Advanced Air Separation Unit (ASU) for Low-Cost H_2 Production Via Modular Gasification Contract DE-FE0032328

Ambal Jayaraman, PhD
Gökhan Alptekin, PhD
Jacob Cleveland, PhD
Sarah Devoss
Ewa Muteba

TDA Research, Inc.

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Acknowledgment and Disclaimer

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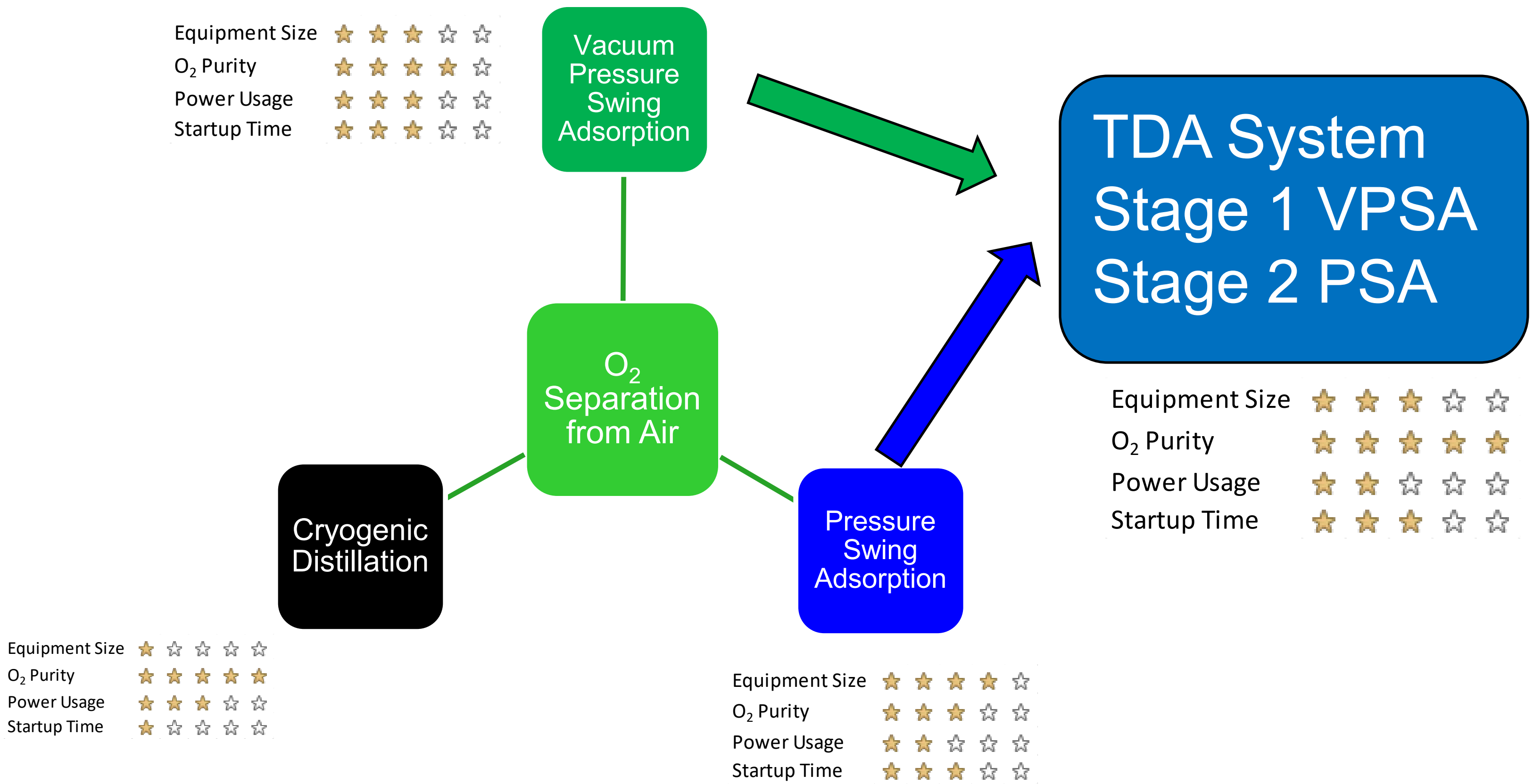
Project Objective

- **Develop a modular, sorbent-based advanced air separation unit (ASU) for high purity oxygen production (>98% (threshold) and >99.5% (objective) to support low-cost hydrogen production from 5 to 30 MW scale gasification of biomass and/or wastes**
- **<u>Specific Objectives</u>**
  - Synthesize sorbents with optimized pore size
  - Optimize adsorption cycles to efficiently produce high purity oxygen
  - Design and fabricate a 10 kg/day prototype that produces high purity O_2 >98+% (& >99.5%)
  - Demonstrate durability over 10,000 cycles
  - Design full scale modular system for use with 5 to 50 MW gasification systems for zero-carbon H_2 production
  - Complete a TEA comparing against cryogenic systems
  - Implement the Community Benefits Plan

DOE Share = $1,250,000
Cost Share = $312,500
Total Project = $1,562,500

Project Duration = 2 year
Single Budget Period

Commercial State of the Art



TDA's Approach

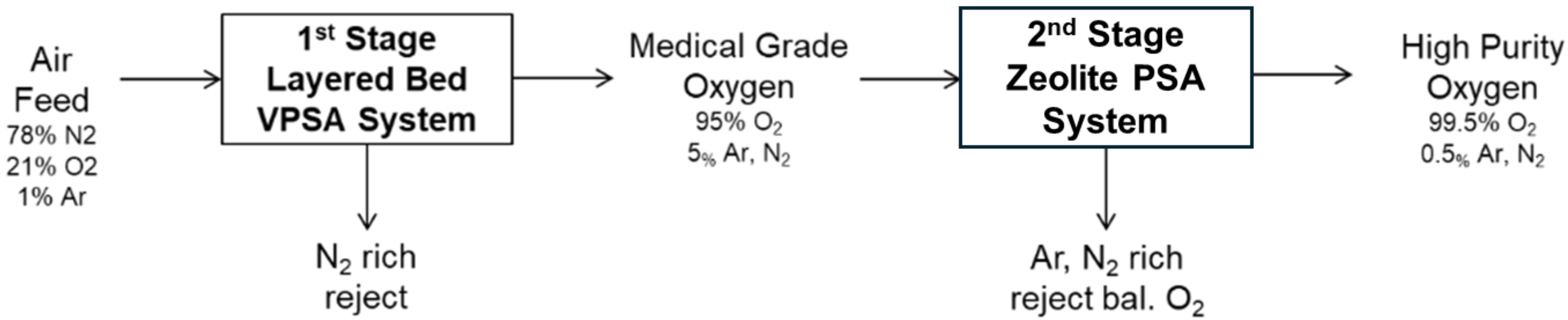
TDA's Approach:

- **Use two stage separation process**
- **TDA's VPSA 1st stage produces 95% oxygen product**
- **Argon separation 2nd stage process that removes Ar from Oxygen to produce high purity O_2 (99.5% or higher)**

TDA's Sorbents:

- **TDA previously developed a new sorbent that is tailored for VPSA operation**
  - High N_2 capacity - Smaller sorbent bed and overall system size
  - Particularly advantageous if used together with regular Li based Zeolite sorbent (US Patent 11,786,859) in the 1st stage VPSA
- **TDA currently proposes to develop a more efficient PSA sorbent based on a novel zeolite to efficiently separate Ar from O_2 to achieve high purity >98% O_2**

Two Stage Adsorption Process



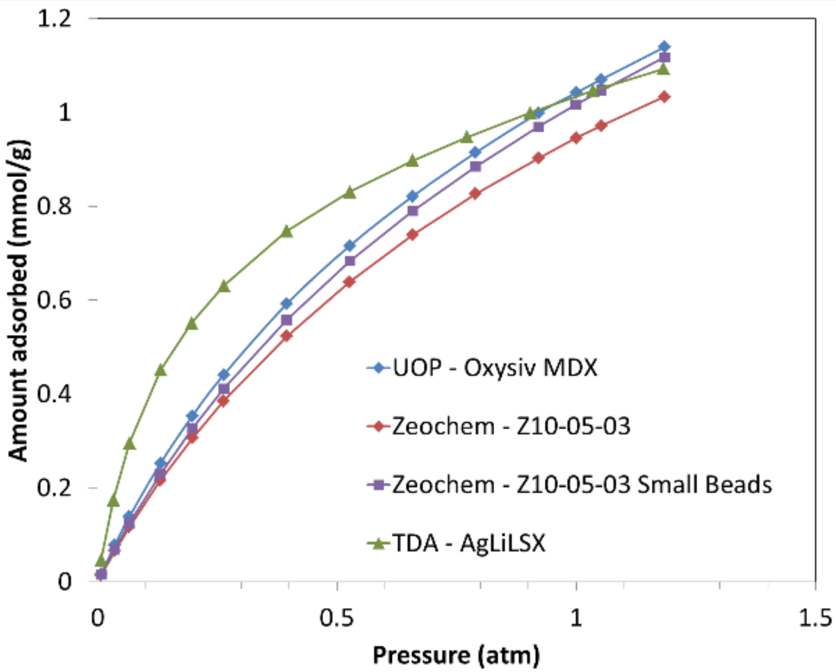
1st Stage to deliver Medical Grade Oxygen 93-95%

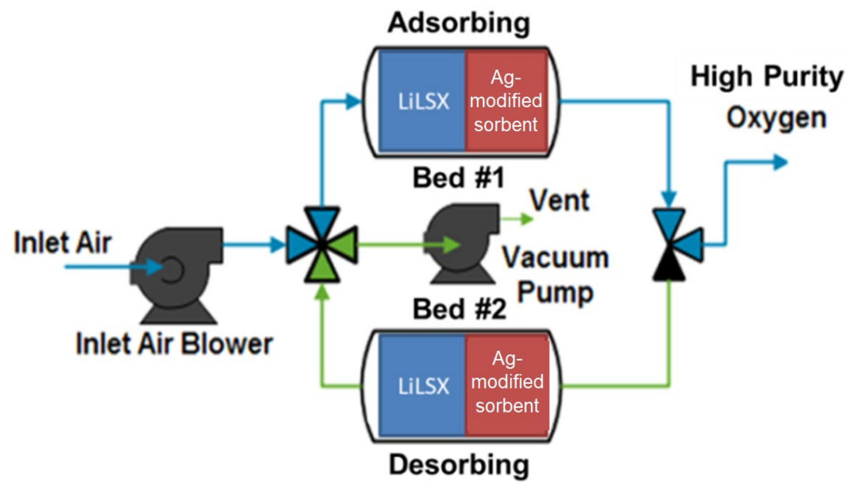
- Pressure Swing Adsorption (PSA) Technology
- Vacuum Assisted Pressure Swing Adsorption (VPSA) Technology
- **Silver (Ag)-VPSA - Technology used by TDA in our Medical Oxygen Generators**

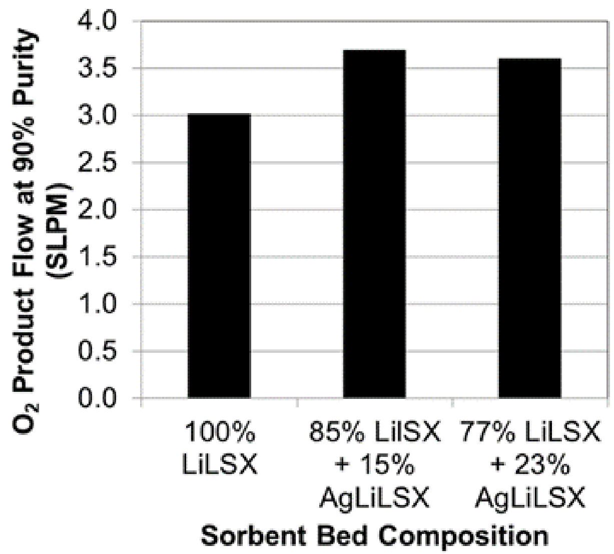
2nd Stage to Upgrade to High Purity Oxygen 98+ or 99.5+%

- Silver zeolite (AgZ) based VPSA Stage (Selectively adsorbs Ar)
- Carbon Molecular Sieve based PSA Stage (Selectively adsorbs O_2)
- **Proposed novel zeolite based PSA Stage (Selectively adsorbs O_2)**

Stage 1 VPSA



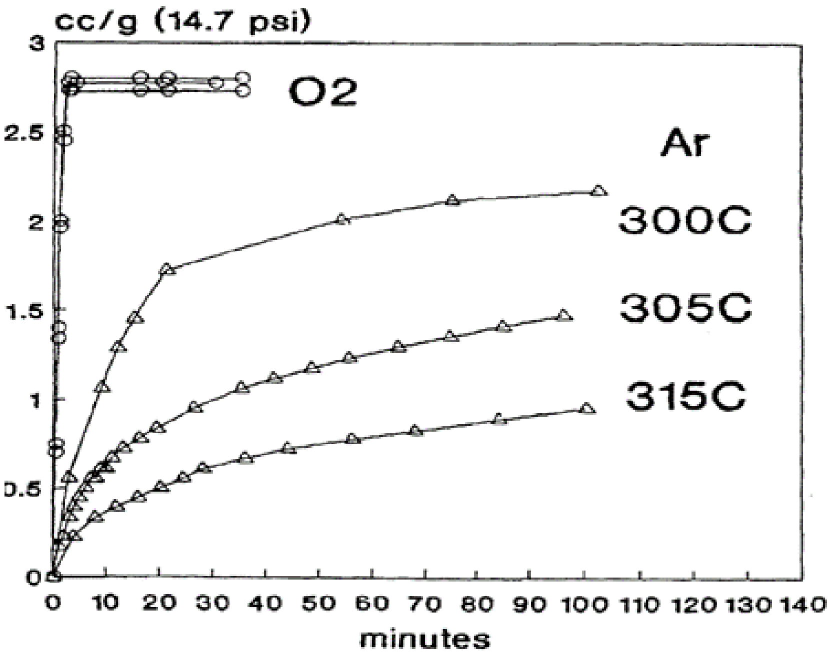




- TDA has previously developed the Stage 1 VPSA sorbent and system for medical oxygen use
- Use of Layered beds of AgLiLSX with LiLSX provides15 to 20% better performance
- These systems are 4 to 20 LPM in size producing 93-95% O_2

Stage 2 PSA – Kinetic Separation

- In the 2nd stage, TDA's system uses a kinetically selective sorbent to separate O_2 from Ar
- Kinetic selective sorbent whose pore size can be tuned to have a high N_2/O_2 selectivity and a high O_2/Ar selectivity,
- Both of which are needed to produce a very high purity oxygen product (>98%).



Molecule	Diameter (Å)
Ar	3.7
N_2	3.6
O_2	3.5
CO_2	3.3
H_2O	2.7

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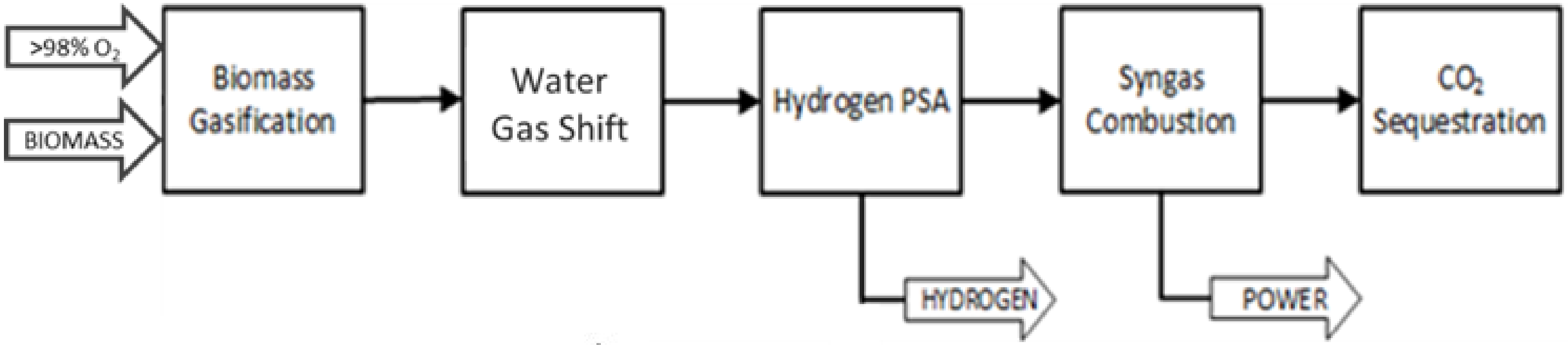
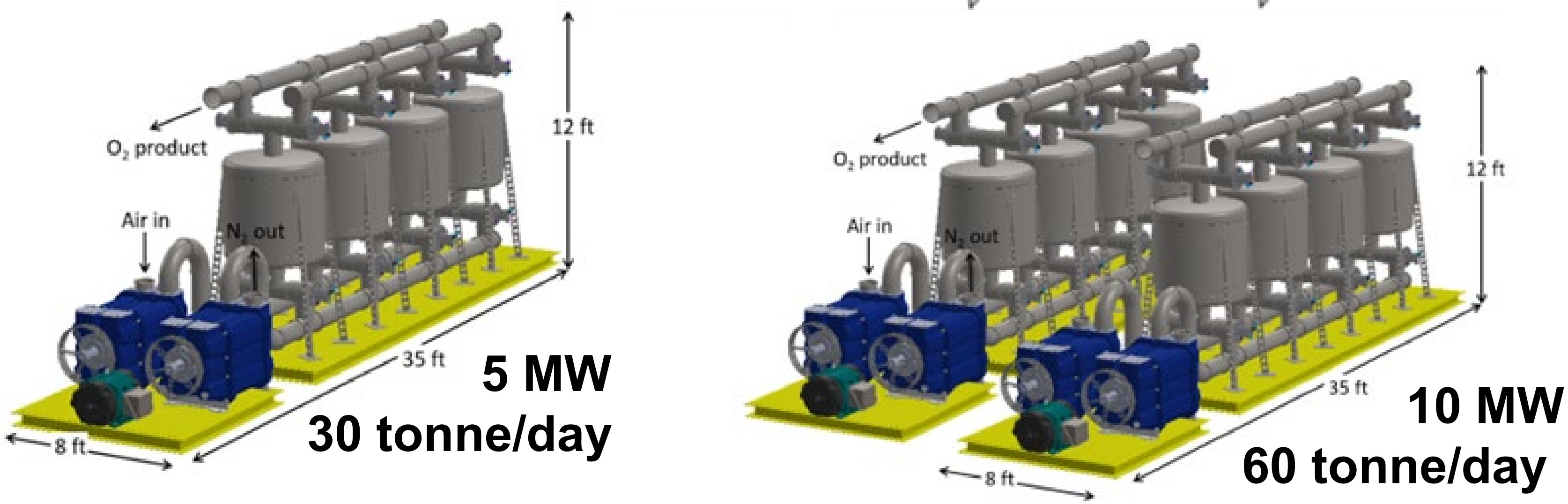
Modular ASU for "green" Hydrogen





- TDA's 5 MW module is similar size to the 1 MW scale cryo ASUs GFED2 being sold by Cosmodyne i.e., our unit is 1/5th the size of the cryogenic ASU in foot print and size

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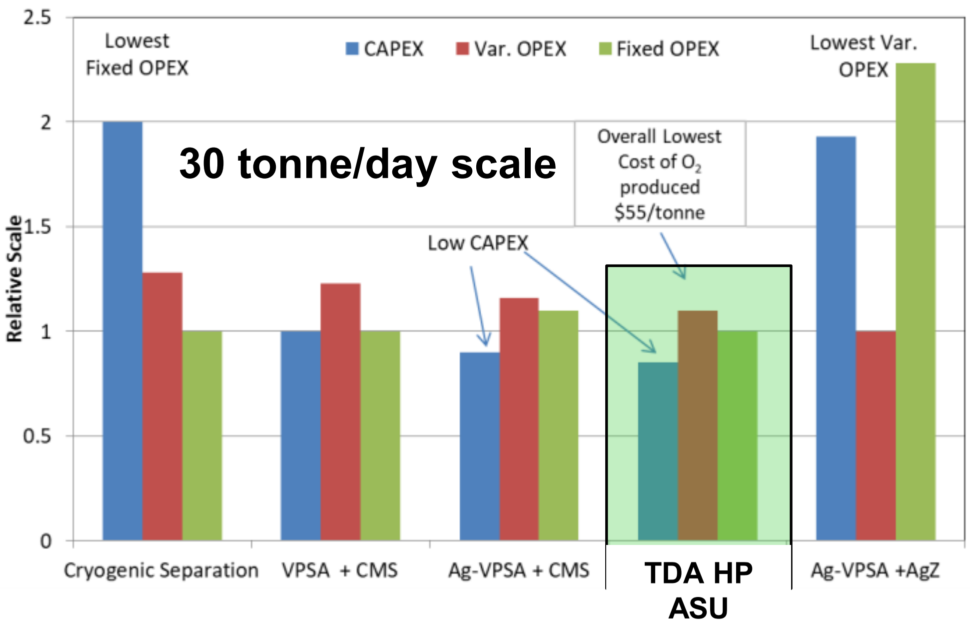
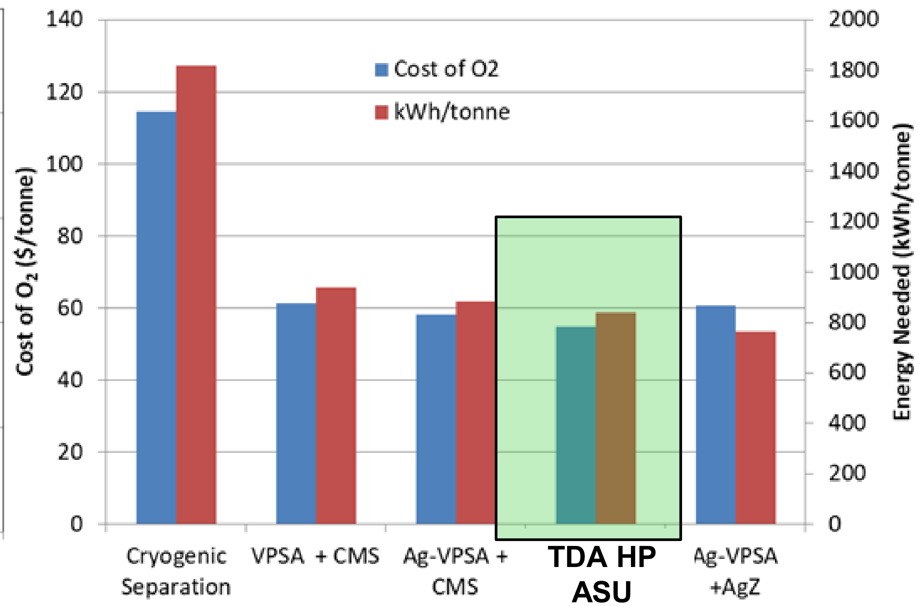
Preliminary TEA





- **TDA's proposed approach has the lowest CAPEX (including Fixed CAPEX i.e., sorbent replacement costs) and second lowest variable OPEX (energy needs)**
- **Cost of the oxygen produced by TDA's two-stage process proposed here will be about $55/tonne compared to $115/tonne for cryogenic system**
- **Cost of oxygen is $61/tonne for the silver free 1st stage that uses only the standard sorbent (LiLSX)**

Technical Objectives

- **Develop a modular, sorbent-based advanced air separation unit (ASU) for high purity oxygen production (>98% (threshold) and >99.5% (objective) to support low-cost hydrogen production from 5 to 30 MW scale gasification of biomass and/or wastes**
- **Specific Objectives**
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Project Partners and Roles:

- **TDA** will synthesize, characterize, test sorbent, design fabricate and test prototype unit, carry out full scale design costing, TEA and LCA
- **University of Alberta** will carry out adsorption modeling, optimization of cycle sequence

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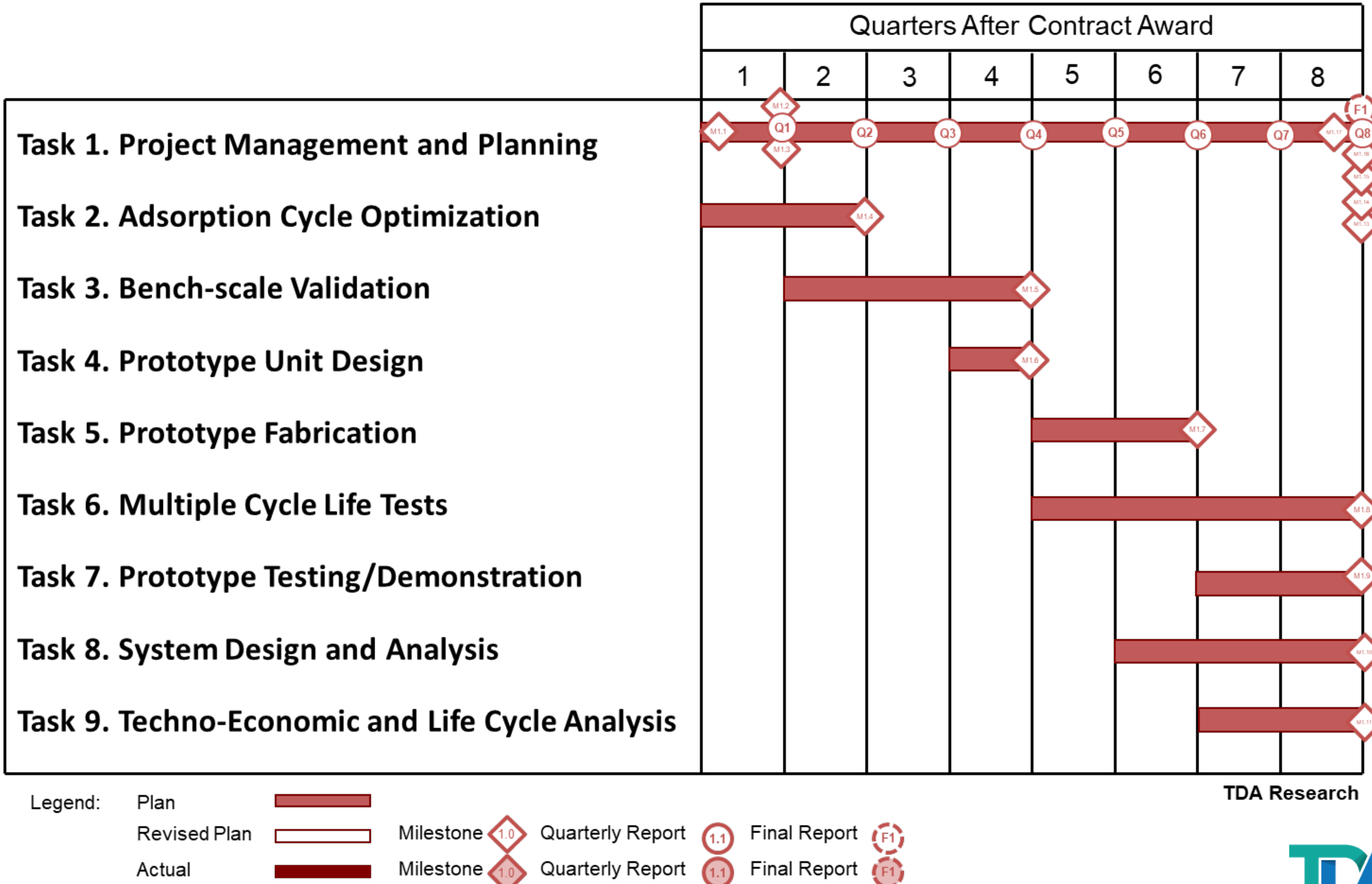
Work Plan

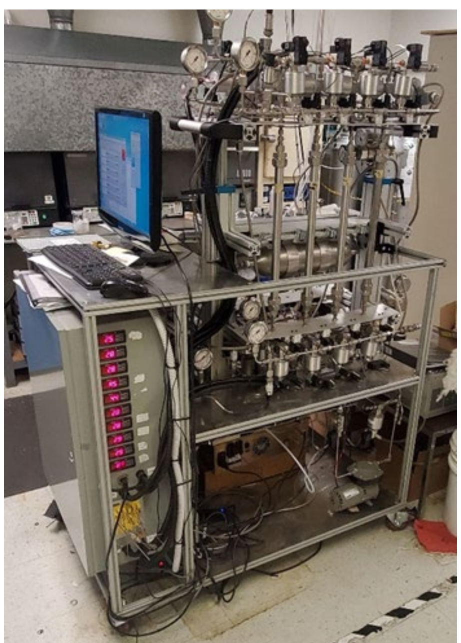
- **Task 1. Project Management and Planning (TDA)**
- **Task 2. Adsorption Cycle Optimization (TDA, UOA)**
- **Task 3. Bench-scale Validation (TDA, UOA)**
- **Task 4. Prototype Unit Design (TDA)**
- **Task 5. Prototype Fabrication (TDA)**
- **Task 6. Multiple Cycle Life Tests (TDA)**
- **Task 7. Prototype Testing/ Demonstration (TDA)**
- **Task 8. System Design and Analysis (TDA, UOA)**
- **Task 9. Techno-economic and Life Cycle Analysis (TDA, UOA)**

Work Schedule

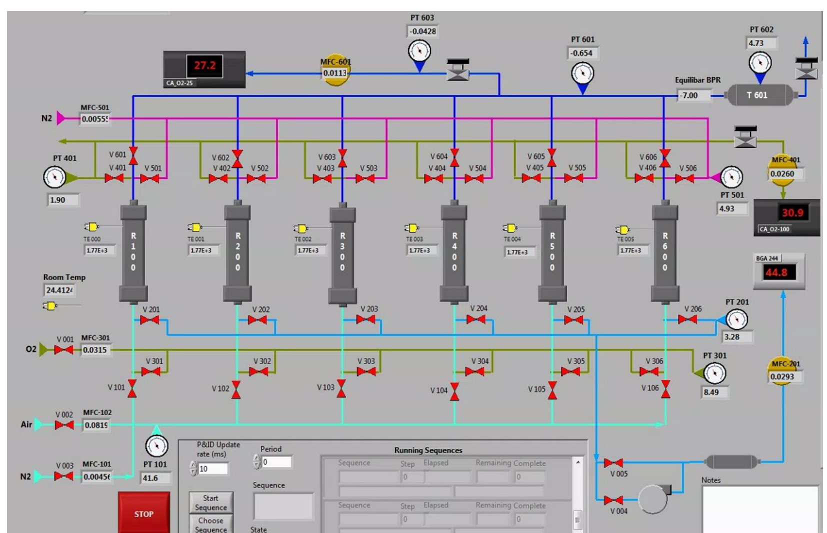


Milestones – Year 1

Budget Period	ID	Task No	Title	Planned Completion Date	Verification Method
			Actual Project Start Date	10/1/2023	
1	1.1	1.1	Update Project Management Plan	10/31/2023	PMP file
1	1.2	1.2	Complete Initial Technology Maturation Plan	12/31/2023	TMP file
1	1.3	1.0	Kickoff Meeting	10/31/2023	Presentation
1	1.4	2.0	Optimized Cycle Design	3/31/2024	Interim Report
1	1.5	3.0	Demonstrate Sorbent Selectivity	9/30/2024	State Point Table
1	1.6	4.0	Complete Prototype Design	9/30/2024	Interim Report
			Annual Briefing #1	9/30/2024	Presentation



Milestone (1.5): Demonstrate sorbent selectivity of >10.4 (almost 6x increase over current materials)



TDA's existing multi-bed PSA system ~1 kg O_2/day

Milestones – Year 2

Budget Period	ID	Task No	Title	Planned Completion Date	Verification Method
1	1.7	5.0	Complete Prototype Fabrication	3/31/2025	Interim Report
1	1.8	6.0	Complete Sorbent Life Tests	9/30/2025	Interim Report
1	1.9	7.0	Complete Prototype Testing/Demonstration	9/30/2025	Interim Report
1	1.10	8.0	Complete System Design	9/30/2025	Final Report
1	1.11	9.0	Complete Final TEA	9/30/2025	Final Report
1	1.12	9.0	Complete Final LCA	9/30/2025	Final Report
1	1.13	1.3	DEIA Survey Results	9/30/2025	Final Report
1	1.14	1.2	Complete Final TMP	6/30/2025	TMP file
1	1.15	1.3	Environmental Justice Questionnaire	9/30/2025	Final Report
1	1.16	1.4	Economic Revitalization and Job Creation Questionnaire	9/30/2025	Final Report
1	1.17	1.0	Final Review Meeting	9/30/2025	Presentation file
			Final Report	9/30/2025	Final Report

Milestone (1.8): *Complete multiple cycle life tests with less than 10% drop in working capacity over 10,000 cycles*
Milestone (1.9): *Demonstrate 99.5% purity* O_2 *produced in prototype at 10 kg* O_2*/day*
Milestone (1.10): *Show >20% reduction in facility foot print over cryogenic* O_2 *system at 30 tonne/day* O_2 *production scale that supplies a 5 MW gasifier module*
Milestone (1.11): *TEA shows TDA's* O_2 *production system can achieve 40% reduction in costs compared to a cryogenic* O_2 *system at 30 tonne/day* O_2 *production scale that supplies a 5 MW gasifier module*
Milestone (1.12): *LCA shows TDA's oxygen production system combined with a gasification-based system for hydrogen production has net-zero carbon performance*

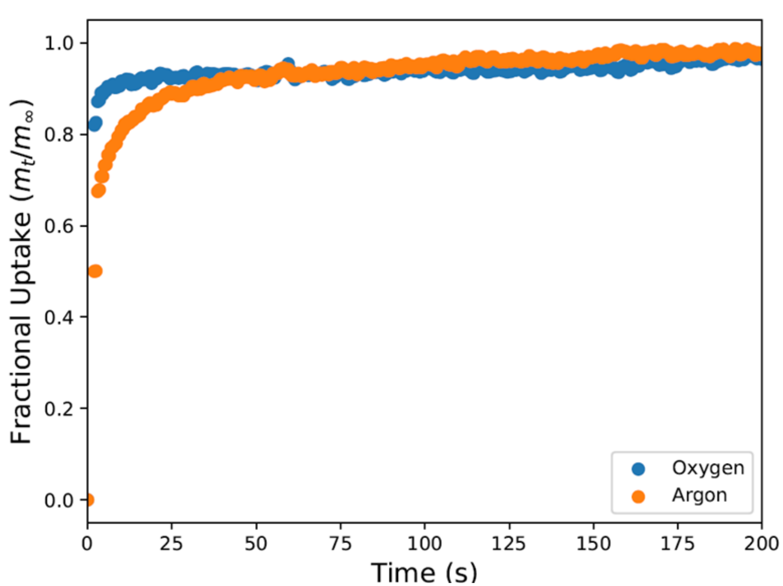
Current Technical Progress

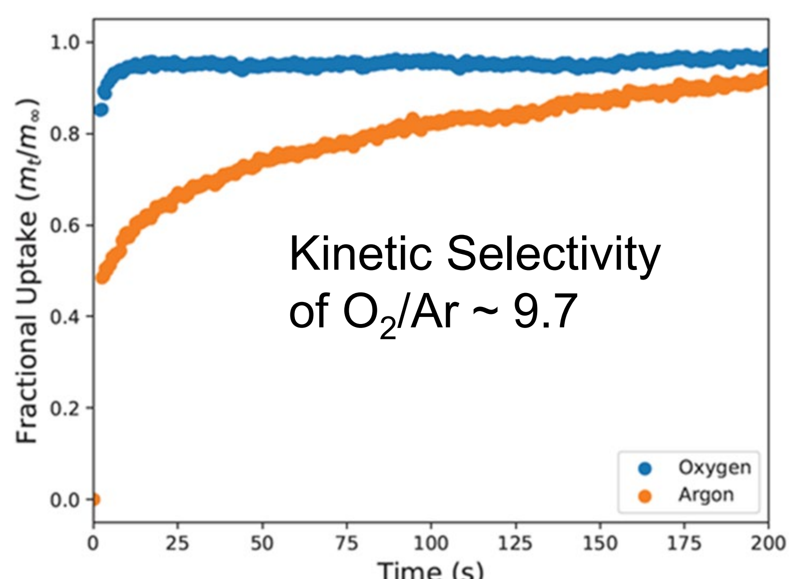
- We are preparing sorbents in sufficient quantities for all testing and characterization, optimizing its pore size and kinetic selectivity for O_2/Ar
- Next, we will also produce about 2 kg of the optimized sorbent for use in prototype tests
- Sorbents are being synthesized in-house at TDA following hydrothermal synthesis recipe
- Sorbent particles will be extruded into 1/16" pellets and granulated to appropriate size for the bench-scale and prototype tests
- Sorbent candidates will be tested for over 200 cycles
- Breakthrough curves obtained in these axial flow fixed bed adsorption tests will be validated against our adsorption models

2^{nd} Stage Sorbent for O_2/Ar Separation

- These materials are extremely temperature stable, and their pore sizes can be tuned to have a high N_2/O_2 selectivity and a high Ar/O_2 selectivity, both of which are needed to produce a very high purity oxygen product (>98%).
- Optimize the framework to ensure only oxygen is adsorbed while both nitrogen and argon are rejected

Molecule	Diameter (Å)
Ar	3.7
N_2	3.6
O_2	3.5
CO_2	3.3
H_2O	2.7





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DEIA Plan - Progress

- **Nearby Disadvantaged Communities**
  - Arvada – Low income, traffic proximity and volume, proximity to superfund site, wastewater discharge, lack high school education
  - Edgewater – Low income, low life expectancy, lack of indoor plumbing, lack high school education
  - Lakewood – Low income, high housing cost, lack of indoor plumbing, low median income, lack high school education
- **SMART Milestone #1 – Create role models for high school students**
  - Seminar for high school students at TDA
  - Teamed with Arvada West High School to do the seminar in Fall 2024
- **SMART Milestone #2 – Increase interest in STEM careers by employing a college intern**
  - We listed job postings for several interns: Summer Engineering Intern (college), Summer CAD Intern (college) and Summer Pre-STEM Intern (High School)
  - We posted the Summer Engineering Intern on the Society of Hispanic Professional Engineers (SHPE) website
  - After posting closes, statistics about diversity of applicant pool will be assessed

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