Pilot Testing of a Modular Oxygen Production System Using Oxygen Binding Adsorbents

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Project Objectives and Summary

Objective: The design, fabrication, and testing of a 10 to 20 kg/day modular oxygen (O_2) production system

- Be cost competitive with current state-of-art process
- Modular process for small scale oxygen production
- Sorbent bed-factor less than 600 lb-sorbent/TPD O_2 (tons/day O_2)
- O_2 purity greater than 95%

Specific Challenges

- Rapid PSA cycle development
- Structured sorbent module development
- Rapid cycle modeling tool development and cycle optimization
- Material and module scale up and manufacturing
- Design and fabrication of pilot O_2 production system
- Parametric and long-term testing
- Techno-economic analysis

Timeframe: 12/1/2017 to 11/30/2020

Technical approach

- Modular O_2 production
- O_2 binding materials
- Structured adsorbent beds
- Rapid PSA cycles,
- Tools to optimize the structured bed and rapid PSA cycles
- Pilot system testing
- Techno-economic analysis

Adsorbent Properties and Projected Operation Conditions		
	Units	Projected Performance
Material Properties		
Adsorbent materials		Complexed cobalt solids with permanent mesoporosity, Co-PEI complexes on silica support, and Li-exchanged zeolite
Adsorbent O_2 capacity	*Wt%*	>0.5
Operating Conditions		
Feed gas	–	Air
Temperature	°C	20–40
Pressure (adsorption)	*kPa*	Absorber: ~120 to 1,000 kPa; Regeneration: under vacuum (0.1–0.5 kPa) or atmospheric pressure
Process (adsorption)		Vacuum-swing adsorption or PSA

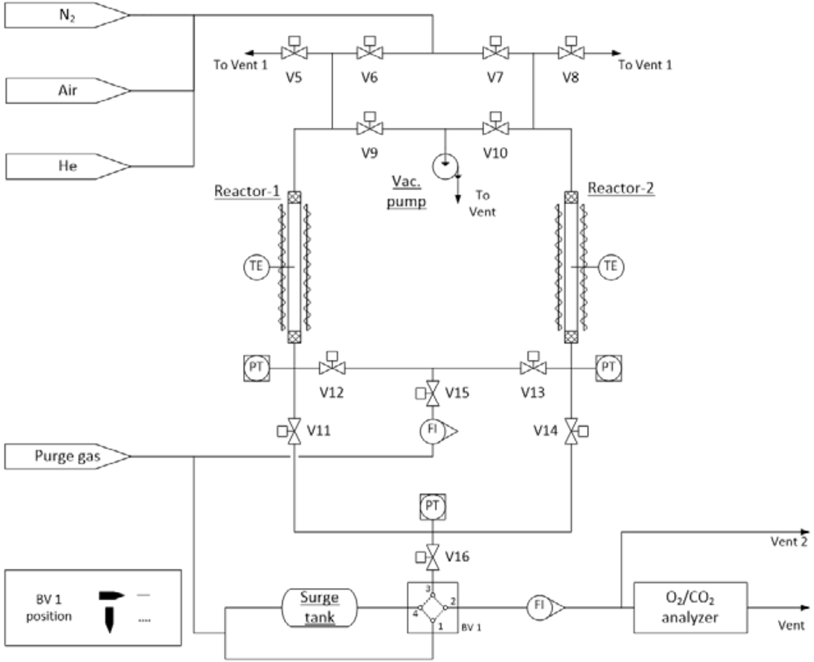
Success Criteria

1. Structured sorben stable >1,000 rapid sorption/desorption cycles
2. BSF<600
3. Target O_2 production cost ≤ $46.74/ton O_2 (1996 Constant dollar) , $61.49 in 2016$
   (cost benchmark for state-of-the-art cryogenic air distillation)

Process design package & final techno-economic analysis for full-scale, modular, rapid-cycle PSA O_2 production system using novel structured sorbent to produce 10-50 TPD of high-purity (≥95%) O_2 from air as the oxygen feed for DOE's 1- to 5-MW oxygen-blown REMS gasifier skid for power generation

RTI PSA System

L&C-300



Wide range of VPSA (Vacuum Pressure Swing Adsorption) testing capabilities

- While O_2 in air is adsorbed at sorbent in Reactor-1, product N_2 purity is monitored via effluent O_2 analyzer; meanwhile Reactor-2 is evacuated through vacuum for regeneration

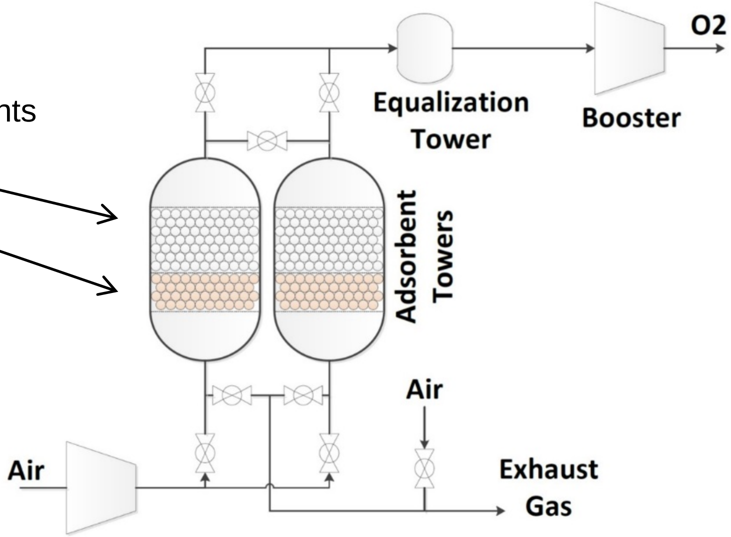
Sorbent and Structured Sorbent Module Development and Characterization

Air Liquide Objectives:

- Develop and characterize structured adsorbents formulations using commercial adsorbents
- Develop and characterize structured adsorbents beds
- Manufacture and ship 2 to 4 structured adsorbers for pilot testing
- Support activities (e.g. Pilot design, operating parameters for traditional adsorbents)

BP1 Approach

- Conventional O_2 VSA ➔ uses 2 adsorbents
- Top adsorbent used to capture N_2
- Bottom adsorbent used for air drying



Sorbent and Structured Sorbent Module Development and Characterization

Air Dehumidification:

- 2 options: activated alumina (AA) or silica gel (SG)

Multi-Step Approach

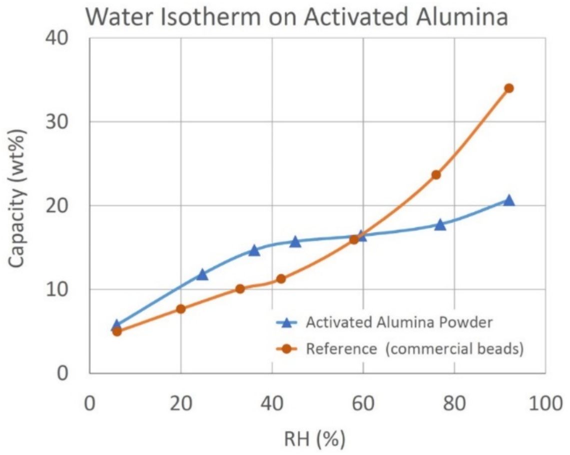
- Selection of powdery sources of AA and SG
- Characterization (Water isotherm)
- Sources with adequate capacity can be formed with a binder

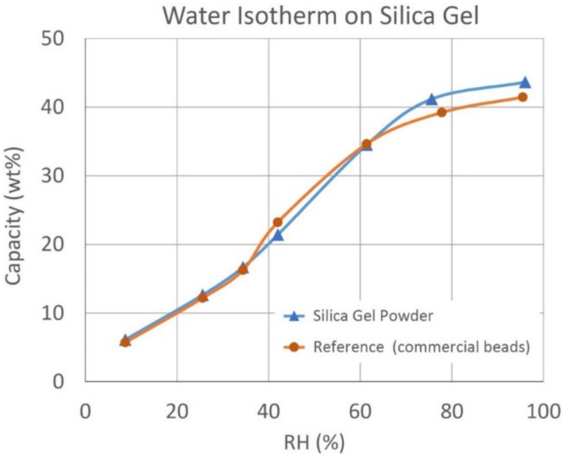
Results

- H_2O capacity of AA powder is below expectation
- H_2O capacity of SG powder meets expectation

Next steps

- Form SG powder with a binder
- Make / characterize SG structured adsorbent bed





Sorbent and Structured Sorbent Module Development and Characterization

N_2-Binding Adsorbent

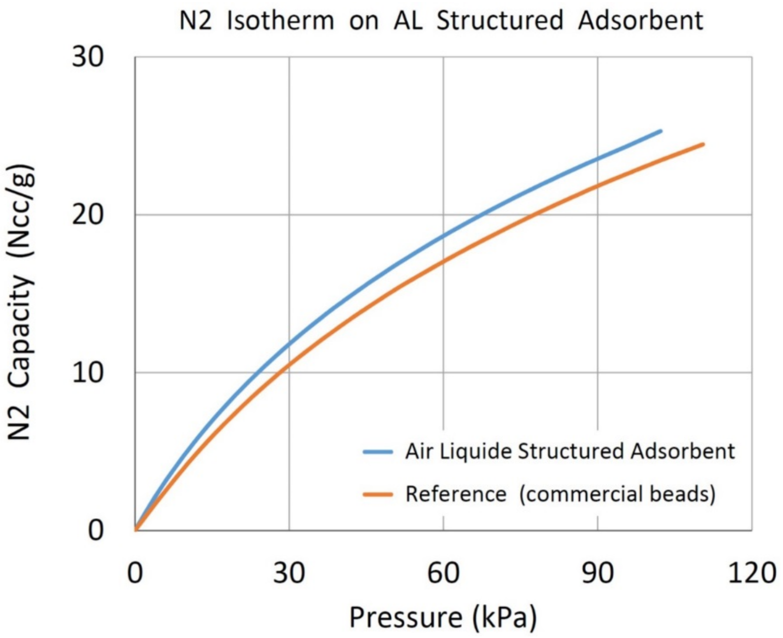
- Various zeolites typically used as N_2 binding adsorbents

Multi-Step Approach

- Selection of zeolite powder
- Forming with binder
- N_2 isotherm carried after activation

Result

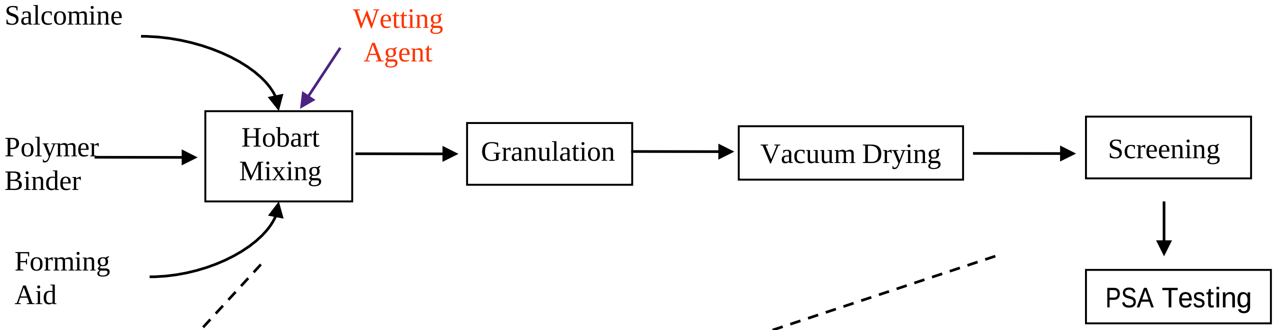
- Similar N_2 capacity compared to commercial adsorbents



Next steps

- Generate O_2 isotherm to derive N_2/O_2 selectivity
- Make and characterize Air Liquide structured adsorbent bed

Bead Forming of O_2-Sorbent for PSA Evaluation

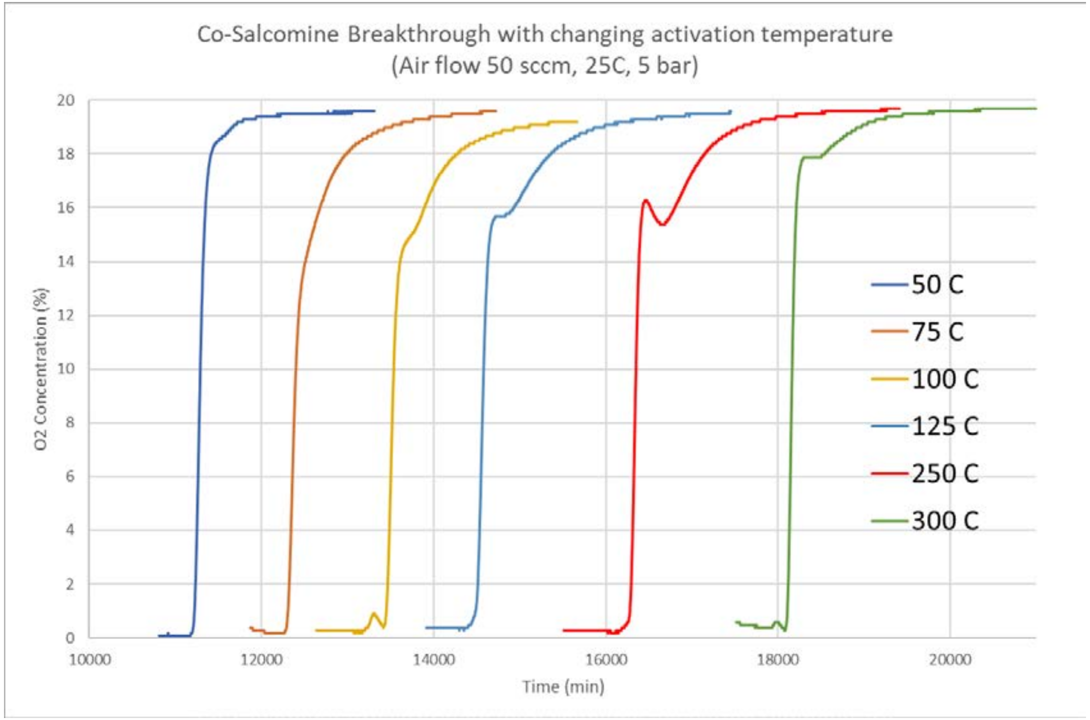


Hobart Planetary Blender

- 40-50 mesh, 0.33mm
- 30-40 mesh, 0.45mm
- 18-30 mesh, 0.75 mm
- **16-18 mesh, 1.06mm**
- **10-16 mesh, 1.51 mm**
- **8-10 mesh, 2.15 mm**

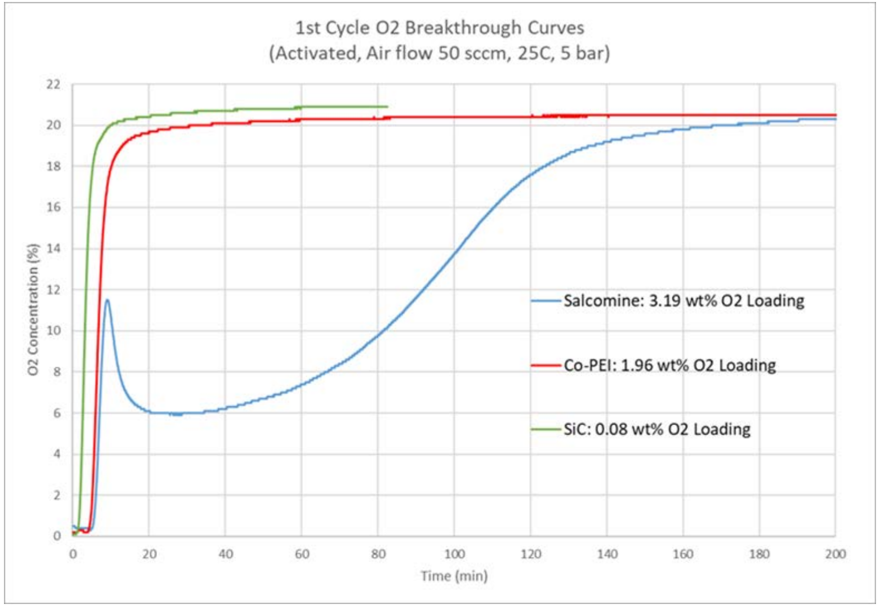
N_2-sorbent O_2-sorbent

Optimize Activation Conditions for O_2-Sorbent



- Elevated temperature needed to pre-activate Co-complex to promote active sites readily available for O_2 adsorption, while maintaining molecular structure intact

Breakthrough Testing – Manual Mode

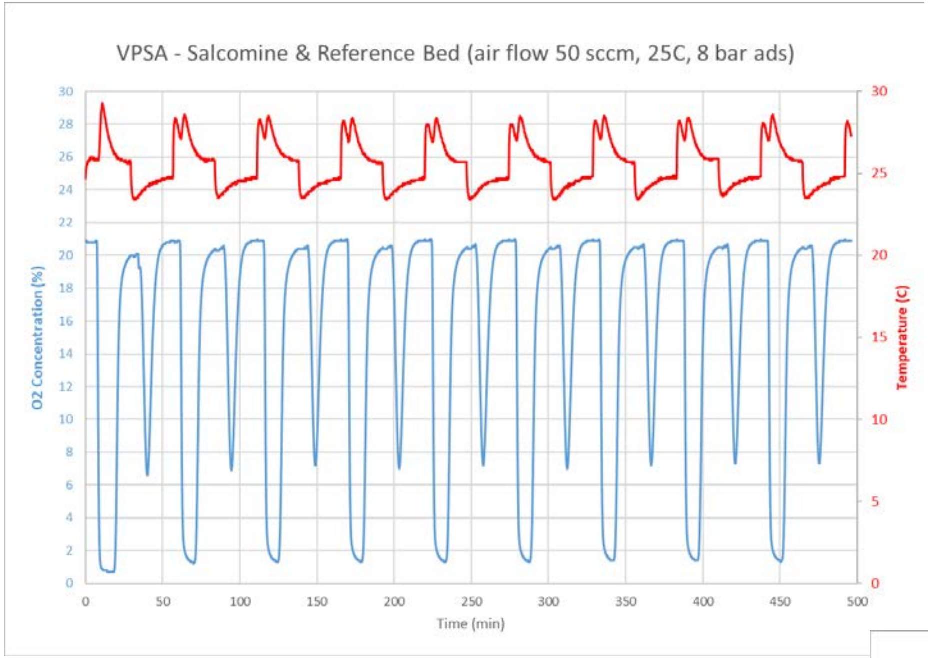


2nd Cycle O_2 Loading:

- Salcomine: 1.09 wt%
- Co-PEI: 0.76 wt%
- SiC (reference): 0.11 wt%

Findings: (1) Commercial Co(II)-salen showed both regenerable O_2 sorption and irreversible sorption; (2) the slopes of reversable portion of breakthrough curves are fast; (3) Confirmed > 0.5 wt% total O_2 loading on both Co-Complex sorbents

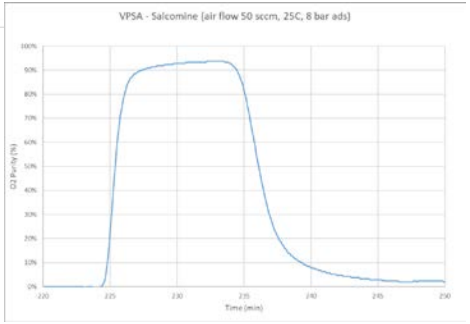
VPSA Cyclic Testing



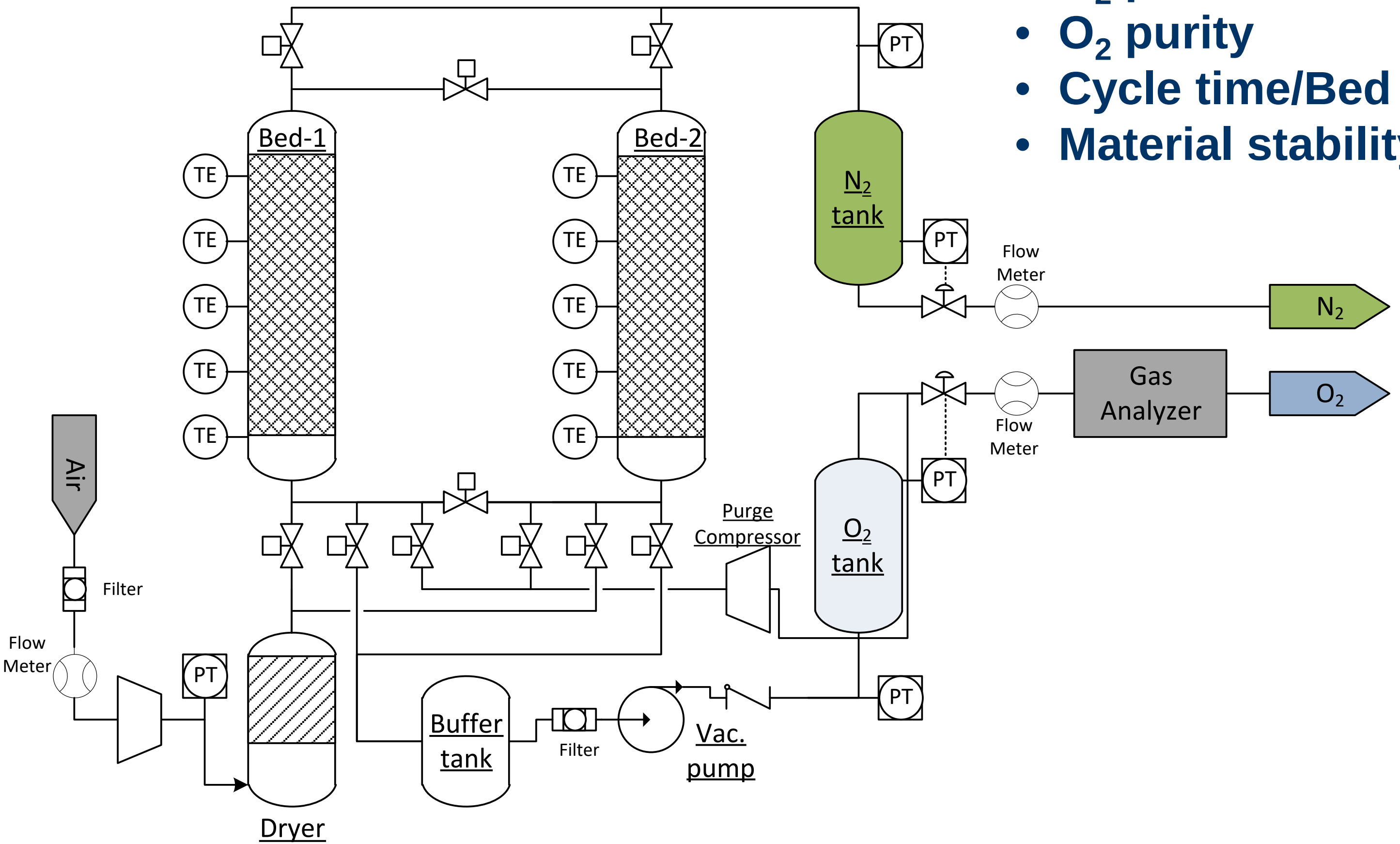
- Reactor temperature profile reflecting the heat of adsorption
- T rose at adsorption step and dropped at regeneration step

- Effluent O_2 concentration showing quick drop when air (21% O_2) passing through sorbent
- O_2 concentration reached 1.3%, indicating 95% product purity in effluent gas

Achieved 95% O_2 purity of cyclic sorption efficiency



O_2 Pilot Plant Process Flow Diagram



- **O_2 production rate**
- **O_2 purity**
- **Cycle time/Bed size factor**
- **Material stability**

Technoeconomic Analysis - Results

Parameter	Cost
Purchased Equipment Cost (PEC)	$ 313,300
Installation Cost (Matls + Labor)	$ 432,200
Total Installed Costs	$ 745,500
EPC (8% of TIC)	$ 59,640
Contingency (15% of TIC+BEC)	$ 120,770
Total Plant Cost (TPC)	**$ 925,910**
Taxes & Insurance (2% of TPC)	$ 18518
Spare parts (0.5% of TPC)	$ 4630
Financing Costs (2.7% of TPC)	$ 25000
Initial sorbent fill	$ 42,972
Total Owner's Cost	**$1,017,030**
OPEX (Electricity costs) ($8.00/MWh)	**$ 91,250**

Levelized Cost of O_2

$$\frac{TOC * CCF + VOPEX * CF}{O_2 \text{ Production} * CF}$$

where

TOC = Total Owner's Cost
CCF = Capital Charge Factor
VOPEX = Variable Operating costs
CF = Capacity factor

Levelized Cost of O_2 = \$59.4/ton of O_2
SOTA O_2 = \$61.49/ton O_2 in 2016\$

- CAPEX estimated using Aspen Process Economics Analyzer
- Cost of electricity takes from DOE's Annual Energy Outlook, 2019 for electricity costs for industrial sector

Acknowledgments

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Questions?

Thank you!

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