



PNWS-AWWA
Water 2024
Spokane, WA • May 1-3

Comparison of Oxygen Sources for Ozone Generation

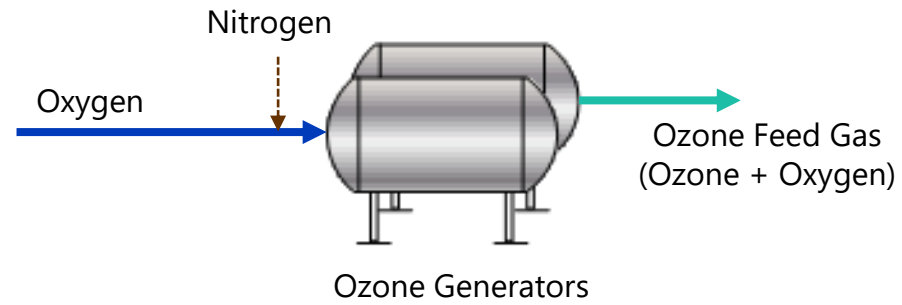
Ali Leeds

PNWS-AWWA

May 2, 2024 4 pm



Oxygen for Ozone Generation



Oxygen Sources

Typical Unit for sizing =
tons/day

1 tpd = 16.7 scfm of oxygen

Air

- Used historically for ozone generation.
- Modern reactors are much more efficient and require higher purity oxygen.

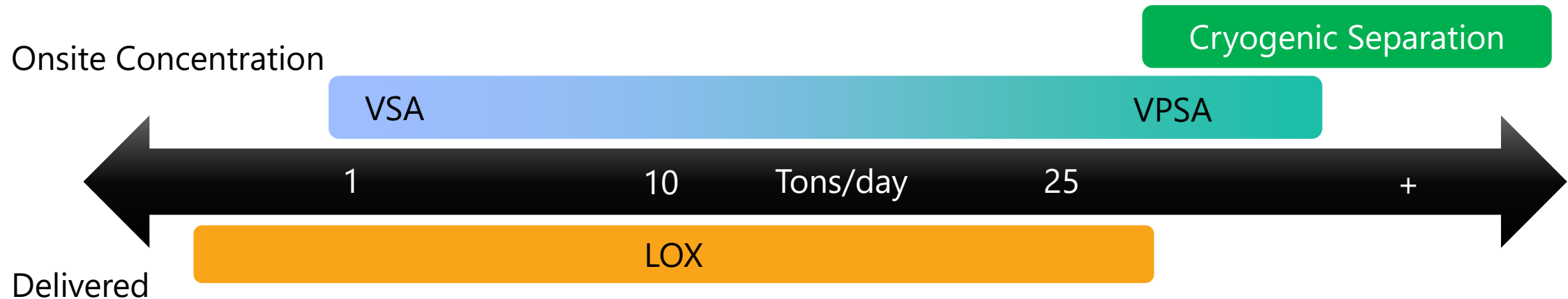
Pressure Swing Adsorption (PSA)

- Widely used in the 1970's and 1980's at smaller wastewater treatment plants
- Refined for efficiency into vacuum/pressure swing adsorption (VPSA)

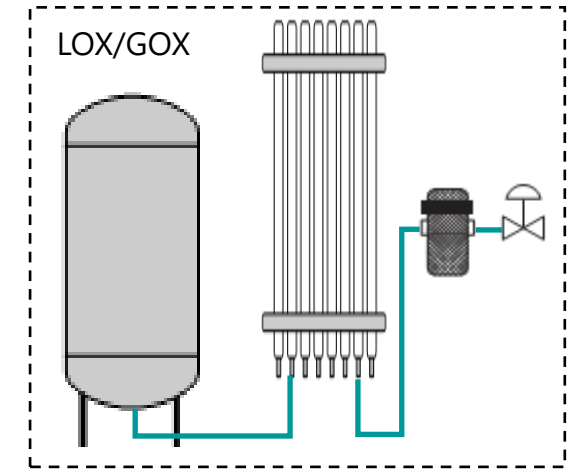
LOX = Liquid Oxygen

VPSA = Vacuum/Pressure Swing Adsorption

VSA = Vacuum Swing Adsorption



Liquid Oxygen (LOX)



- LOX stored in a tank is passed through a vaporizer to convert to a gas (99% pure)
- System typically includes a particle filter and pressure regulator
- Include a nitrogen stream for ozone generation

Cryogenic Separation

VSA

VPSPA

1

10

Tons/day

25

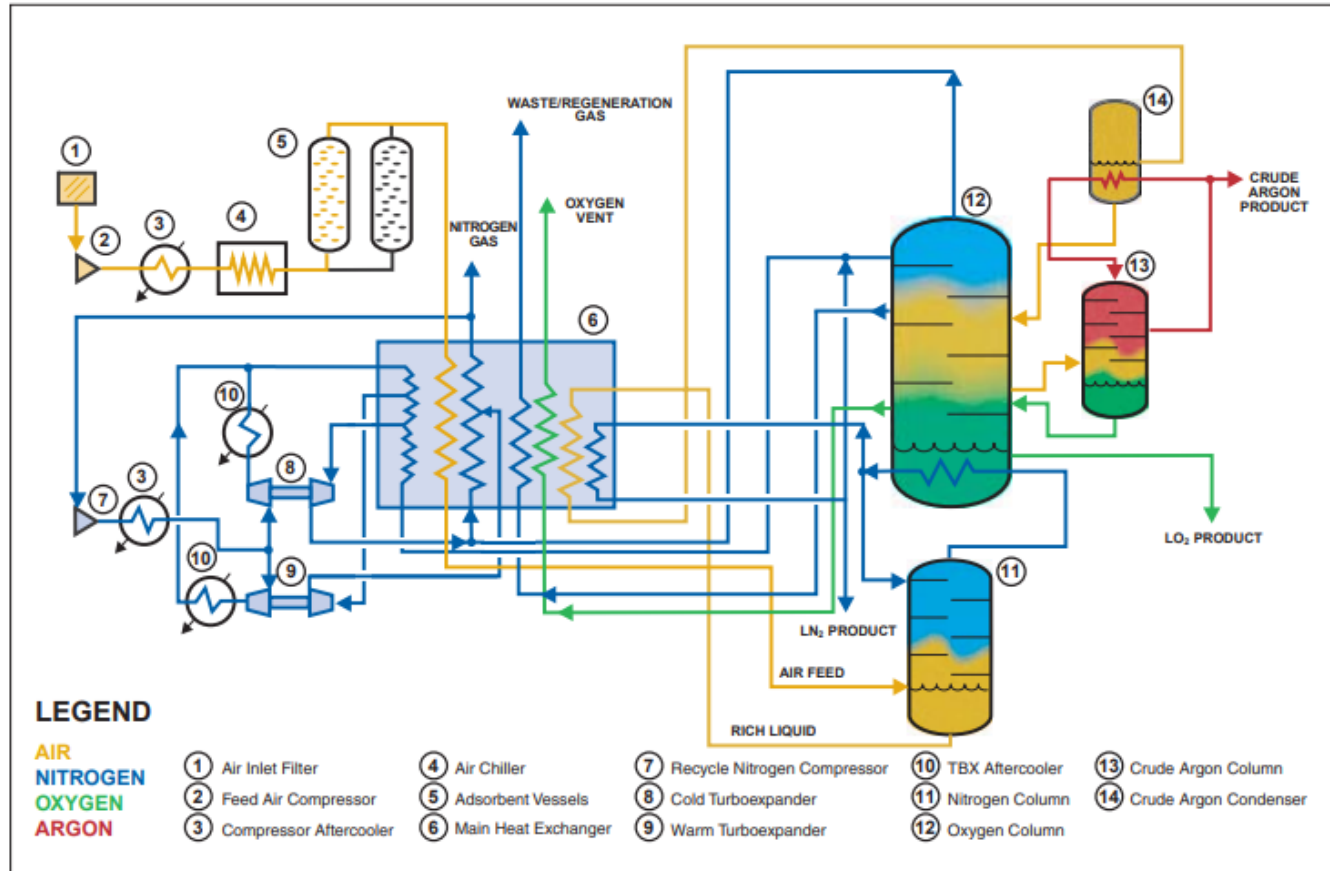
+

LO

/ 4

LOX

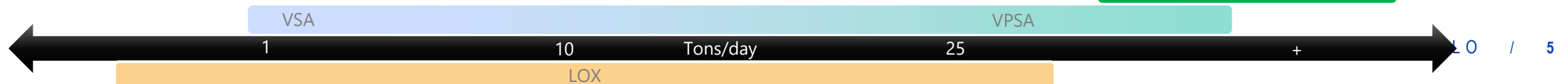
Cryogenic Separation



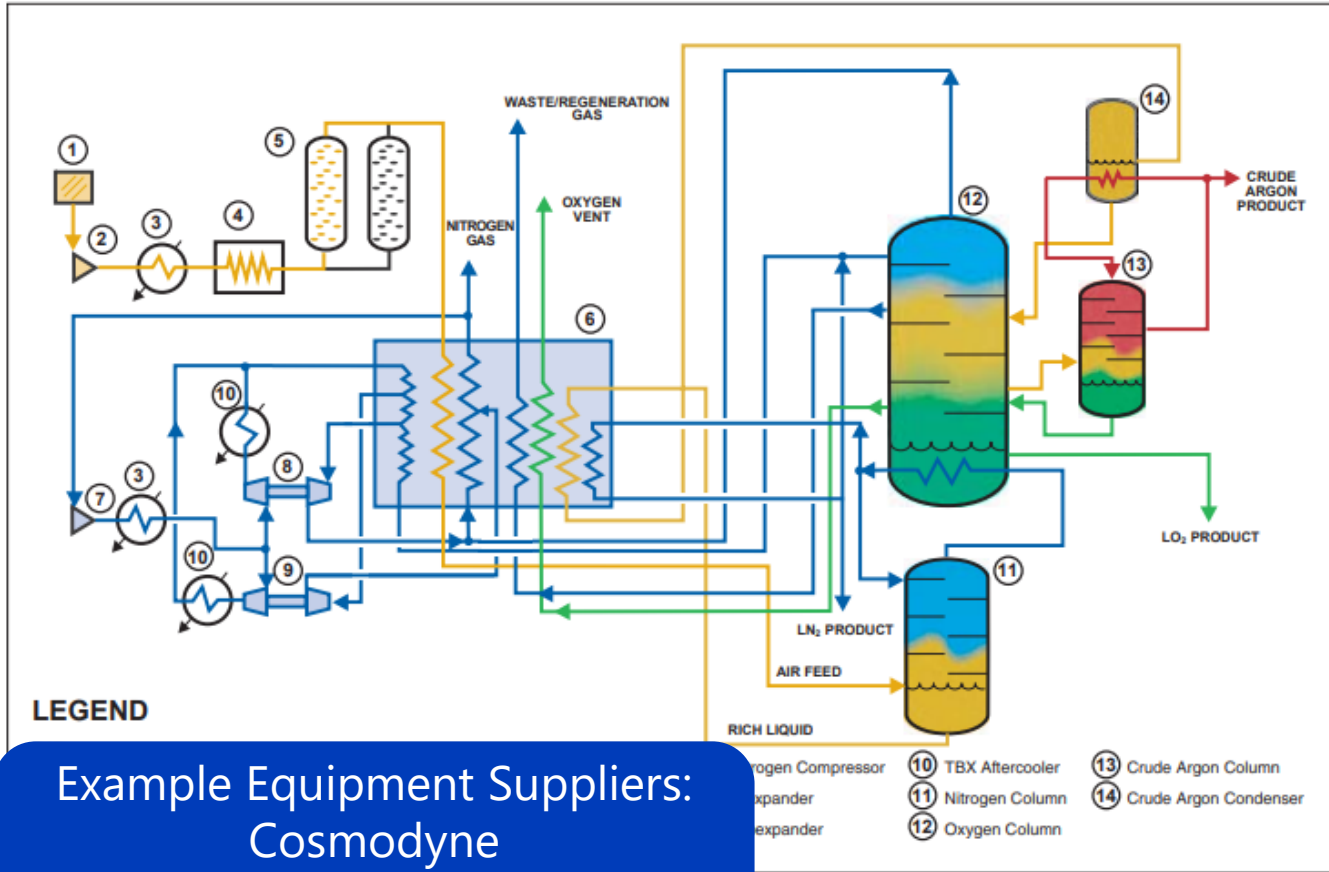
- Compress and cool gas to cryogenic temperatures for distillation
- Requires significant energy for cooling and booster compression
- Turndown to 70-80% of capacity
- Oxygen produced in combination liquid and gas forms – liquid form can be stored



Cryogenic Separation



Cryogenic Separation

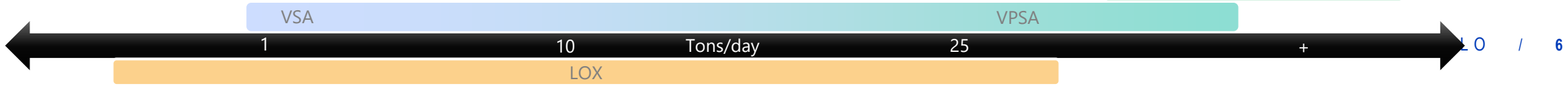


- Used by industrial gas suppliers (produces 99% pure oxygen)
- Used historically at the largest wastewater treatment plants (now largely VPSA or air)



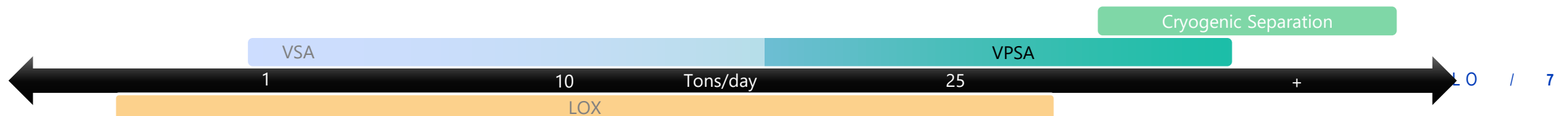
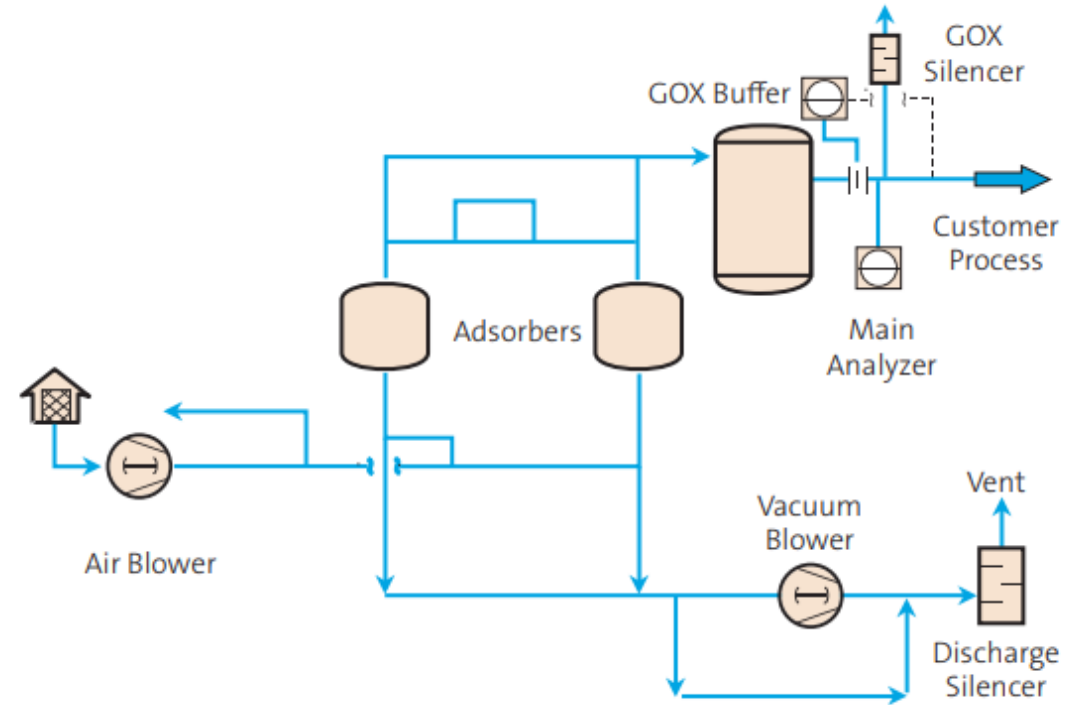
Example Equipment Suppliers:
Cosmodyne
Air Products
Linde

Cryogenic Separation



Vacuum/Pressure Swing Adsorption (VPSA)

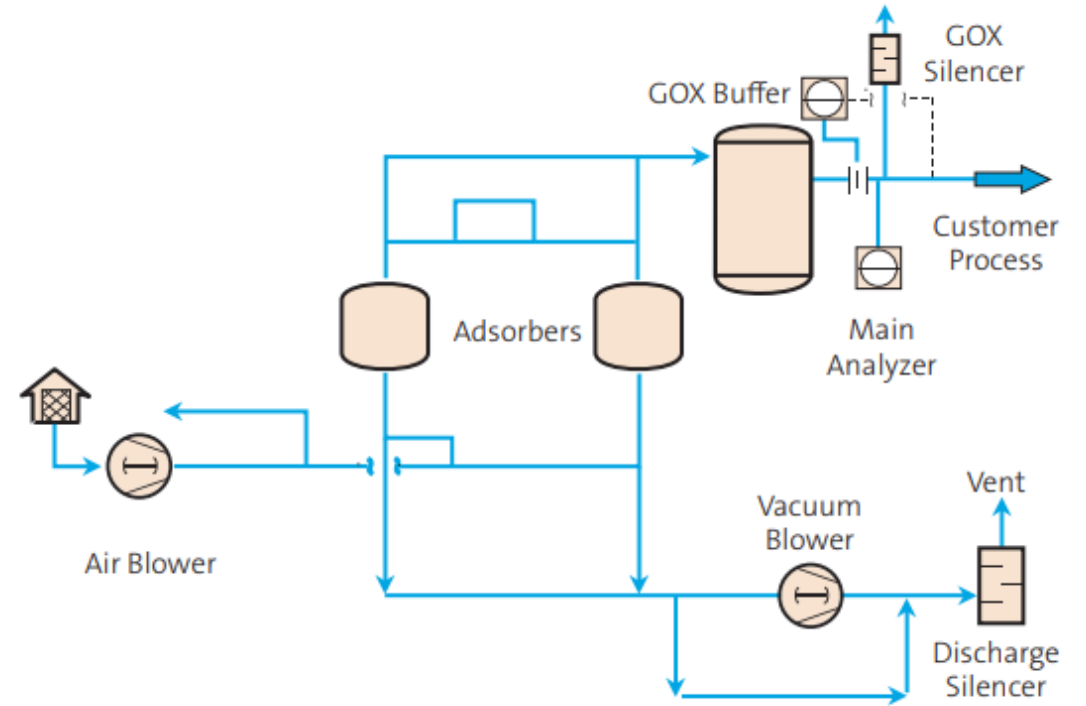
- Blow air through molecular sieve – “filter out” water and nitrogen so oxygen comes out
- Booster compressor increases pressure out
- Turndown to ~50% of production capacity
- Operates at near atmospheric temperature
- Produces gaseous oxygen at 90 – 93% concentration



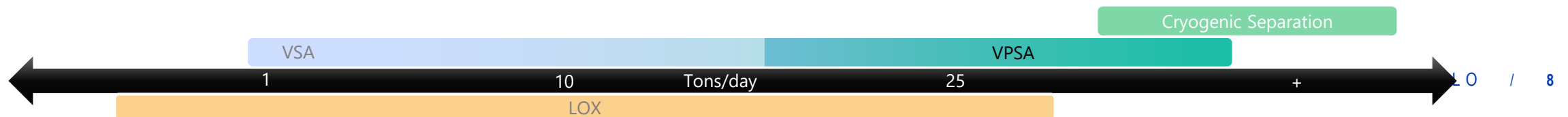
Vacuum/Pressure Swing Adsorption (VPSA)



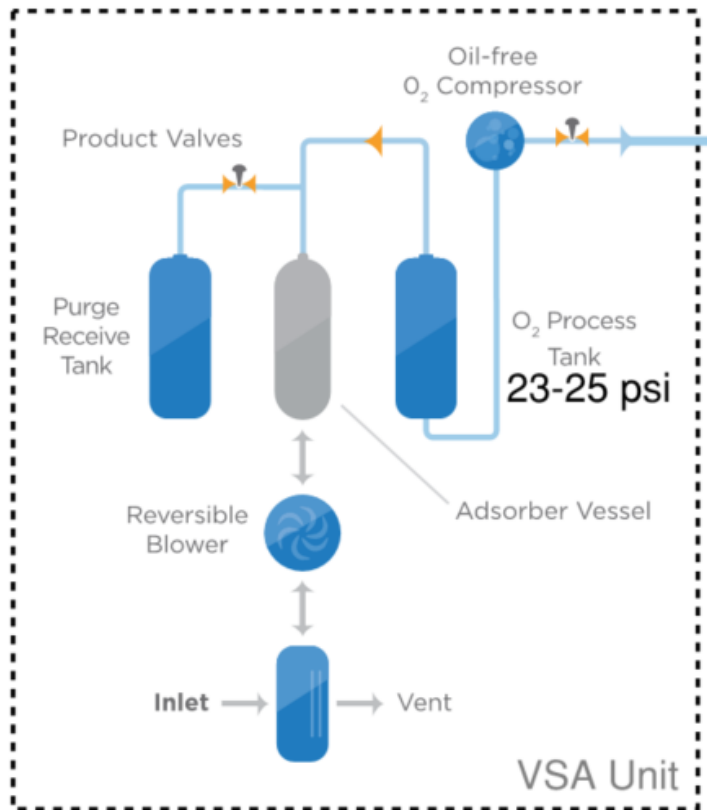
Example Equipment Suppliers:
Air Products
Linde



- Batched process so instantaneous power draw is 2-3x larger than average power.



Vacuum Swing Adsorption (VSA)



- Similar process to VPSA, but utilize lower positive pressure.
- Turndown to 30-40% of capacity



PCI Gases:

- Make skid system "DOCS" (Deployable Oxygen Concentration System)
- Originally target use was military field hospitals
- 40 installations in the US



Case Studies



*David L Tippin Water Treatment Facility
Tampa, FL*

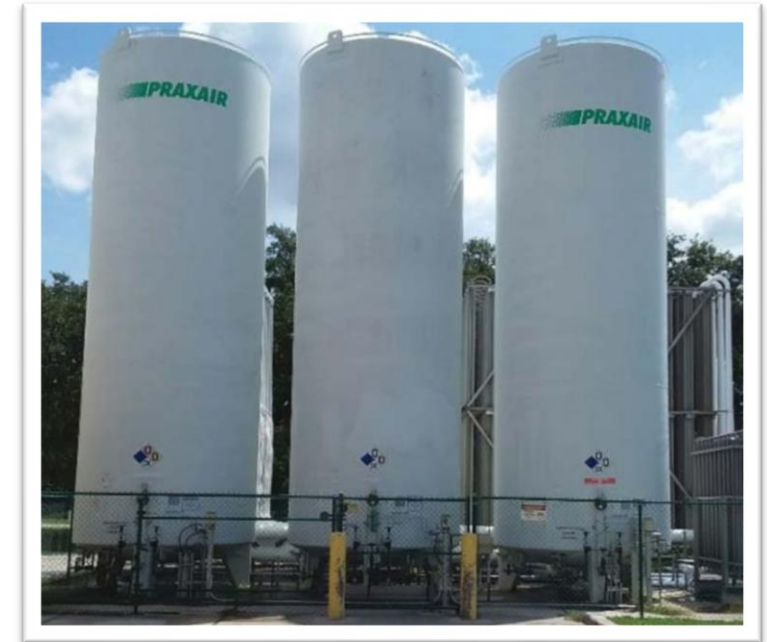


*Fargo Water Treatment Facilities
Fargo, ND*

David L Tippin Water Treatment Facility

- Conventional WTP with intermediate ozone, used for primary disinfection
- Max capacity of 120 mgd, expanding to 140 mgd

- ❖ LOX cost ~\$120/ton; contract includes potential rate adjustments for the future
- ❖ During the height of COVID hospitalizations, oxygen was prioritized for hospitals. Ozone system was shut off due to lack of LOX for months.



Existing LOX

- Three 13,000 gallon tanks, average of one truck delivery/day
- In need of refurbishment and upgrades for future capacity

Tippin Facility

- Historic ozone doses up to 7 mg/L (future ozone need of almost 6,000 ppd)
- Fine bubble diffusion contactors; during lower demand periods, utilize lower concentrations of ozone gas to maintain flow through diffusers
- Require 25-30 tpd of generation capacity (with LOX supplement)

Cryogenic Separation	VPSA
Highest specific energy consumption Energy use ~750 kWh/ton	Lowest specific energy requirement Energy use ~615 kWh/ton
Periodic maintenance on rotating equipment	Periodic maintenance on cycling valves and rotating equipment
Bigger footprint	Smaller footprint
Higher capital cost	Lower capital cost

Selection: VPSA

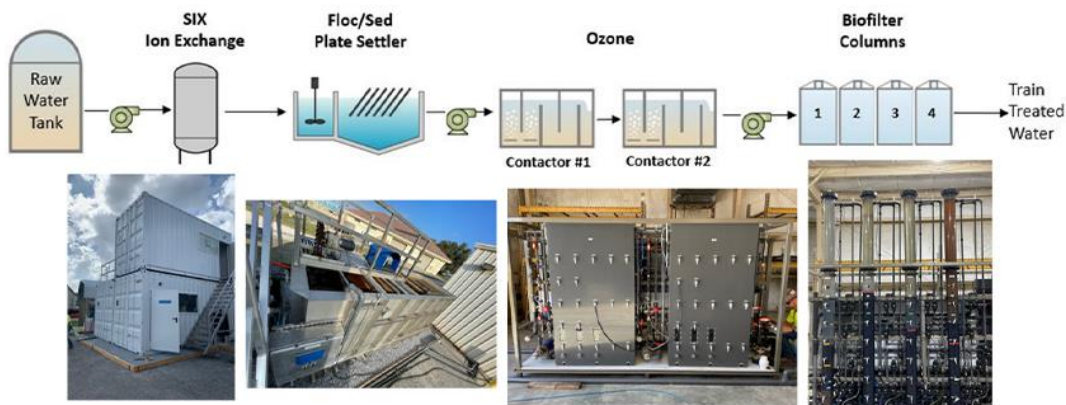
Tippin Facility

“Supply of Gas” VPSA vs LOX

Supply of Gas

- City provides secure space that is accessible to SOG provider
- City provides utilities and completes site work for supporting equipment
- SOG provides equipment and maintenance
- 15 year contract

Item	LOX Delivery	Sale-of-Gas Contract
Capital Cost	\$2,100,000	\$3,820,000
Annual LOX Delivery Cost	\$1,545,000	\$85,000
Annual Sale-of-Gas Contract Cost	\$0	\$600,000
Annual Electrical Cost	\$3,460	\$263,000
Present-Worth of Annual Costs	\$18,430,000	\$11,280,000
TOTAL PRESENT-WORTH COST	\$20,530,000	\$15,100,000



Follow-Up: Suspended Ion Exchange (SIX) significantly reduced TOC and other components. Ozone system capacity increases likely no longer needed.

Fargo, ND

Lime-Softening Water Treatment Plant (LSWTP)
Membrane Water Treatment Plant (MWTP)



<https://fargond.gov/city-government/departments/water-treatment>

- Conventional WTP with lime softening and intermediate ozone (primary disinfection) – 30 mgd (early 1990s)
- UF/RO WTP with a sidestream of ozone – 15 mgd
- LSWTP utilizes fine bubble diffusion – low demand season requires reduced ozone concentration to maintain diffuser flow



Existing LOX

- Two 9,000 gallon tanks
- Upgrade water circulating vaporizers

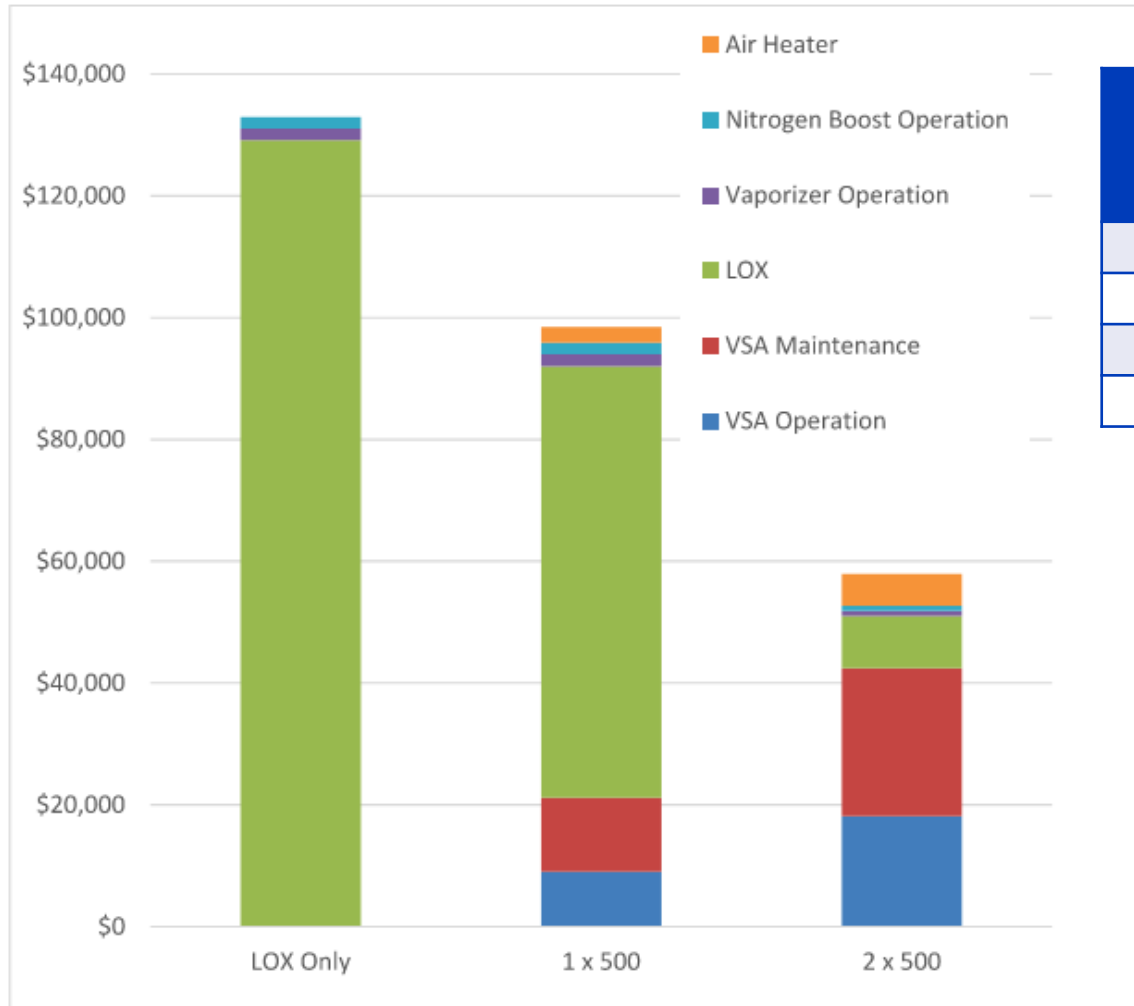
Fargo

- ❖ Receiving LOX deliveries from Minneapolis (3.5 hour drive), unreliable in the winter
- ❖ LOX cost ~\$165/ton
- ❖ SRF Loan available @ 2%

- Space and infrastructure for future generator
- Existing functional LOX system to backup the VSA



Fargo

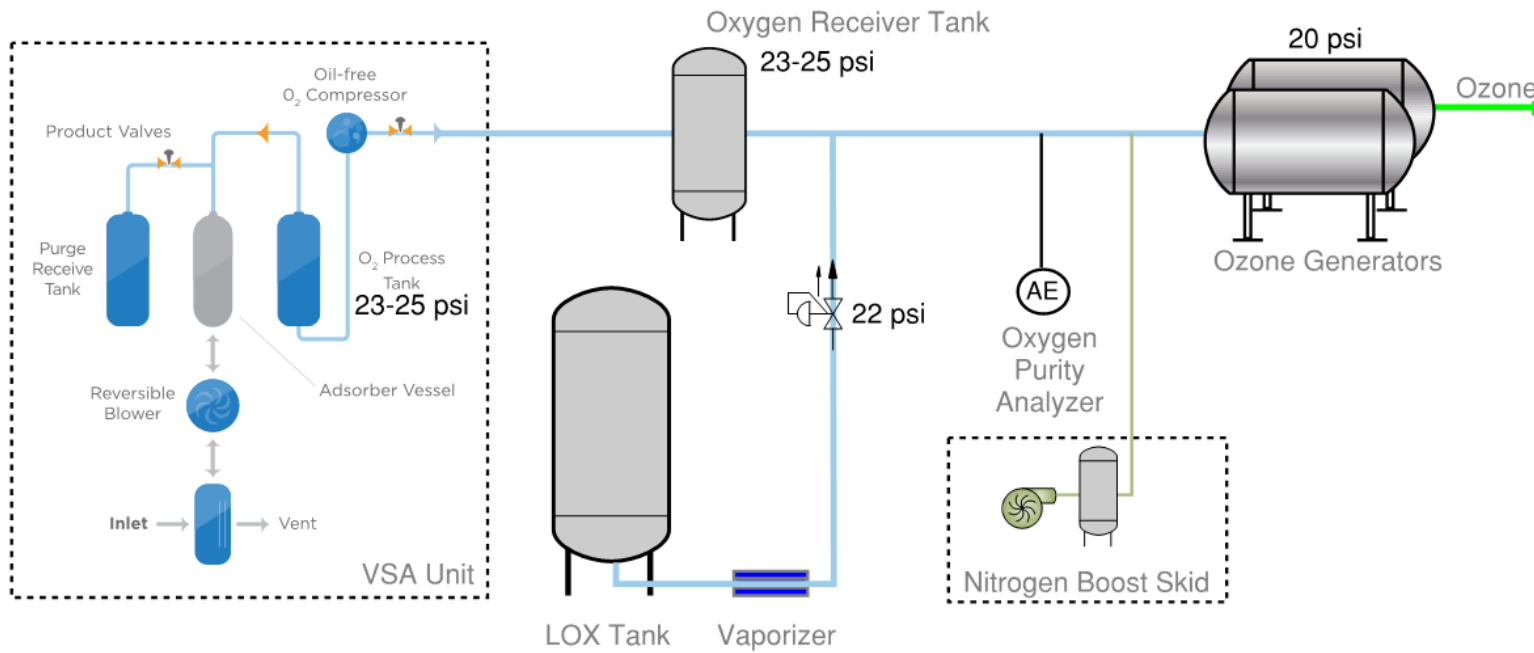


Average Annual Cost of Operation

	LOX Only	With VSA	VSA Savings over LOX	Amortized Payment
1 x DOCs 500	\$132,979	\$98,500	\$34,479	\$26,466
2x DOCs 500	\$132,979	\$57,901	\$75,708	\$52,932

Cost assumes a unit LOX cost of \$164.25/ton, 1 or 2 DOCs 500 units, with a 40 kW supply air heater, and a minimum flow of 35.3 scfm to contactors.

Fargo



Follow-Up: DOCs 500 installed and operating well. Most significant concern is management of LOX during low demand.

Takeaways

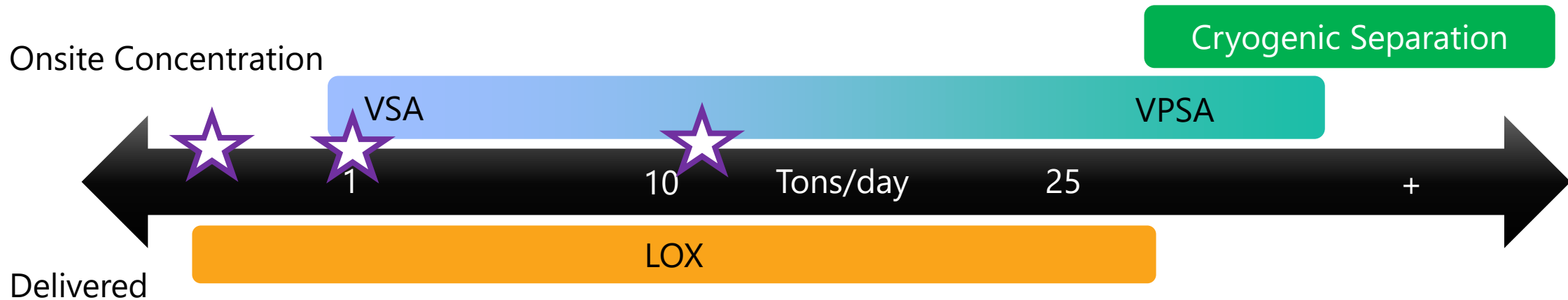
We have relatively low flows of oxygen in use in the PNW

1.5 mg/L ozone @ 5 mgd (10% con) = 6 scfm → 0.4 tpd

1.5 mg/L ozone @ 15 mgd (10% con) = 17 scfm → 1 tpd

1.5 mg/L ozone @ 100 mgd (10% con) = 200 scfm → 12 tpd

- ❖ VSA is the most viable option to concentrate oxygen onsite
- ❖ VSA carries significant infrastructure requirements (space, building, power) and generally requires LOX backup, so typically not lower cost than LOX



Questions?

Ali Leeds
aleeds@carollo.com