The Next Generation Oxygen Delivery Systems

Low-Power-Compact Portable Medical Oxygen Technology for Forward and Prolonged Care near the Battlefield

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Introduction

In Business since 1987 (Golden, CO)

- Privately held
- 125 employees, 34 Ph.D.'s in chemistry and engineering
- About **$32 million** in annual revenue

Facilities

- Combined 78,000 ft2 laboratory and office space near Denver, Colorado
- Manufacturing / Scale-up
- Fully equipped Chemistry and Engineering Labs
- Sorbents:
  Sulfur removal from natural gas; post-combustion CO2 capture; heavy-metals removal
- Materials processing and testing
- Process development

Desiccant wheel at the Space Station

Carbon Capture Technologies

Ambient Temperature CO/VOC Oxidation Catalyst

Air Separation Sorbent for Medical Systems

Business Model

- Identify opportunities with industry
- Perform R&D
- Secure intellectual property

Commercialization

- Commercialize technology *via* spin-off licensing, joint ventures, and internal business units
- **$117 million** in product value sold based on our SBIR work
- **$281 million** in Phase III investments (driving future sales)

Military Readiness

Focus Areas for Designing Products for the Military-Arena

- Test and evaluate to meet military standards depending on application (MIL-STD-810H, JECETS, etc.)
- Perform in the field simulated scenarios throughout the design phase to capture a variety of DoD user requirements
- Extreme condition testing such as high altitude, high temp-humidity, and sub-zero artic environments

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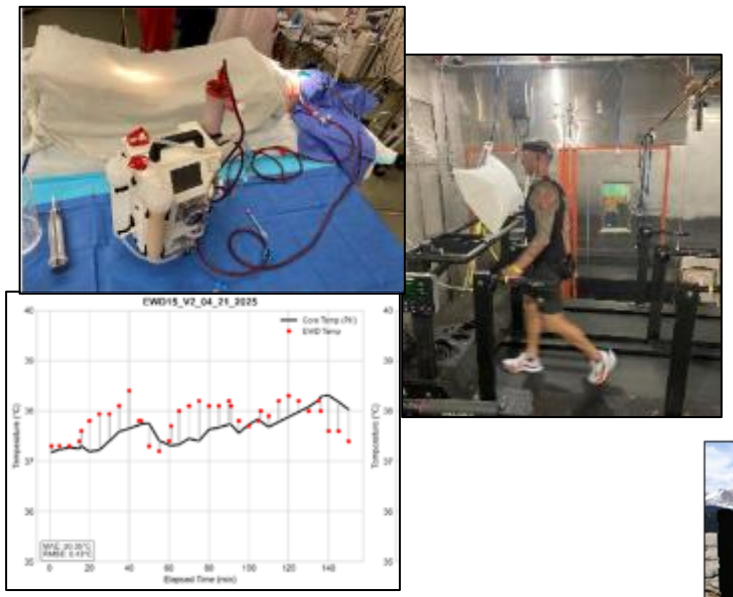


Clinical Studies

MIL-STD Evaluations

Military Cross Platforms

Oxygen near the Battlefield

Military Gap of O_2 Technology

Future combat outcomes may rely heavily on forward and prolonged care capabilities. Medical devices such as oxygen delivery systems must be compact and robust to the austere military arena. Current portable oxygen generation solutions suffer from shelf-life degradation and provide low flow.

FRSS and STP

- Military experience demonstrated that overall surgical capability closer to the point of incident has assumed greater importance than mobility.
- To overcome forward care efforts groups such as the Forward Resuscitative surgical system (FRSS) teams and shock trauma platoon (STP) were established.
- At Role 1 and 2 support is typically provided with medical equipment that does not require resupply such as portable oxygen concentrators.

- **To Bulky for Forward Care**
- **Heavy (644lbs) and No Battery**
- **Power Hungry (1.8kW)**

- **Storage Degradation**
- **Low Oxygen Flow**
- **Low Battery Time**

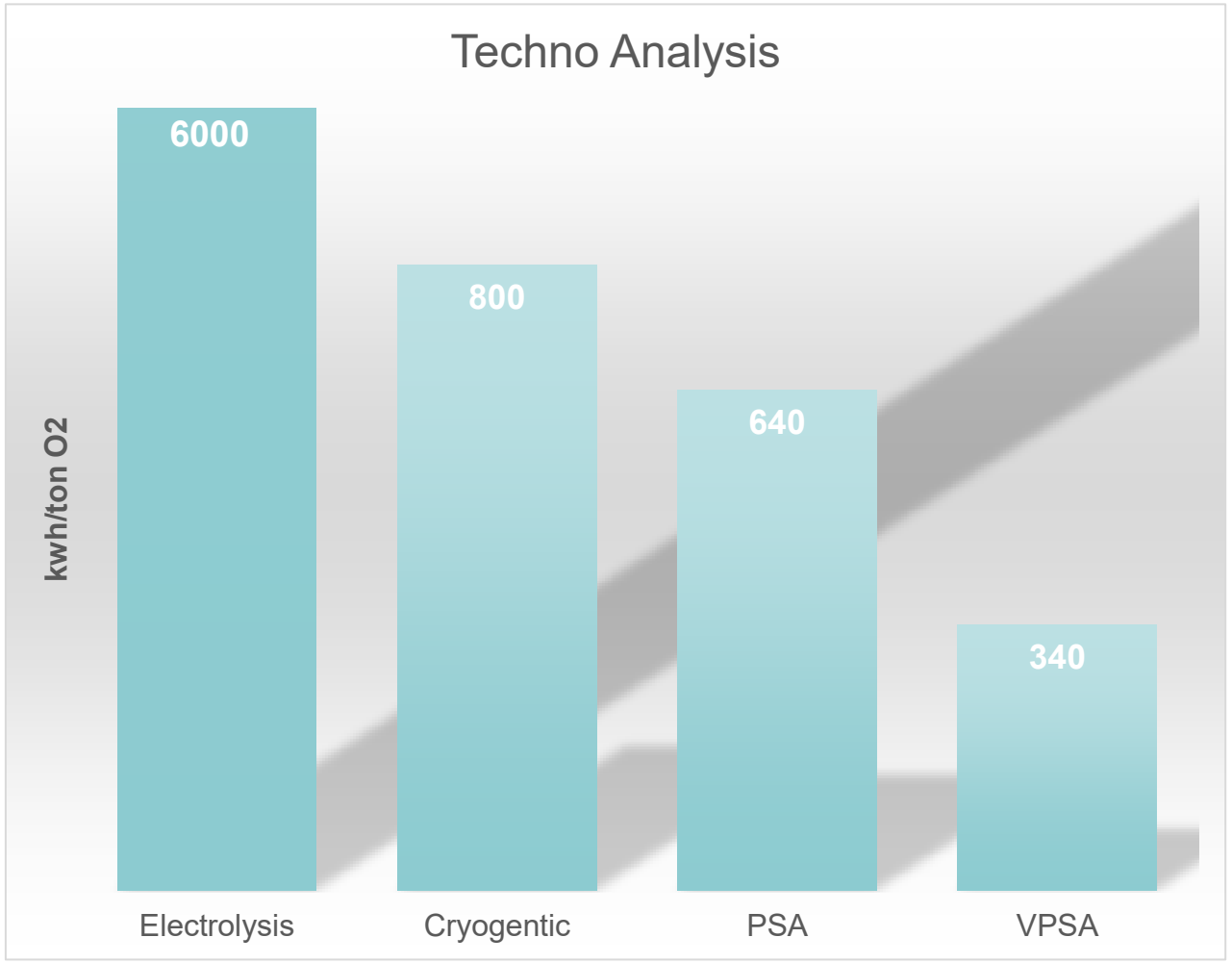
Oxygen Production Methods and Efficiencies

Methods

- Electrolysis – Separates oxygen from water
- Cryogenic Distillation – Separates oxygen from air with subzero condensing temperatures -183°C
- Membrane – Permeates oxygen by pore size specific filter using driving compression
- PSA/VPSA – Separates oxygen from the air by highly selective sorbents under compression/vacuum

Efficiencies

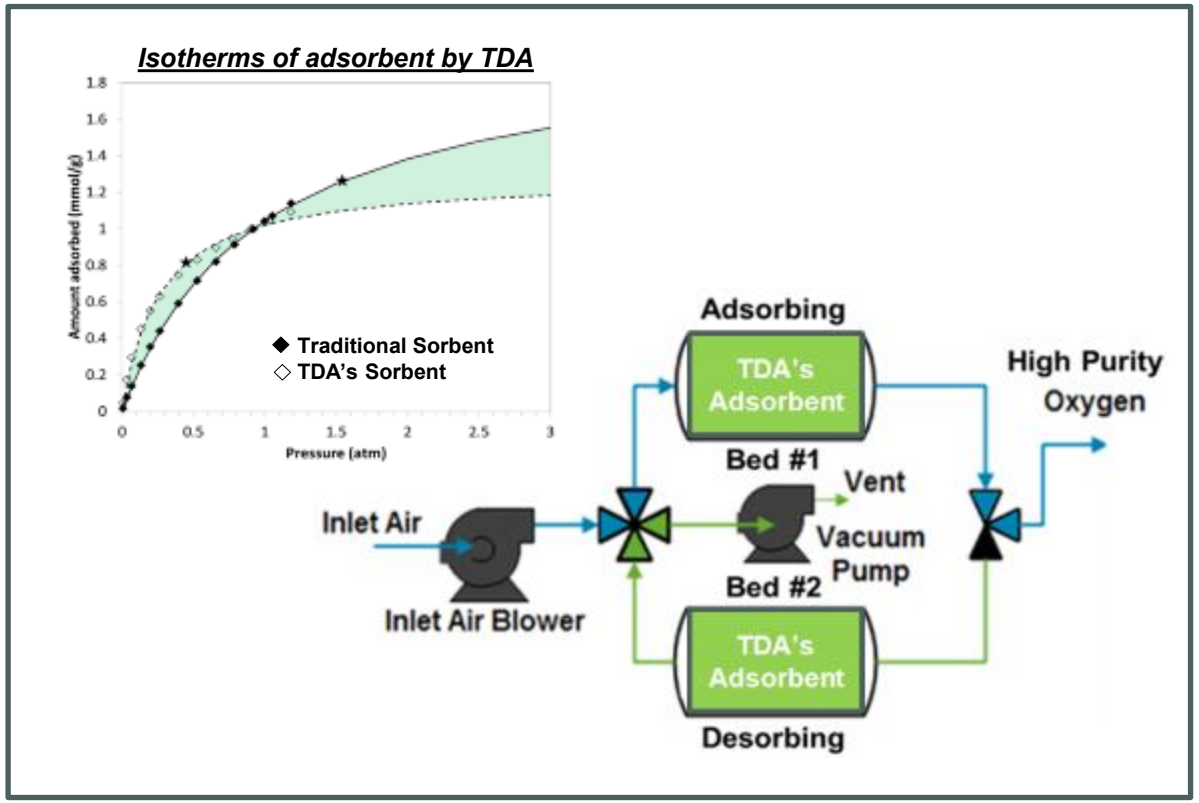
- Electrolysis – requires water supply and high energy
- Cryogenic – medium energy cost but relatively large systems due to refrigeration control
- Membrane – low energy but can not generate high purity due to selectivity and permeation limitation or requires high thermal energy.
- PSA – medium to low cost and robust
- VPSA – most cost effective due to low compression ratios and high-sorption-capacity advantage.

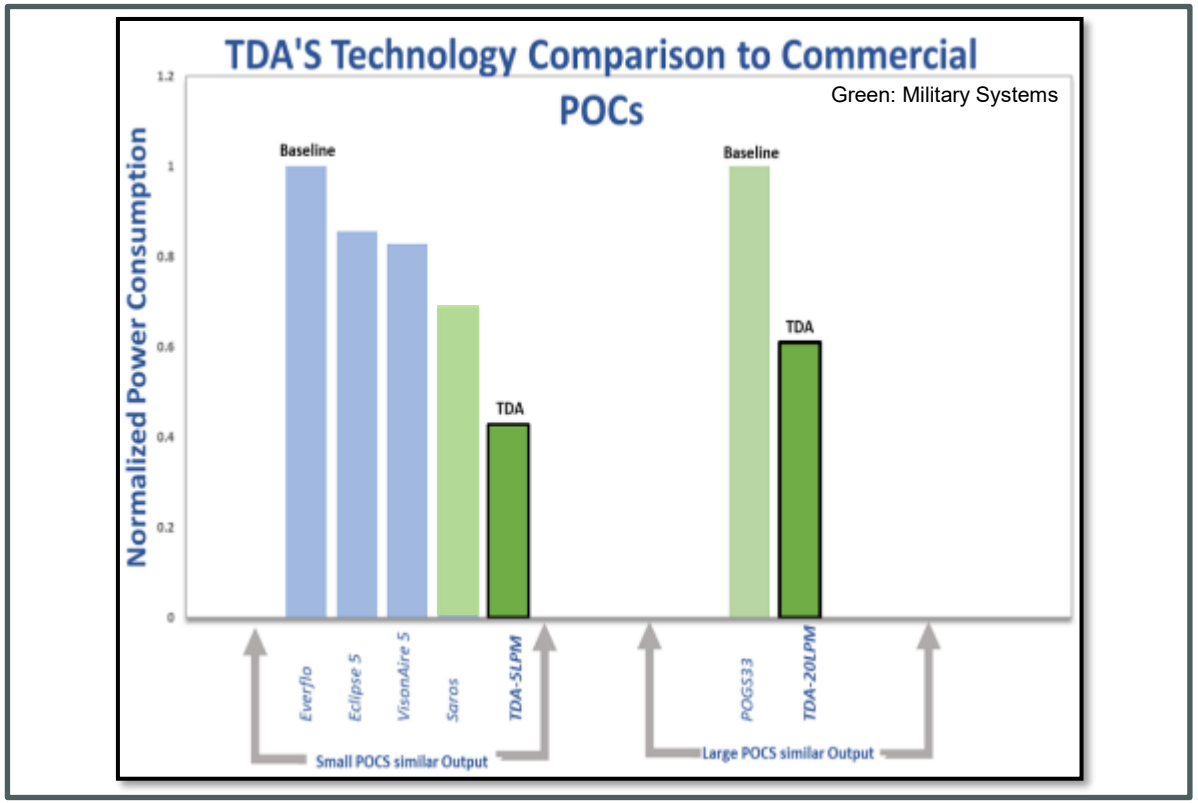


Our Medical Oxygen Technology

TDA's Low Powered Portable Oxygen Technology

1. Traditional systems use a zeolite that adsorbs N_2 at high pressures delivering O_2 at high purity (87-96% vol.).
2. N_2 is released at a lower pressure (sorbent regenerates) via Pressure Swing Adsorption.
3. TDA's zeolite has high N_2 capacity at lower pressures, reducing the power need for compression.
4. We use a vacuum pressure swing adsorption process (VPSA) to reduce the weight and power consumption.
5. Our system are also designed for storage resilience by rejecting water during operation, extending the shelf life of the product.





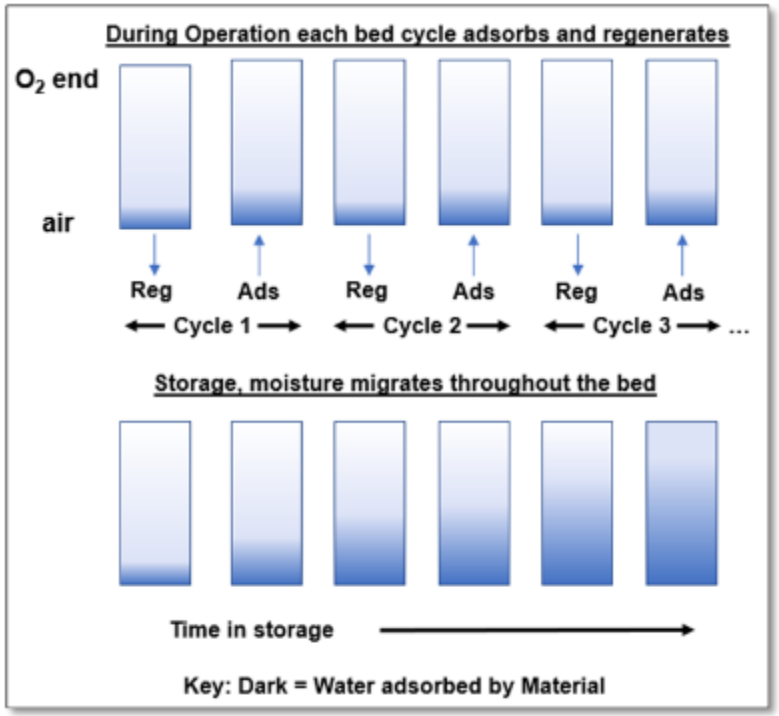
Extending the Shelf Life and Low Maintenance

Storage Shelf Life

- **The SAROS is a widely used military POC which uses a sieve bed module called the ATF.**
- **The ATF module (SAROS units) show degradation in oxygen purity after extended periods of storage (non-use)**

Maintenance Challenge

- **OEM providers which use the ATF module, may require routine maintenance schedule requiring the military to operate the device periodically to maintain performance.**



TDA's Development Focus

Developed a moisture resilience systems both in operation and storage

System must be easily serviced

- Self sealing beds
- Robust sub modules

In-The-Field Replaceable Sieve Bed

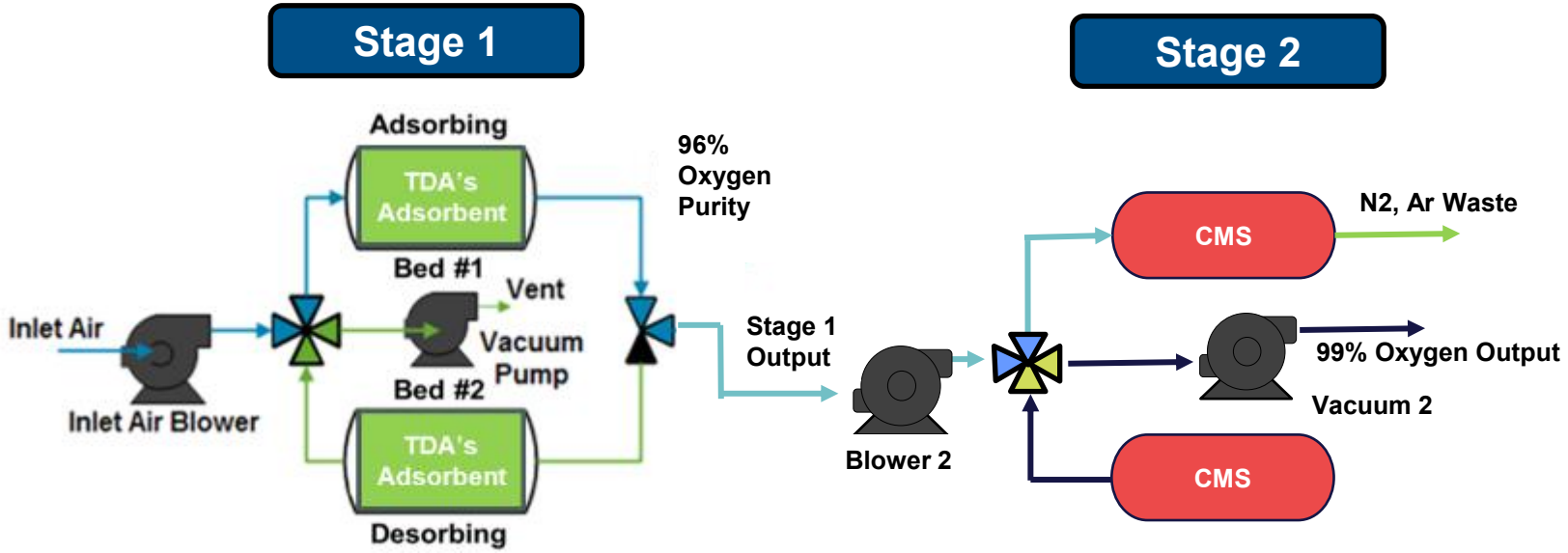
Multi-Stage High Purity Oxygen 99%

Stage 1

- VPSA 96% Oxygen Concentrator
- Utilizes TDA's modified zeolite
- Low power
- Adsorbs more Argon than traditional zeolite

Stage 2

- 96%+ Oxygen, 4% Ar/N2 blend
- Carbon Molecular Sieve is highly selective to Oxygen
- Argon and Nitrogen do not adsorb under the right operating conditions
- 99% Oxygen is then collected during the regeneration stage



Advantages

- High Purity Oxygen at or above 99% possible from air
- Can be optimized for high altitude and sea level
- less energy intensive than Cryogenic Distillation

Multi-Stage VPSA replacement of NPTLOX

NPTLOX-20

- A storage and oxygen delivery system used by USAF
- Doesn't generate oxygen once storage is depleted
- Weights 125lbs and delivers up to 55 psig
- 19hrs of usage at 15LPM before resupply is required
- Only utilizes liquid oxygen and requires humidification

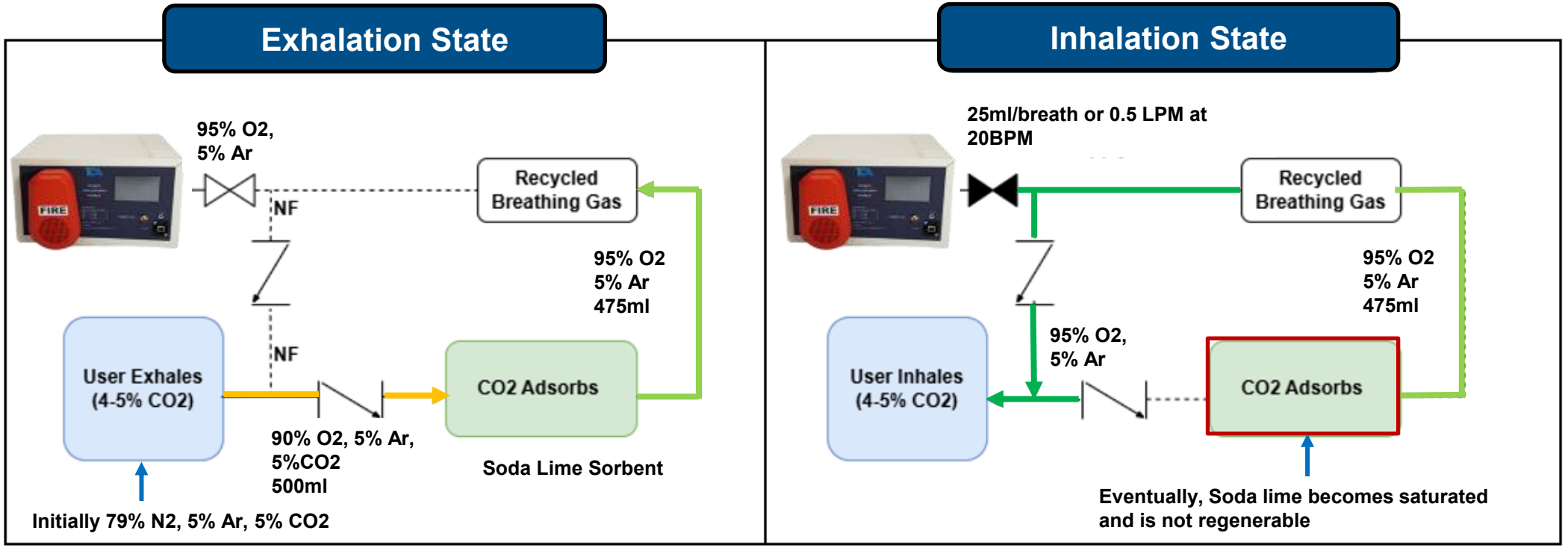
Future Designs Considerations

- High pressure might not be needed
- Most Military/Commercial Ventilators have low pressure oxygen capabilities.
- Some Military/Commercial Anesthesia devices don't require high pressure oxygen

TDA's Deployable Oxygen Generator System

- Multistage 99% O2 Generator
- Scaled down to improve size, weight, and power
- Designed for high altitude applications
- Oxygen anywhere, anytime
- Can be sized for smaller applications 15-20LPM 99% O2 with higher delivery pressure if needed.

Next Generation Closed Loop Rebreathing of Oxygen



Recirculating the expired breathing loop can reduce the volumetric flow rate for oxygen supply significantly

Soda lime is a reliable way to adsorb CO2 from the expired breath

These are non-regenerable solutions, therefore after a few hours the Soda lime needs to be replaced.

Regenerable CO2 for rebreathing circuits

Regenerable CO2 Sorbent

- TDA's CO2 capture sorbent
- High sorption capacity for low pressures of CO2
- Powered, Laminate, or 3D printing for specific applications
- Low energy for regeneration using thermal and/or vacuum

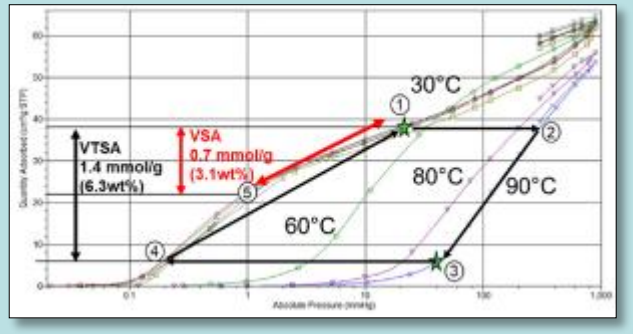
Applications

- Closed loop oxygen circulation via vacuum
- Extended rebreathing circuits for divers
- Demonstrated 3.5% CO2 removal on simulated diver lung.

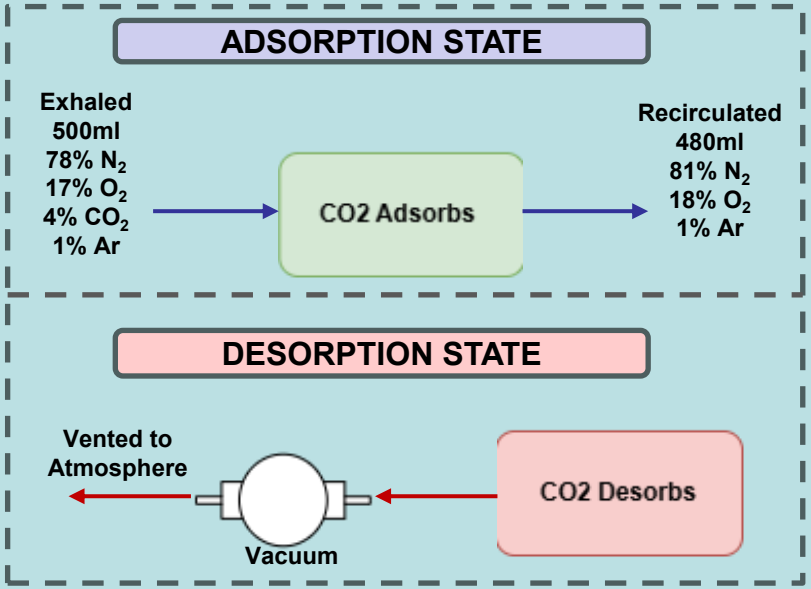
1. Formulation Types

Pelleted Laminates Filaments

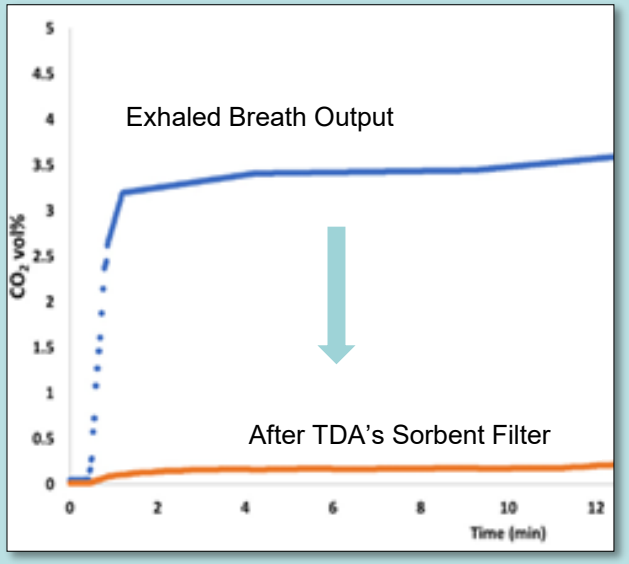
2. CO_2 Working Capacity Range



3. Regeneratable operation diagram

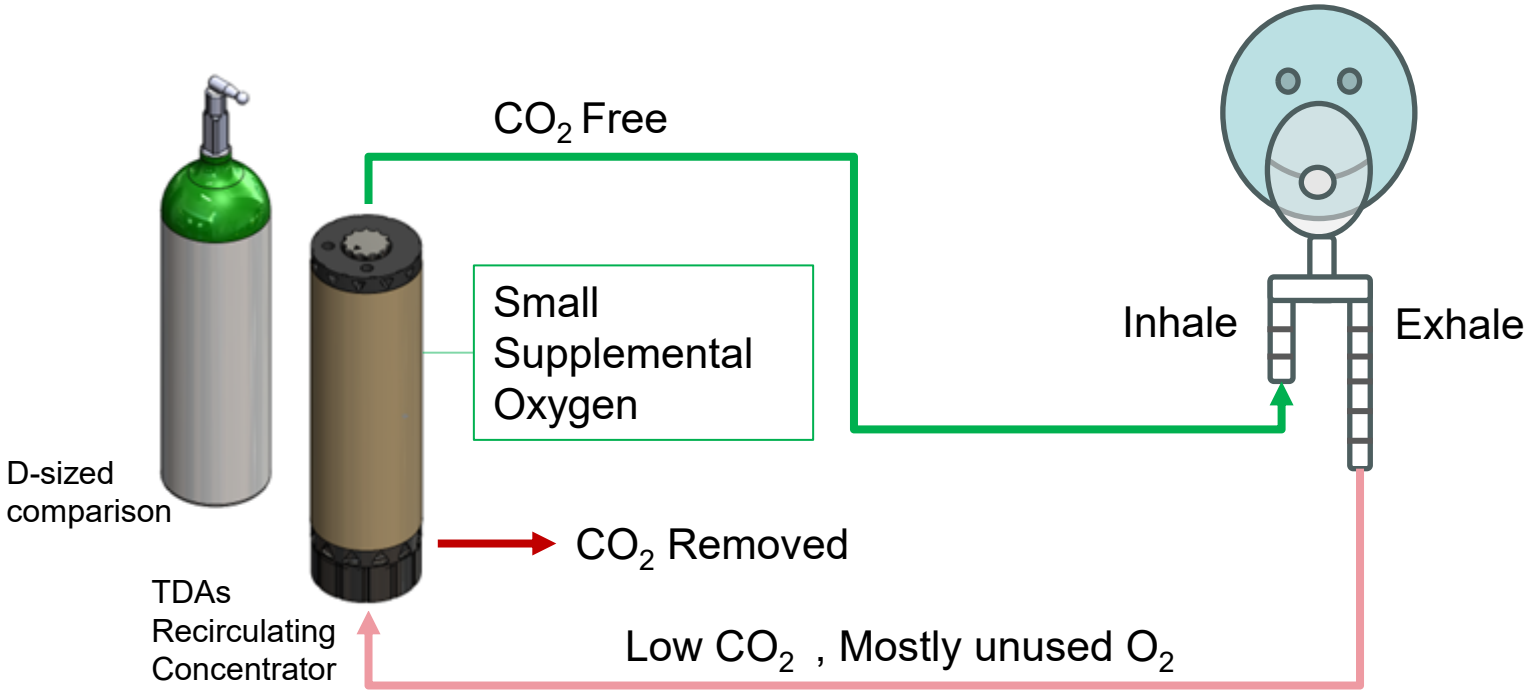


3. Closed loop lung Simulation



Next Generation Closed Circuit Rebreathing of Oxygen

TDA's closed circuit oxygen recirculation device patient flow diagram



Estimated Utility Matrix

Component	Value	Units
Total Weight w/o Battery	9	(lbs.)
Total w Battery	10	(lbs.)
Size	247	in^3
Power	60	W
Closed Circuit Flow	15-20	LPM
[1]Open circuit Flow	2	LPM
Single Stage Max Purity	96	%
[2] Second Stage Max Purity	99	%

1. When a patient is not recirculating the oxygen, open circuit mode supplies oxygen directly from the concentrator. This can be designed for a higher oxygen flow rate, virtually the recirculation technology can be coupled with any sized concentrator for higher through put.
2. To achieve higher purities above 96% a second stage system can be applied. The weights provided in the table above are for a single stage system

TDA's Portable Oxygen Generators

TDA Hi-FOX

- Militarized 10-LPM, 25lbs Portable Oxygen Concentrator

TDA FOX

- Militarized 4-LPM Portable Oxygen Concentrator
- 125W

TDA Expeditionary Medical Oxygen Generator

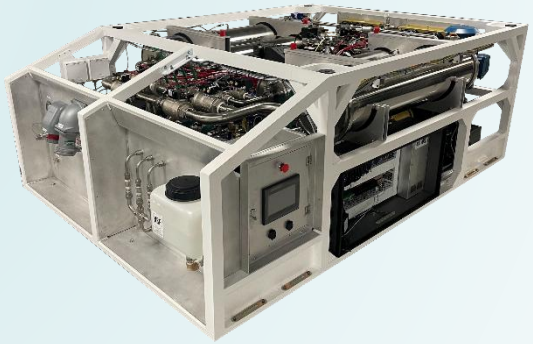
- Militarized 20-LPM Portable Oxygen Generator with Bottle Fill Capabilities
- 250lbs, 800-1000kW

TDA OxyGEN

- NASA ECLSS sustainment and cabin air oxygen reduction
- 125W

TDA OxyPack

- Developing under NIH
- The worlds first 4 LPM portable oxygen concentrator
- Combating COPD and LAMs



TDA Deployable O2 Generator System – 175 SLPM

- Large 98%+ Oxygen Generator for in-the-field high purity oxygen to support sustainment and torching efforts