Cathode Distance	4-8 cm	3-6 cm
Cell Internal Diameter	290 cm	Not Available
Electrolyte Capacity	20 MT	20-90 MT
Refractory	MgO Based	Al_2O_3-SiO_2
Operating Temperature	1100-1150 C	675-800 C

SOM Cell Operating Parameter Comparison

Output	SOM (2 MT/day)	$MgCl_2$ (1-4 MT/day)
Current Density	1 Amp/cm^2	0.4-0.7 Amp/cm^2
Cell Voltage	4.4-5.4 V	4.5-7.2 V
Potential Drops		
Dissociation Potential	0.82 V	2.75 V
iR drop (Electrolyte)	1-2 V	1.3 V
iR drop (YSZ, 2mm thick)	1.3 V	Not Applicable
Anode	0.7 V	0.7 V
Cathode	0.3 V	0.3V
Contact and Leads	0.25V	0.25V
Specific Power (k Whr/kg)	10-12	10-16

Comparison of Projected Energy Balance

Energy Sources	**SOM (2 MT/day) k J/hr**	**$MgCl_2$ (0.62 MT/day) k J/hr**
DC Electrical Energy	3,568,270	1,148,801
Chem. Energy-anode feed	379,070	-----------
Pre-Melted Feed Material	------------	154,682
Total Sources	3,947,340	1,303,483
Energy Sinks		
Heating of raw material	353,916	--------------
MgO Decomposition	2,061,786	671,293
Impurity Decomposition	12,000	9,121
Heat Escaping with Mg	596,116	22,175
Heat in Spent Electrolyte	---------	80,814
Heat Escaping with Anode Gas	157,344	10,418
Heat Loss Cell/Carrier Gas	65,678	14,016
Heat Losses (Top Lid, Walls, Floor, Anode Heads)	700,500	495,646
Total Heat Consumed	3,947,340	1,303,483

SOM Features

- Cost Effective & Environmentally friendly
  - Direct reduction of Magnesium oxide
  - Minimize pre-processing, reduce capital and operating cost
- High Current Density (>1 Amp/cm^2) → Good Scale up Potential
- Specific Energy consumption of MgO reduction is 10 KWh/Kg

Acknowledgements

Department of Energy

Boston University

Safe Hydrogen, LLC

Shh... Its quiet power