AFRL

Next Gen On-Board Oxygen Generating System (OBOGS)

2023 Oxygen Standardization Coordinating Group Meeting

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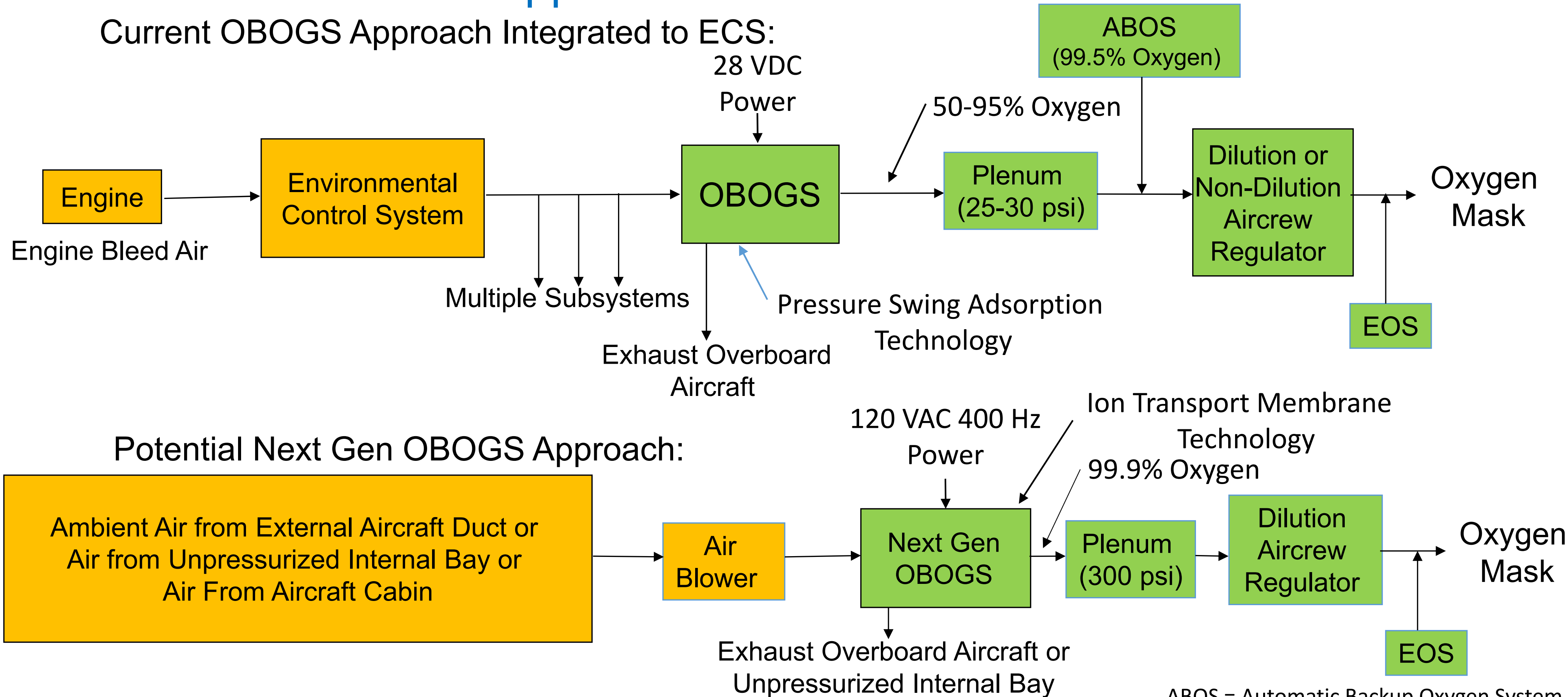
Overview: Next Gen OBOGS

- Background
- AFRL Solid Electrolyte Oxygen Separator (SEOS) Exploratory Development
- NASA and American Oxygen HHS Funded Effort
- New Strategy
- Project Status
- Conclusions

Background

- Current Pressure Swing Adsorption (PSA) based OBOGS are highly dependent on aircraft Environmental Control System (ECS) air supply pressures to maintain safe performance
  - Fighter OBOGS typically need 1 to 4 pounds air/minute at minimum pressure of 25-30 psig – aircraft ECS air supply availability has been become problematic due to increasing number of aircraft subsystems requiring an air supply
  - ECS air supply low pressure transients can cause OBOGS performance issues, such as, degraded oxygen and restricted breathing flow – OBOGS is unable to maintain performance when inlet air supply pressures drop too low, even for short periods (a few seconds)
- Next Generation OBOGS would use ion transport membranes to produce pure oxygen from electric power
  - System not dependent on ECS air pressure but it needs air flow
  - System produces continuous 99.9+% oxygen – only oxygen passes through solid ceramic membrane
  - Solid state approach could be very reliable but it will require more electrical power than current OBOGS
  - Current OBOGS require ~100 Watts of electrical power -- ECS air supply (pneumatic power) primarily used to drive PSA process

Next Gen OBOGS Approach



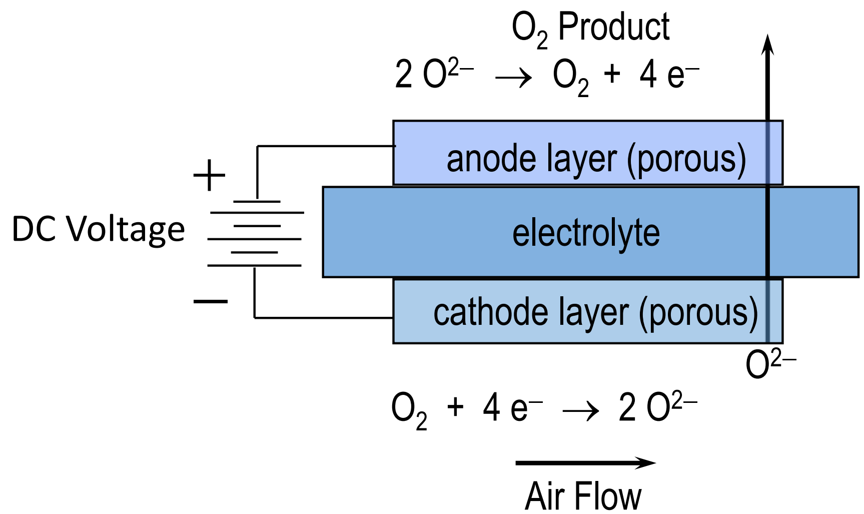
ABOS = Automatic Backup Oxygen System
EOS = Emergency Oxygen System

Solid Electrolyte Oxygen Separator (SEOS) Exploratory Development

- AFRL Solid Electrolyte Oxygen Separator (SEOS) Technology program developed ion transport membrane technology (ended 2011)
  - Prime contractor was Air Products and Chemicals, Allentown PA and subcontractor was Ceramatec Inc., Salt Lake City UT
  - Technology produced 99.9+% oxygen using “planar,” i.e. flat plate, electrochemical cells
  - Oxygen flow rates increased from 0.1 liters/min (LPM) to 33 LPM
  - Oxygen delivery pressure increased from slightly above ambient pressure to 50 psig
  - SEOS oxygen confirmed Aviators’ Breathing Oxygen (ABO, 99.5% oxygen) compliant
  - Early prototype 6 liter/minute (LPM) SEOS cylinder fill device operated and demonstrated at OC-ALC, Tinker AFB OK for 10 months
    - Produced ABO compliant oxygen for maintenance facility
    - Device located in unconditioned utilities room
    - 2200 psi bottle fill pressure achieved using integrated oxygen compressor
  - 3 liters/min SEOS flight breadboard passed explosive atmosphere, EMI, and altitude testing per MIL-STD-810F
  - 33 liters/minute SEOS breadboard device built and successfully tested – Next Gen OBOGS target likely 60 liters/minute

Solid Electrolyte Oxygen Separator (SEOS) Exploratory Development

- SEOS "planar" electrochemical stack uses heated (~750ºC) ion conducting membrane, electric power, and ambient air to produce 99.9+% oxygen



SEOS approach

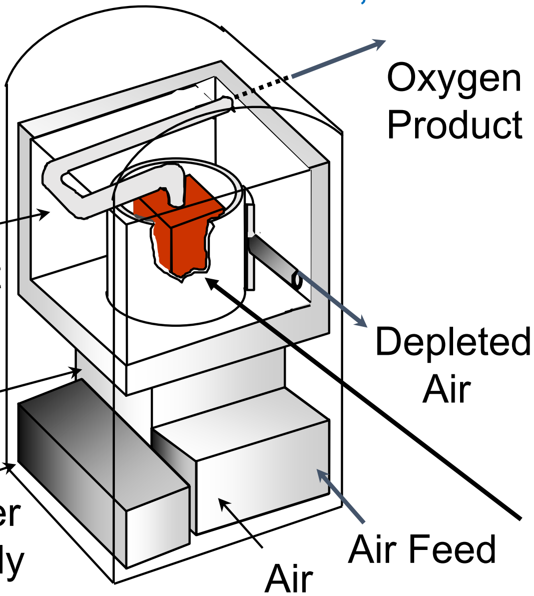
Electrochemical Stack

- Oxygen ions are produced from oxygen molecules in the air flow and then DC voltage pumps ions to anode layer where pure oxygen forms – only oxygen ions can move across solid electrolyte membrane

Solid Electrolyte Oxygen Separator (SEOS) Exploratory Development

Air + Electric Power → Pressurized, Pure Oxygen

Solid Electrolyte Oxygen Separator
5 Liters/Minute (LPM) Breadboard



Electrochemical Stack
(4” x 4” x 4”)

Solid Electrolyte Oxygen Separator (SEOS) Exploratory Development

- 33 liters/minute (LPM) SEOS breadboard device (2010)
  - "Planar" electrochemical stacks in "parallel" configuration to inlet air flow
  - Measured oxygen purity: 99.99%
  - Total electric power (electric heaters, stack power, etc.): 3200 Watts; 97 Watts/LPM
  - Stack operating temperature: 750ºC
  - Delivery pressure: 20 psig
  - Weight: 660 pounds
  - Size: 2.1 ft x 2.75 ft x 3.75 ft (21.7 cubic ft)
  - Power source: 120 VAC converted to DC voltage to power stacks

NASA and American Oxygen HHS Funded Effort

- 34 liters/minute (LPM) medical breadboard device (2022)
  - “Planar” electrochemical stacks in “series” configuration to inlet air flow – approach conserves energy for heating stacks
  - Oxygen purity measured: 99.9%
  - Total electric power (electric heaters, stack power, etc.): 2400 Watts; 71 Watts/LPM
  - Stack operating temperature: 700-825ºC
  - Delivery pressure: 100 psig
  - Power source: 120 VAC converted to DC voltage to power stacks

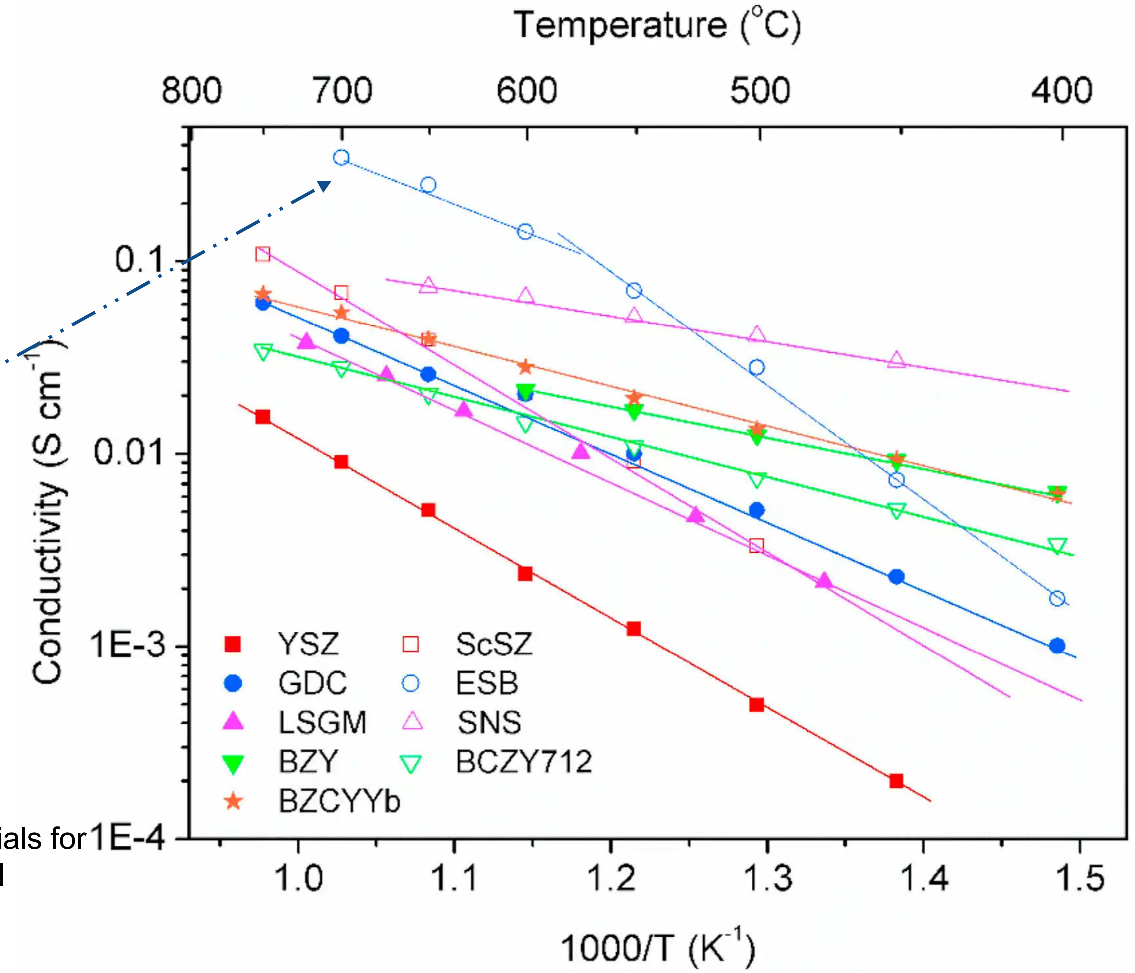
New Strategy

- Based on results to date, technology needs new approach to achieve "technical breakthrough" and viable product
- Need order of magnitude increase in oxygen production per cell (~0.1 LPM/cell to ~1 LPM/cell) to achieve viable system
- Advanced materials may offer "breakthrough" – continued use of legacy materials (zirconia and ceria) likely not to produce viable product
- Advanced materials potentially could:
  - Increase electron and oxygen ion conduction
  - Lower power required
  - Lower operating temperature
  - Reduce start-up time
  - Reduce size and weight
- "Tubular" cell geometry could reliably increase operating pressures
- Miniaturization of "balance of device" components, such as, thermal management system, heat exchangers, heaters, power supplies, controls, etc. needed

New Strategy

Potential advanced materials:

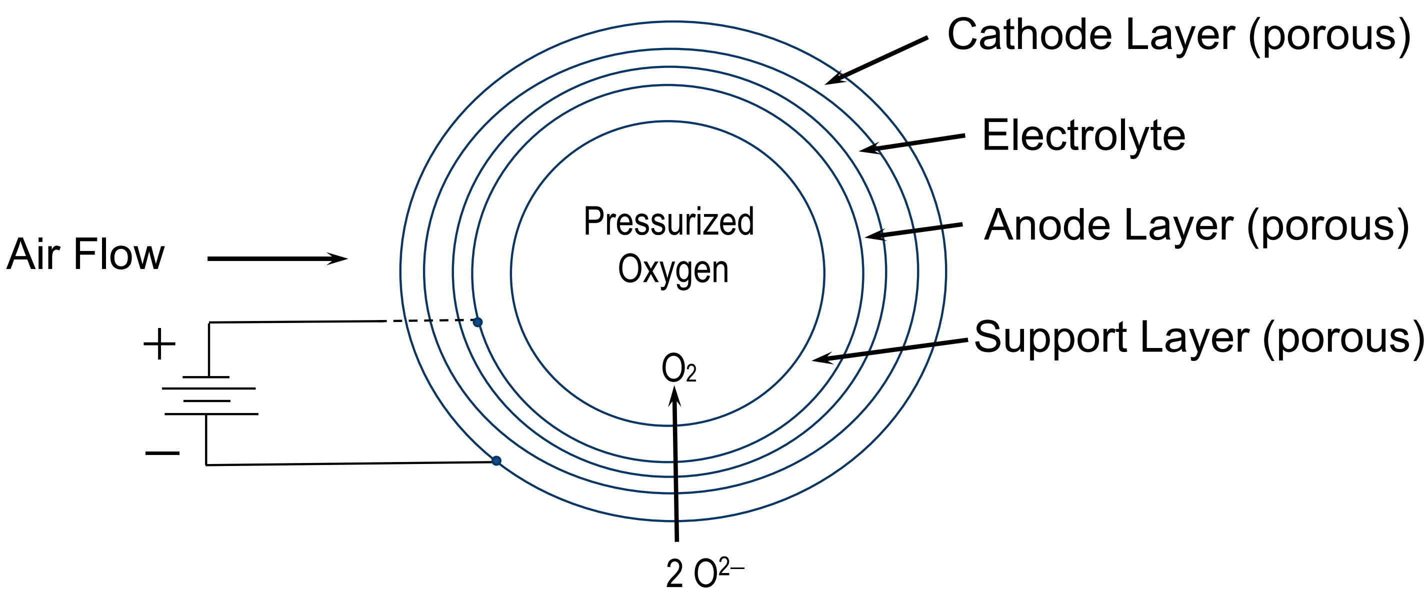
Ionic conductivity vs. reciprocal temperatures for selected electrolyte materials, including
8 mol% Y_2O_3–ZrO_2 (YSZ)*,
8 mol% **scandia** stabilized ZrO_2 (ScSZ),
$Gd_{0.1}Ce_{0.9}O_{1.95}$ (GDC)*,
$Er_{0.4}Bi_{0.6}O_3$ (ESB),
$La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_{3-\delta}$ (LSGM),
$Sr_{0.55}Na_{0.45}SiO_{2.755}$ (SNS),
$BaZr_{0.8}Y_{0.2}O_{3-\delta}$ (BZY),
$Ba\,Ce_{0.7}Zr_{0.1}Y_{0.2}O_{3-\delta}$ (BCZY712), and
$BaZr_{0.1}Ce_{0.7}Y_{0.1}Yb_{0.1}O_{3-\delta}$ (BZCYYb).**



* Legacy material.
** Shi, H., Su, C., Ran, R., Cao, J., and Shao, Z. “Electrolyte materials for intermediate temperature solid oxide fuel cells.” Progress in Natural Science: Materials International, 2020, 30, 764-77.

New Strategy

- "Planar" design can be problematic at increased pressure – "planar" geometry has greater mechanical stresses
- "Tubular" geometry may be more reliable approach (cross section below not to scale)



Project Status:

TODAY

		FY23	FY24	FY25	FY26
Next Gen OBOGS Advanced Cell and Breadboard (Approved Funding $1.55M)		PoP (33 Months) 1 2 3 4 5			
	SBIR ($K)	300	1250	0	0

1 Contracts Awarded
2 SBIR Phase I Final Report
3 Advanced Ceramic Cell Demo
4 Next Gen OBOGS Breadboard Demo
5 SBIR Phase II Final Report

SBIR = Small Business Innovative Research

◇ Milestone

- SBIR Phase I Effort (~9 months):
  - Investigate characteristics of new materials for increased oxygen production per cell
  - Identify materials with best performance
- SBIR Phase II Effort (~24 months):
  - Advanced electrochemical cells will be fabricated and evaluated
  - Multi-cell breadboard device will be built and evaluated
- 16 proposals and expecting 2 awards

Next Gen OBOGS Parameter	Current Value	Estimated Target
Cell Oxygen Production	~0.1 SLPM/Cell*	1 SLPM/Cell
Weight	20 lbs/SLPM*	1 lb/SLPM
Size	0.66 cubic feet/SLPM*	0.033 cubic feet/SLPM (Goal for Fighter OBOGS: 12 in x 12 in x 24 in)
Total System Power	71 W/SLPM**	40 W/SLPM
Heat-up Time	2 hrs*	0.2 hrs
Flow	34 SLPM**	60 SLPM
Pressure	100 psi**	300 psi
Oxygen Purity	99.99%*	99.9%

- SEOS Breadboard

** NASA/AmOx breadboard

Green = Target Achieved

lbs = pounds
SLPM = standard liters/minute
W = watts
psi = pounds/square inch

Conclusions

- Aircraft ECS air supply systems have periods of low air supply pressure transients which can significantly degrade OBOGS performance – new oxygen generation technology needed to decouple OBOGS from aircraft ECS
- Ion transport membrane technology appears promising – solid state approach and not dependent on ECS air pressures
- Progress on ion transport membrane technology development has had limited success -- new strategy needed to achieve viable Next Gen OBOGS
- “Pivot” to advanced materials may lead to “technical breakthrough”
- Future targets:
  - Estimated size and weight for fighter Next Gen OBOGS: 12” x 12” x 24” and 60 lbs.
  - “Tubular” electrochemical cell geometry could reliably increase operating pressures – 300 psig should be possible
  - With technology improvements projected total power for 60 LPM system estimated at 2400 Watts

Questions?