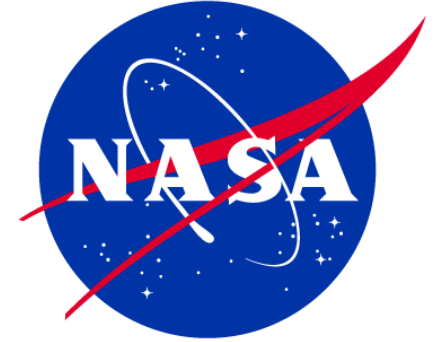




Medical Ceramic Oxygen Generator (M-COG)
Technology description presented to:
ISO/TC121/SC6 Medical Gas Supply Systems

May 13, 2024

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Applications for a Ceramic Oxygen Generator (COG)

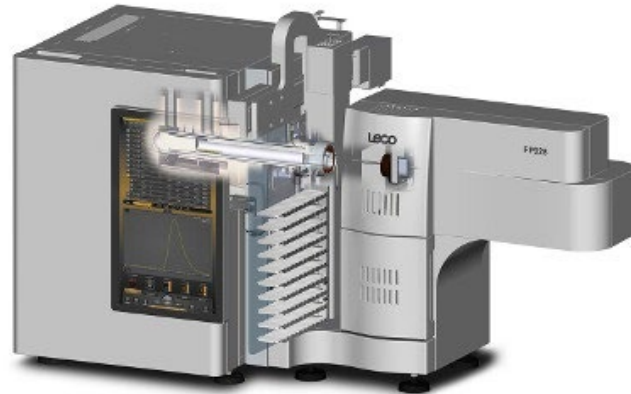
Space Suit
O₂ Tank Recharge



Key Requirements:

Purity: >99.99%
Pressure: >3000 psig
Safety: (no H₂ hazards)

Ultra High Purity (UHP) O₂
for analytical chemistry



Key Requirements:

Purity: >99.999%
Price: < \$500 / cylinder

Medical O₂
In Challenging Environments



Key Requirements:

Purity: >93% (prefer >99.0%)
Service Life: > 10 years
Operates in hot, humid environments
<1 hr Maintenance per year

Attributes of Ideal Medical Oxygen Generator / M-COG Attributes



Attribute			
Reliability	MTBF >5yrs	✓	one moving part, that part has 7 year MTBF)
Service Life	>10 years	✓	>99.9%, > 5 bar after 10 years (35% reduction in flow)
Training	< 1 hr	✓	Training needs: 1 hr instructional video
Maintenance	<1 hr per year	✓	1 hr to replace blower & thermocouple every 2 years
O ₂ Purity	>99.0%	✓	>99.99% (under all operating conditions)
O ₂ Pressure	>5 Bar	✓	>13 Bar
Temp. range	-10 to 50C	✓	-10 to 50C (limited by electronics)
Humidity range	0 to 99.5%	✓	0 to 99.5% (humidity no affect on purity, pressure, power)
Elevation range	0 to 4000 meters	✓	0 to 4000 meters (demonstrated at 3300 meters)
Power	<50 Watts/lpm	In Work	<100 Watts/lpm now, <50 Watts/lpm with Gen2 wafer
Cost	Less than SOA	In Work	with mature manufacturing, equipment cost < \$1000/lpm

M-COG components, terms, definitions



M-COG wafer
3" X 6" X 0.1"
All ceramic



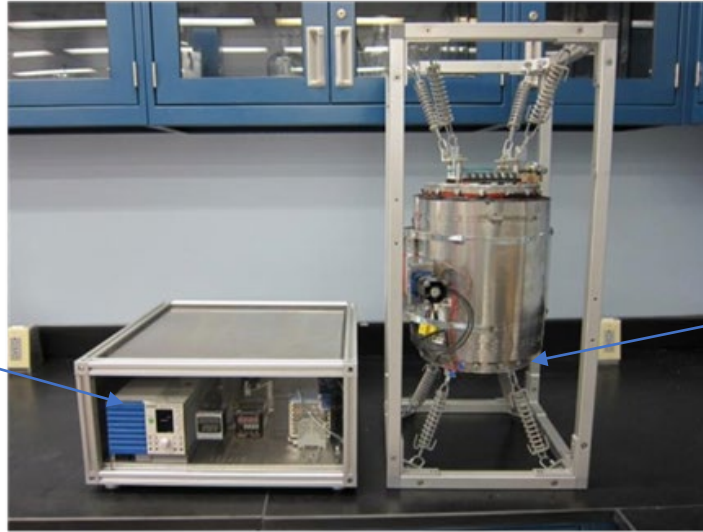
M-COG cell stack
8" X 8" X 4". 30 wafers, joined together into a single system, with thermal and electrical isolation - in a stainless steel housing for modular installation. Each cell stack produces about 4 lpm oxygen.



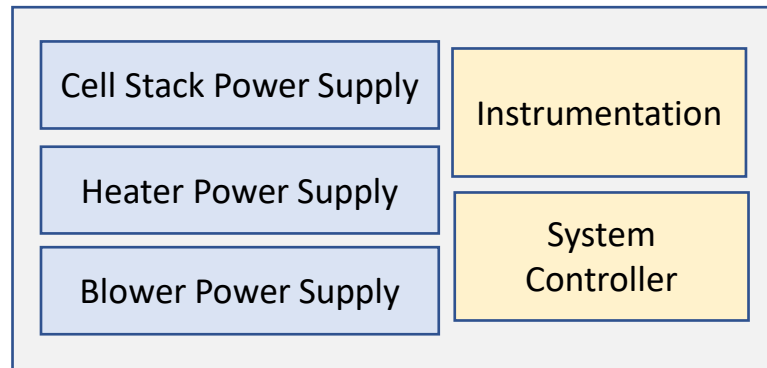
M-COG Oxygen Engine
Cell stack, heater, heat exchanger, blower, structure, packaging for transport. The hot part of the system

The Two Main Components of an M-COG System: Oxygen Engine & Power Supply-Control

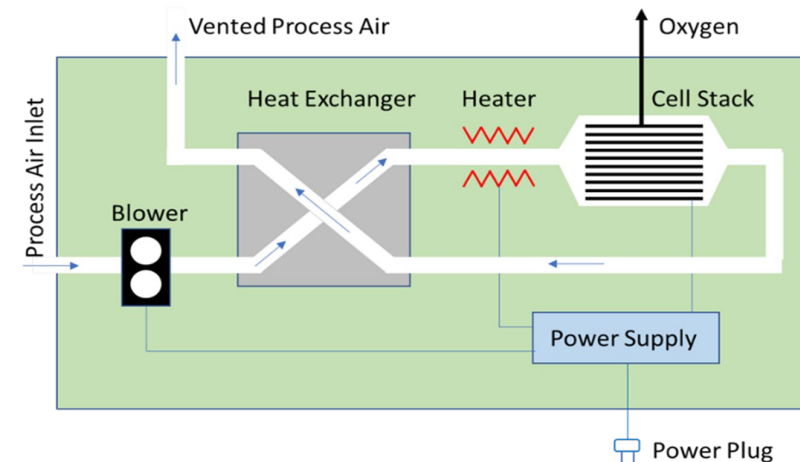
Power Supply & Control Assembly
(Ambient Temperature)



Oxygen Engine
(High Temperature)

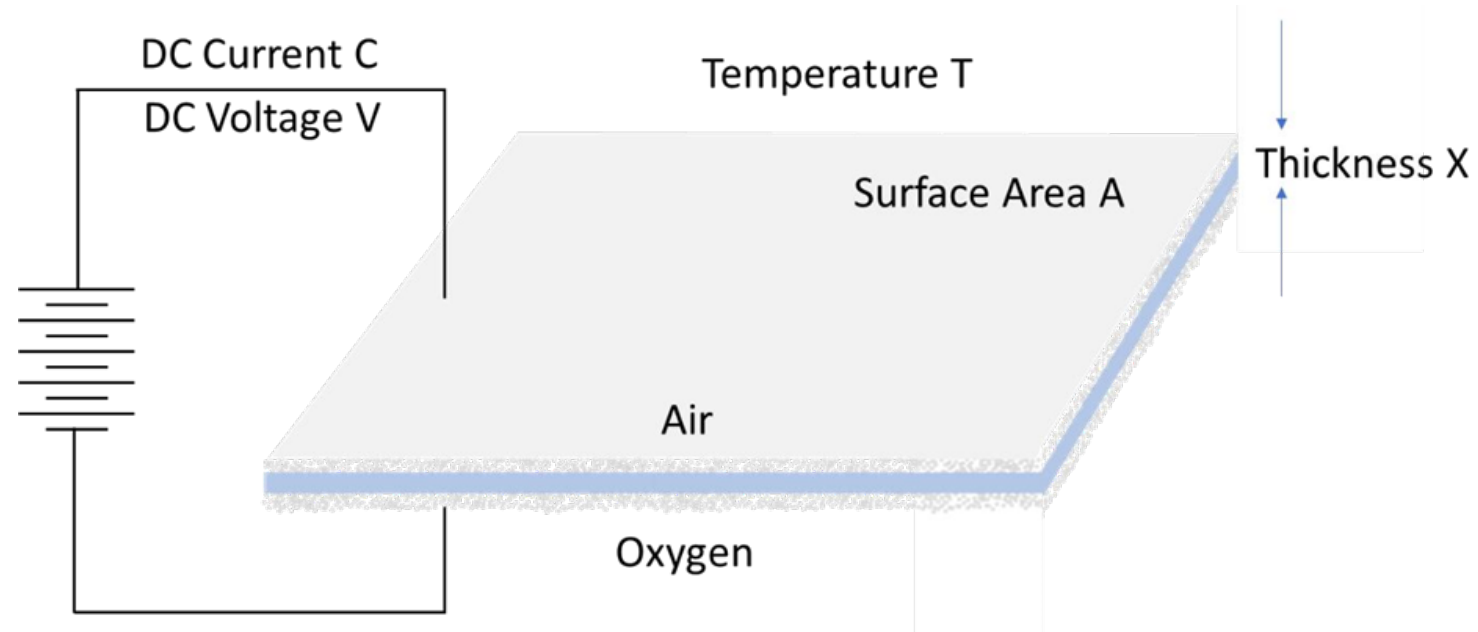


Power Supply & Control Assy
(Ambient Temperature)



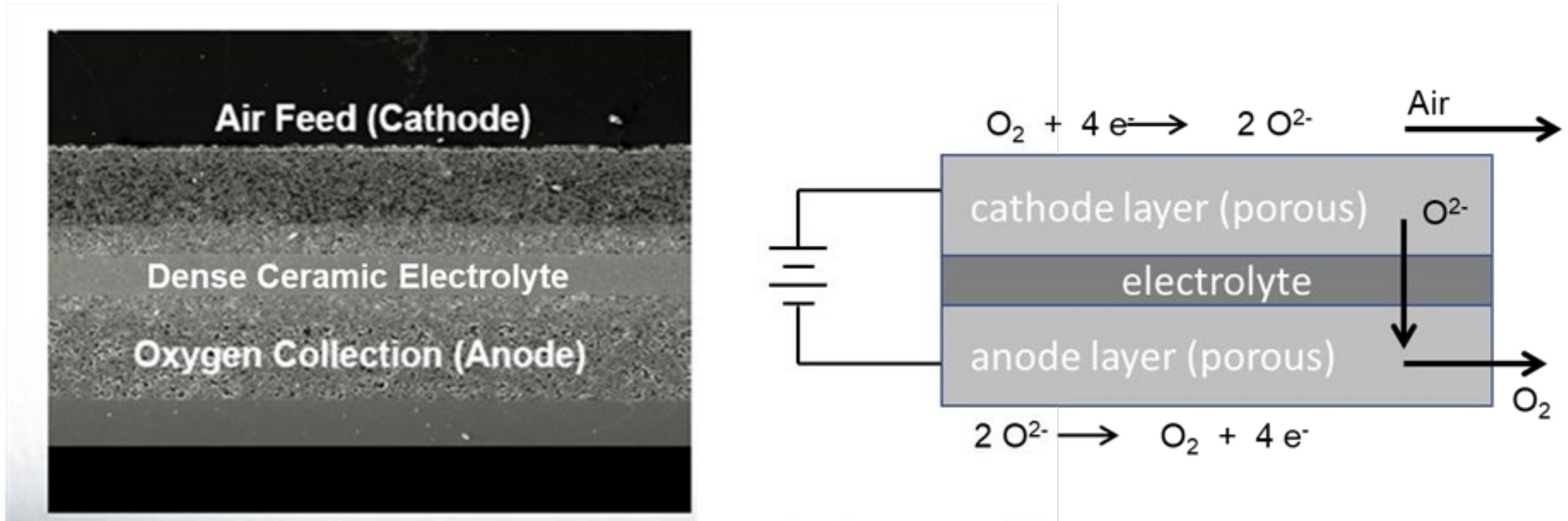
Oxygen Engine
(High Temperature)

Ion Transport Membranes

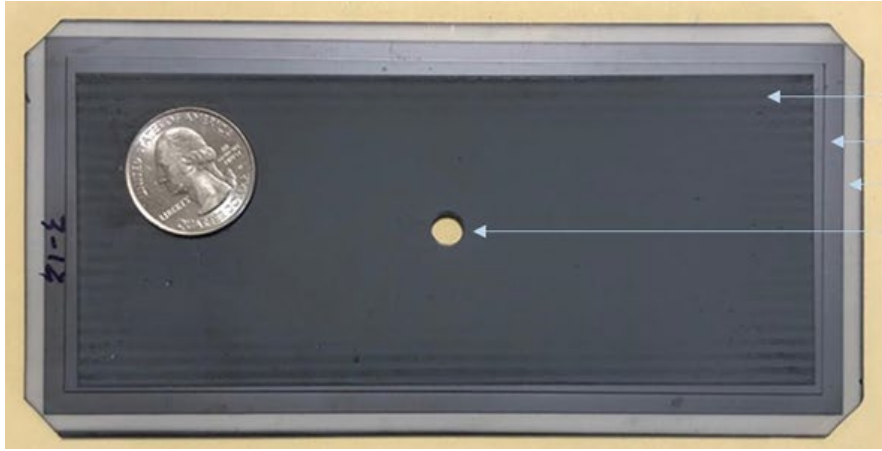


Cathode	Air	Porous	Carries electrons and O^- ions
Electrolyte	No Free Gas	Solid	Carries only O^- ions
Anode	Oxygen	Porous	Carries electrons and O^- ions

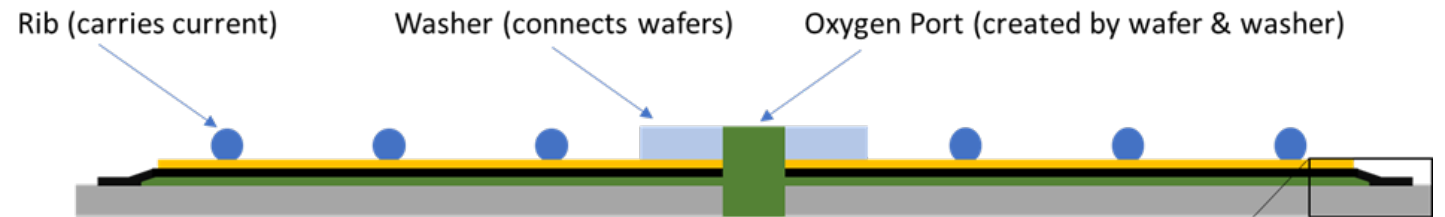
Ion Transport Membranes



M-COG Wafers



- Porous cathode layer
- Solid electrolyte layer
- "Strongback" structural support
- Oxygen delivery port

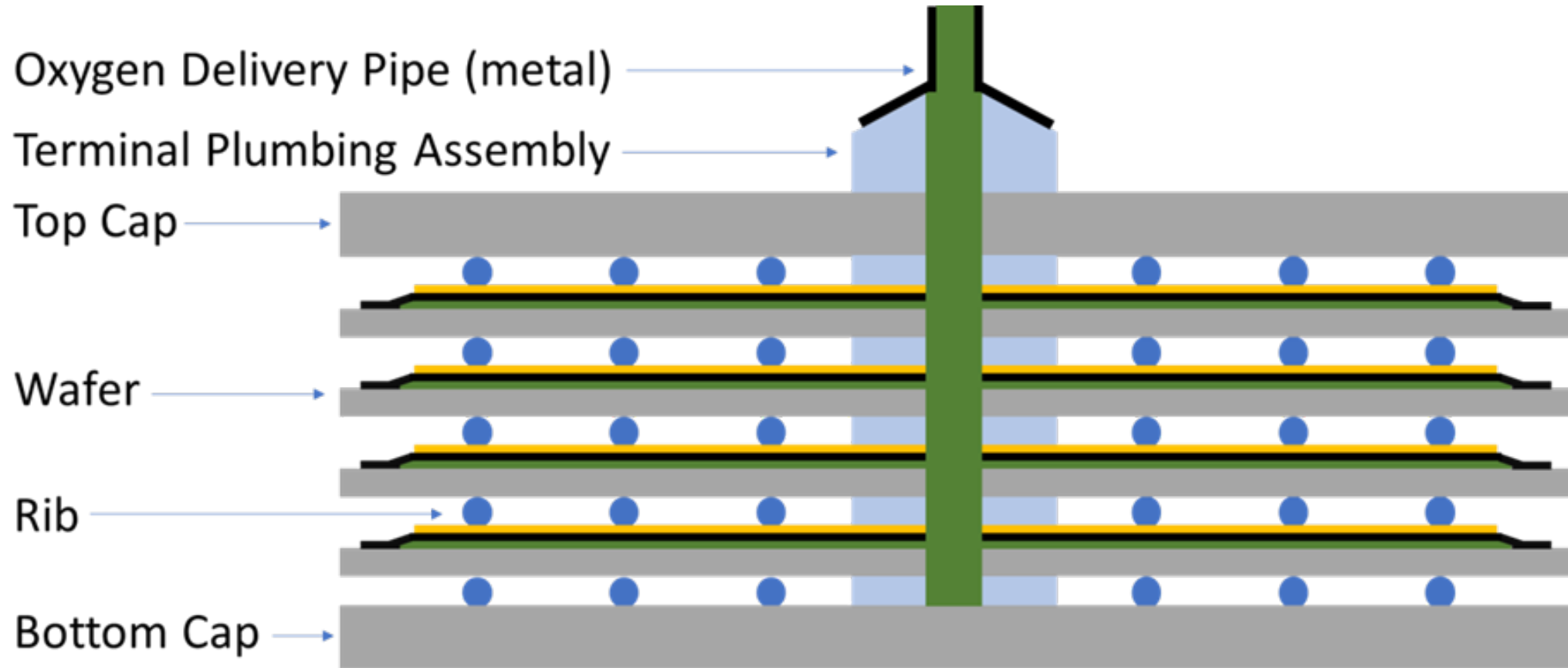


- cathode (porous, air between pores)
- electrolyte (dense & solid, no pores)
- anode (porous, O₂ between pores)
- "strongback" structural support (dense and solid – no pores)



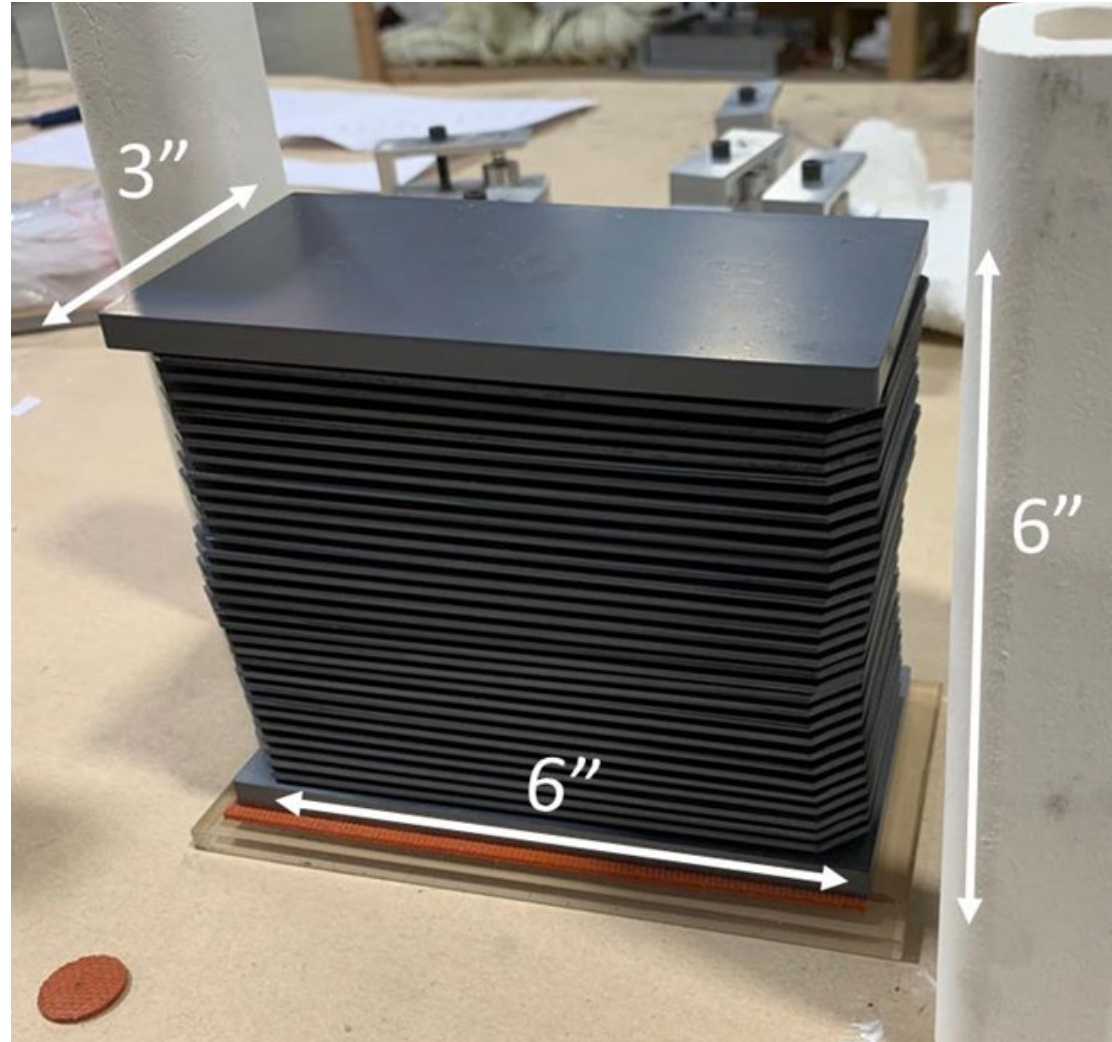
Wafer cross section – in detail

M-COG Cell Stacks (components)

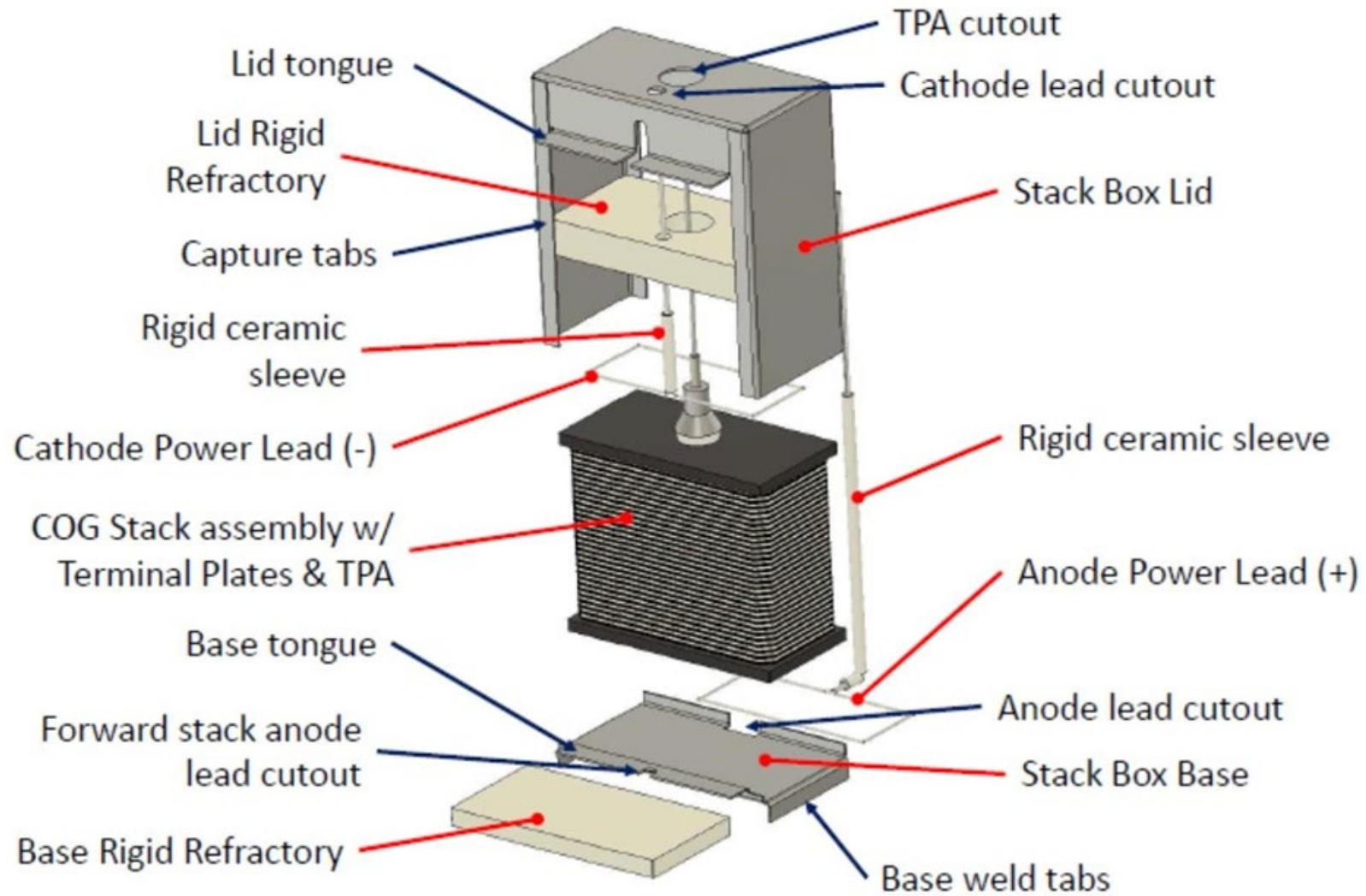


Photograph of M-COG Cell Stack

Dimensions:
7.5 X 15 X 15 cm



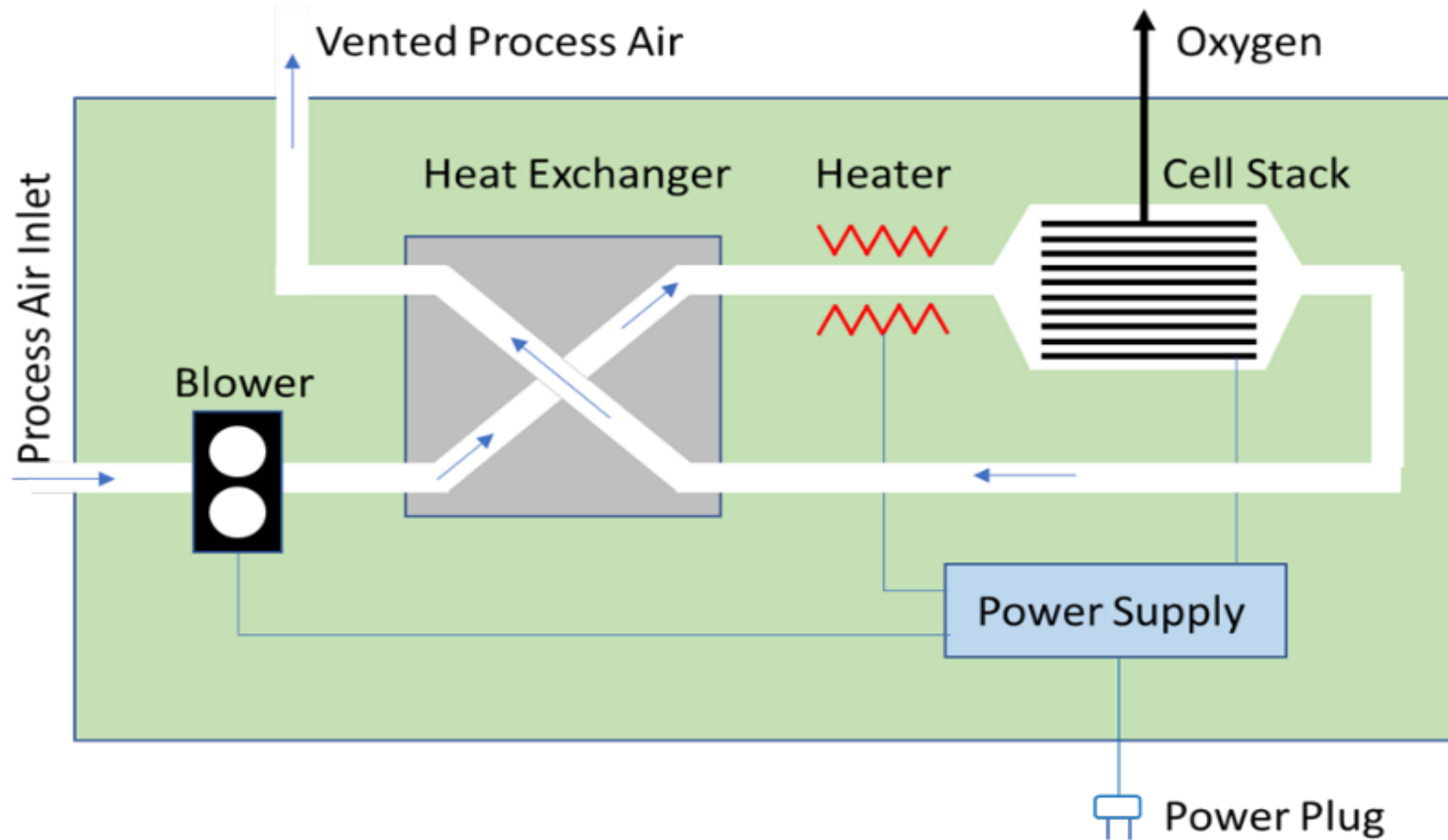
M-COG Boxed Cell Stack (exploded view)



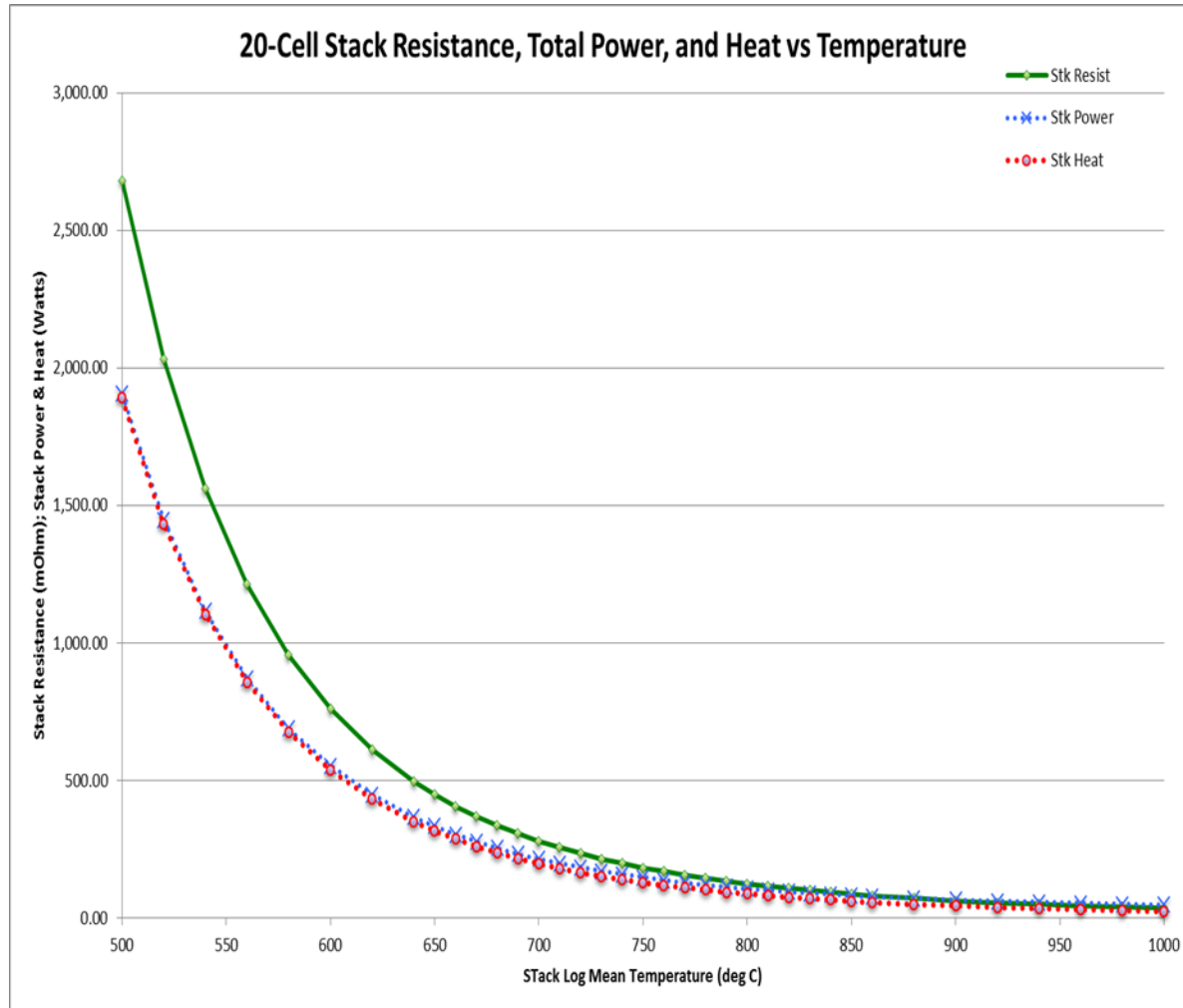
Photograph of M-COG Boxed Cell Stacks



M-COG Process Schematic



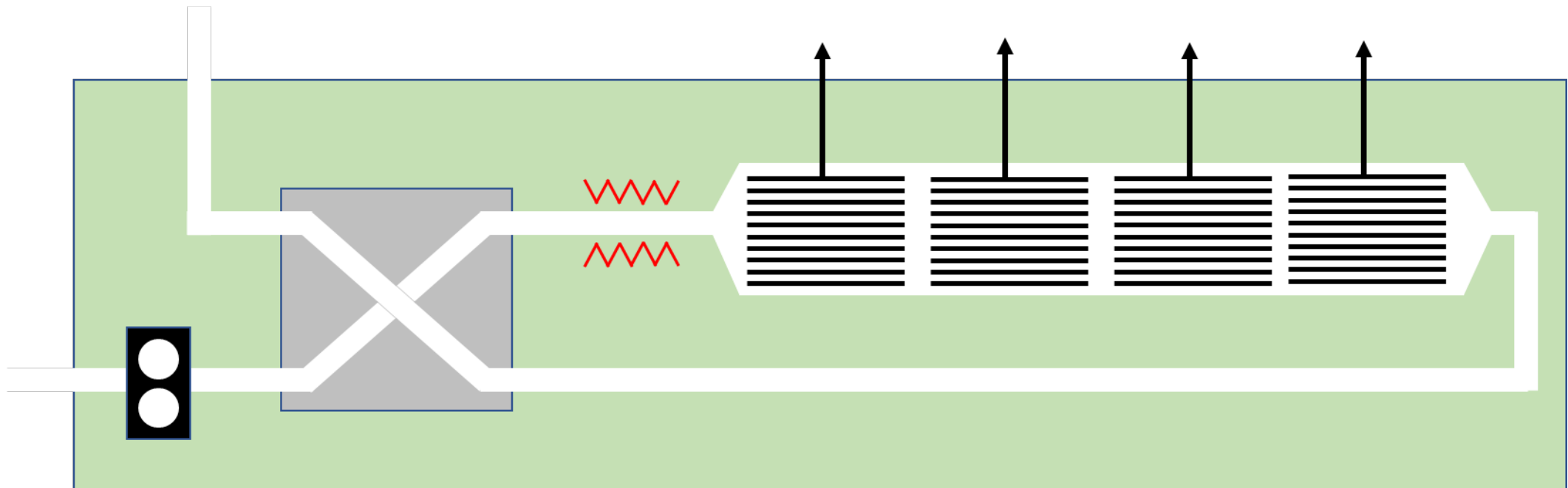
The COG power Dilemma (2012). Either too much cell stack power, or too much heater power.



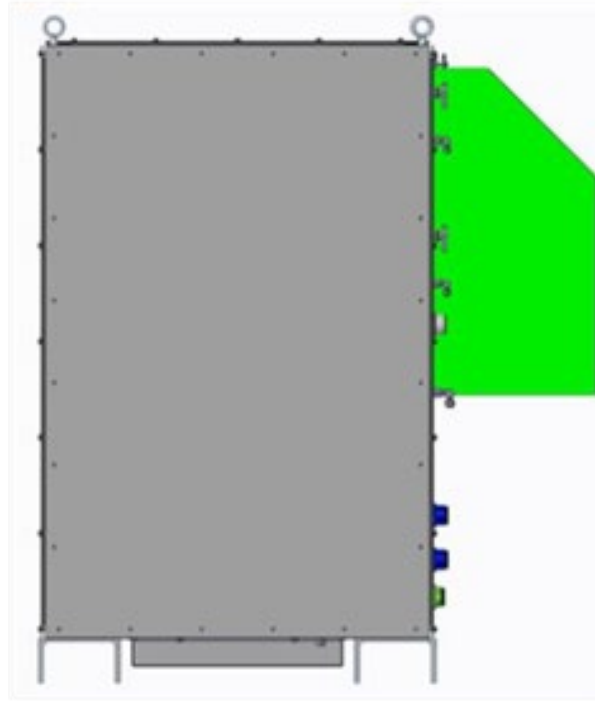
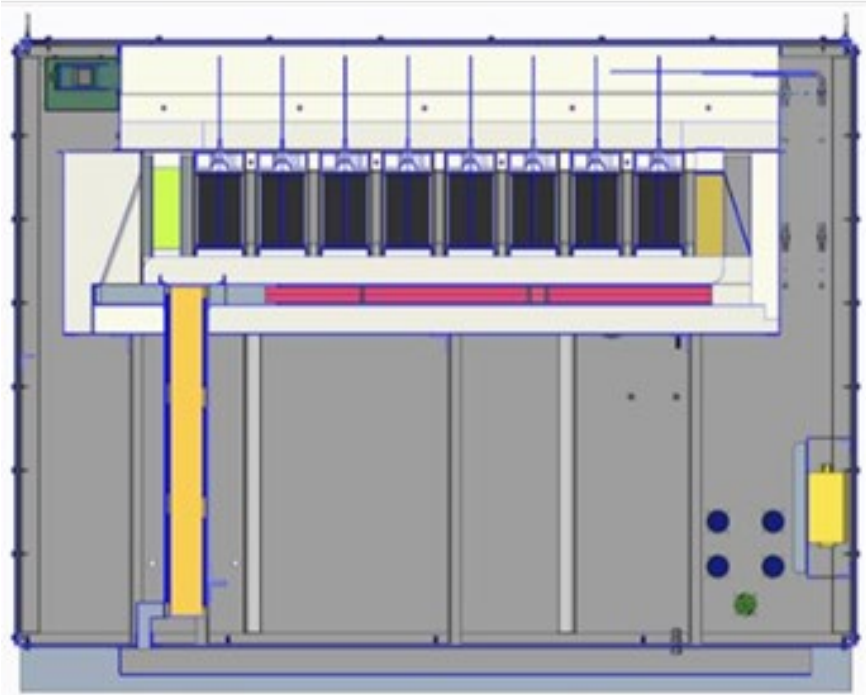
The COG power dilemma

- High stack temps are needed for efficient electrochemical oxygen pumping.
- Wafers need large amounts of sweep gas to remove heat and maintain temperature
- If system operates at high temps (>750C), sweep gas heating power use is exorbitant
- If the system operates at low temps (<650C) DC power use is exorbitant
- Operating a system between 700-750 C is the least worst way to operate, but energy costs will always be high.

M-COG Process Schematic (4 cell stacks in series)



M-COG System Prototype (referred to as Chassis 2)



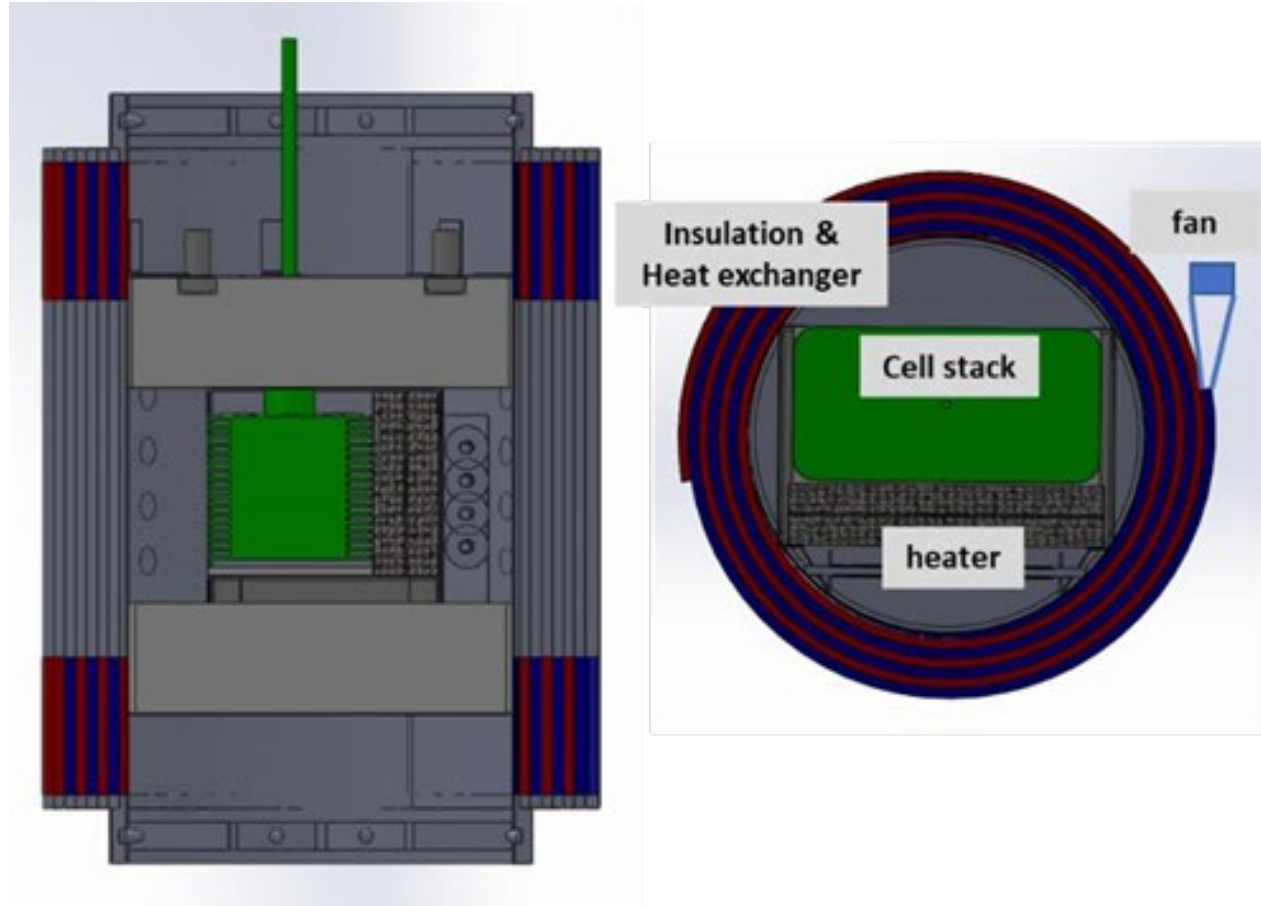
Purity: 99.995%

Production Rate: 4.5 lpm for one stack (total O₂ production 12.5 lpm)

Power Use: 400 Watts for 4.5 lpm (heaters were turned off, cell stack power only)

Pressure: 80 psig delivery pressure at WSTF (200 psig test pressure at AmOx)

M-COG System Prototype (referred to as Cross Flow Cylinder)

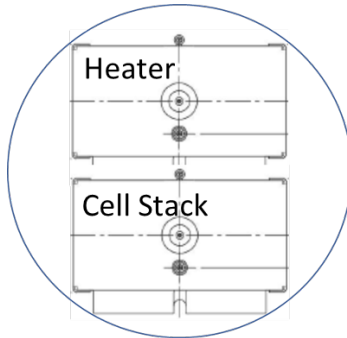


1 cell stack generator (0-4 lpm)

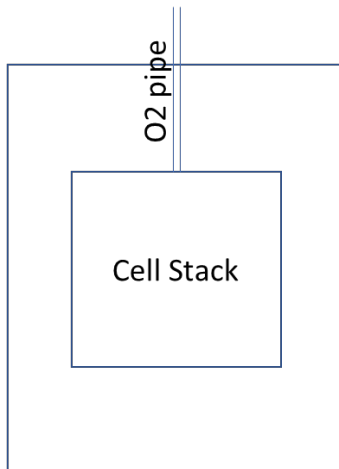
Designed
Built
Tested



Top view section



Side view section

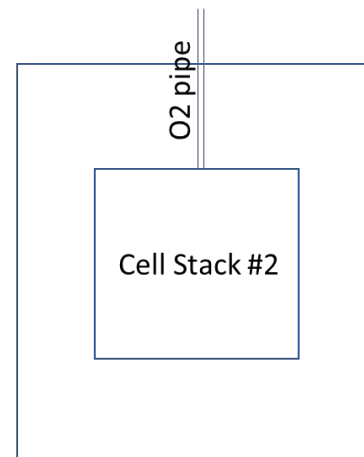
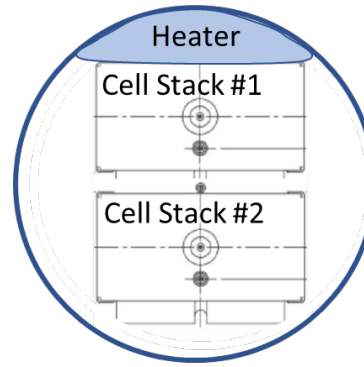


O₂ Engine Configurations

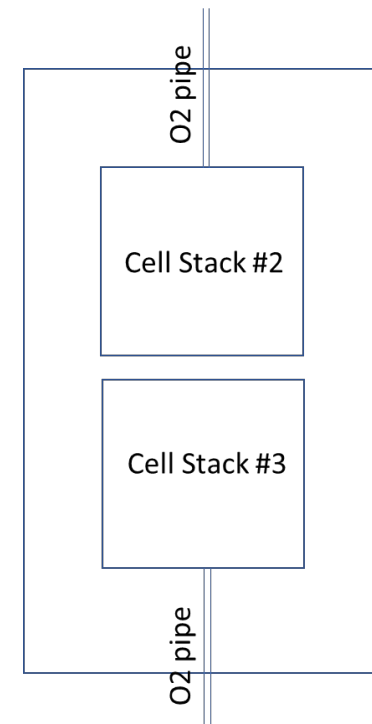
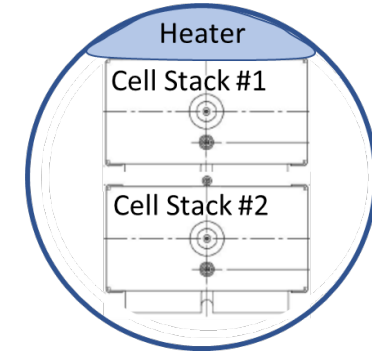
2 cell stack generator (0-8 lpm)

Designed
Not-Yet-Built

1 prototype
Due June 2024



4 cell stack generator (0-16 lpm) Most Energy Efficient Concept Only



2024 Oxygen Engine (1 cell stack with 30 wafers)



M-COG Oxygen Contains Trace Amounts of Water Vapor

- All available evidence suggests that water vapor is permeating through the seals of washers that separate wafers in the cell stack
 - Delivery pressure trends
 - Production rate trends
 - Process air humidity trends
 - Operating temperature trends
- Water Vapor levels are affected by production rates
 - At higher production rates, ppm H_2O is lower
 - At lower production rates, ppmv H_2O is higher
- The highest ppmv H_2O measured at 3 lpm production rate: 58 ppmv
- The highest ppmv H_2O measured at 1.4 lpm production rate: 81 ppmv

Trace Water Vapor in Compressed Gas: Summary Table

Application	Pressure (psig)	Gas	Max water (ppmv)	Line Pressure Dewpoint (C)	Notes / Comments
Med O ₂	3000	O ₂	67	+ 11.9	Ambient temps are common
Med O ₂	2000	O ₂	67	- 5.9	2000 psi is a common use case
SCBA	5500	Air	24	+ 5.7	5500 psi for 45 min rating
SCBA	3000	Air	24	- 2.4	3000 psi is a common use case
Aviator	3000	O ₂	6	- 18.0	Cold temps likely in aviation
M-COG (Low-P)	200	O ₂	250	- 6.0	Receiver tanks rated to 200 psig
M-COG (Hi-P)	3000	O ₂	6	- 18.0	Actual water vapor <1 ppm

Medical Oxygen Specifications

WHO International Pharmacopoeia Definition of Medical Oxygen

Oxygen: Not less than 99.5% v/v
Carbon Dioxide: Not more than 300 ppm v/v
Carbon Monoxide: Not more than 5 ppm v/v
Water Vapor: Not more than 67 ppm v/v

USP 29 Standards for Medical Oxygen

Oxygen: Not less than 99.0% v/v
Carbon Dioxide: Not more than 300 ppm v/v
Carbon Monoxide: Not more than 10 ppm v/v
Water Vapor: n/a (no specification for water vapor)

Note:

Oxygen that is produced by the air liquefaction process is exempt from the requirements of the tests for carbon dioxide and carbon monoxide

Recommended Specifications for M-COG Produced Medical Oxygen

Oxygen: Not less than 99.5% v/v
Carbon Dioxide: Not more than 300 ppm v/v
Carbon Monoxide: Not more than 5 ppm v/v
Water Vapor: Not more than 250 ppm for gases stored at pressures less than 15 Bar
Not more than 6 ppm for gases stored at pressures between 15 and 200 Bar

Summary

- M-COG performance is insensitive to temperature.
- M-COG performance is insensitive to elevation/atmospheric pressure.
- M-COG performance is not compromised by humidity.
- M-COG can use any air (provided it is safe to breathe) without filtration or preconditioning.
- M-COG can operate at small scale
- M-COG is easy to ship
- M-COG does not need a mechanical compressor.
- M-COG is energy efficient.
- Compared to PSA, M-COG requires less maintenance.
- M-COG oxygen is 99.9% pure
- A two-stage version of M-COG can deliver high-pressure oxygen (capable of cylinder recharge)
- In some operating environments, M-COG can be the most reliable and method of oxygen supply.