Low-cost Oxygen (LCO) for Small-scale Modular Gasification Systems

Project DE-FE0028002
U. S. Department of Energy
National Energy Technology Laboratory
PO: Steven Markovich

Prime Contractor:
Thermosolv LLC
Partners:
Western Research Institute

2019 Project Review Meeting for Crosscutting, Rare Earth Elements, Gasification and Transformative Power Generation
April 9, 2019

Mr. Beau D. Braunberger
Dr. Anthony R. Richard
Dr. Vijay K. Sethi

Who is Thermosolv…

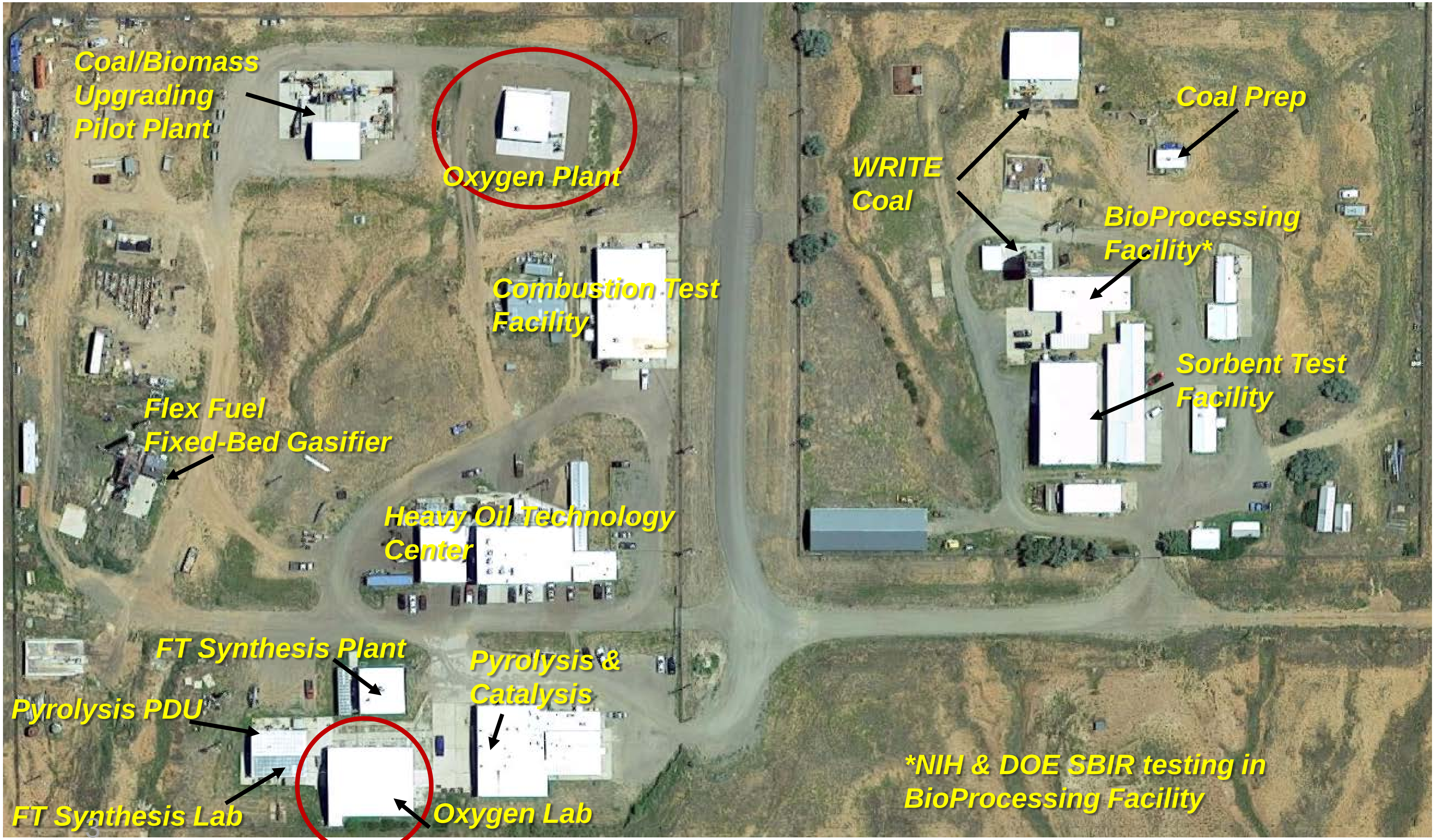
Western Research Institute (WRI)

- WRI is a 501 (c) 3 research, technology development and contract services organization serving the energy, environment and highway materials industries.
- WRI is a former U.S. DOE Energy Technology Center (LETC). In 1983, LETC was privatized and WRI came into existence.
- Science to Technology to Commercialization

Thermosolv LLC

- For profit spin-off of a business unit from Western Research Institute
- Established in 2011 to commercialize technologies
- Ten employees with full access to laboratory and pilot facilities
- Analytical Support from Wyoming Analytical Laboratory
- Access to Advanced Instrumentation at University of Wyoming

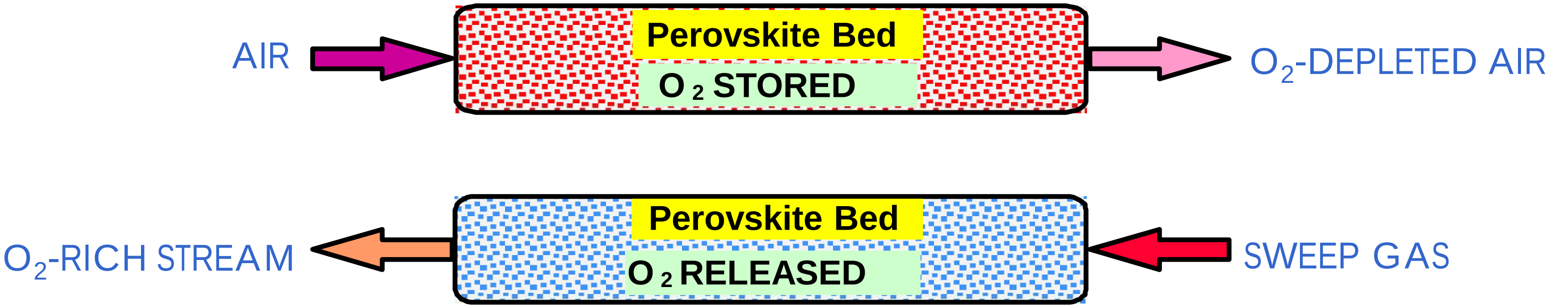
Advanced Technology Center



Low-Cost Oxygen…

Background

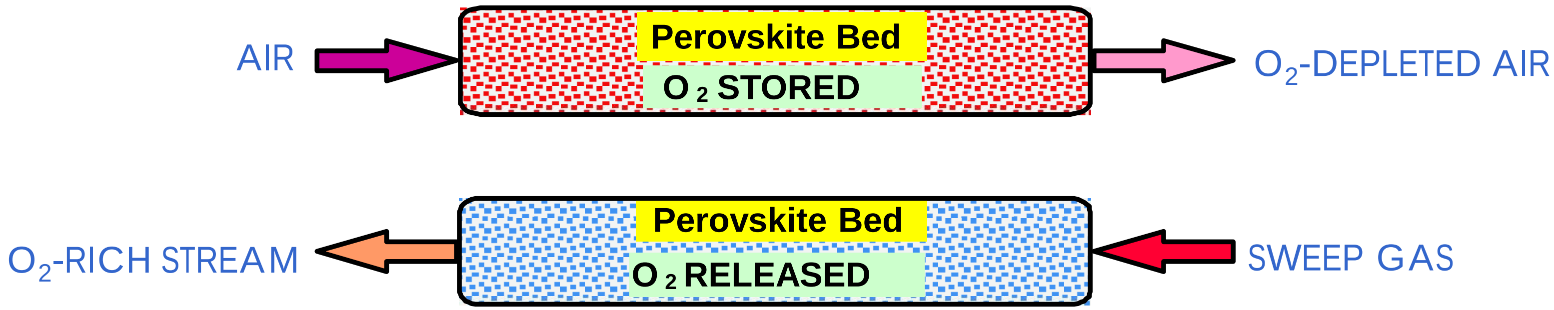
LCO Process (Perovskite Sorbent-based Oxygen)



- Adsorb O_2 from air in a solid sorbent
- Use of CO_2-rich flue gas as sweep gas allows optimization of the O_2 concentration for oxy-combustion
- Use of vacuum or condensing steam sweep to produce oxygen
- Elevated-temperature process driven by partial pressure of oxygen

Background

LCO Process (Perovskite Sorbent-based Oxygen)



Between 2005 and 2008, under two separate Cooperative Agreements, a two-bed, 60-pph unit was developed by BOC/Linde and tested at EP&G/WRI (Thermosolv LLC). The unit was integrated with an existing 250,000 Btu/h Combustion Test Facility to demonstrate oxy-fuel combustion concepts.

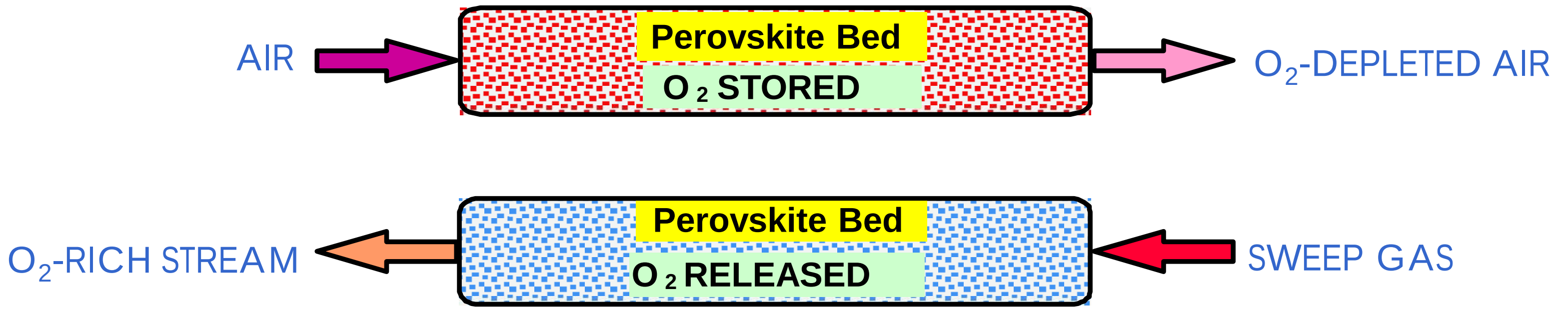
Conclusions:

- Improve sorbent oxygen uptake capacity
- Lower operating temperature from 850° C
- Improve desorption kinetics

THERMOSOLV LLC

Background

LCO Process (Perovskite Sorbent-based Oxygen)



Project DE-FE0024075 (Completed in Late 2016)

Perovskite(s) with order-disorder transition ($La_{0.1}Sr_{0.9}Co_{0.9}Fe_{0.1}O_{3-\delta}$, LSCF1991)

- Lower heat of oxygen sorption
- Improved oxygen uptake capacity
- Lower operating temperature (about 500° C)
- Improved desorption kinetics
- CO_2 sweep can provide oxygen for oxy-fuel combustion
- Using air sweep enriched air can be provided for commercial applications
- VPSA cycle optimized to demonstrate 95% pure oxygen

THERMOSOLV LLC

Project FE28002

Goal

Develop and demonstrate an advanced oxygen production technology for use in coal-fed gasification plants. The specific technical objectives are to scale-up the low-cost oxygen production based on vacuum pressure swing with high-temperature perovskite sorbent, evaluate performance as a function of operational parameters, and perform cyclic adsorption/rinse/desorption experiments to demonstrate oxygen production rate and purity.

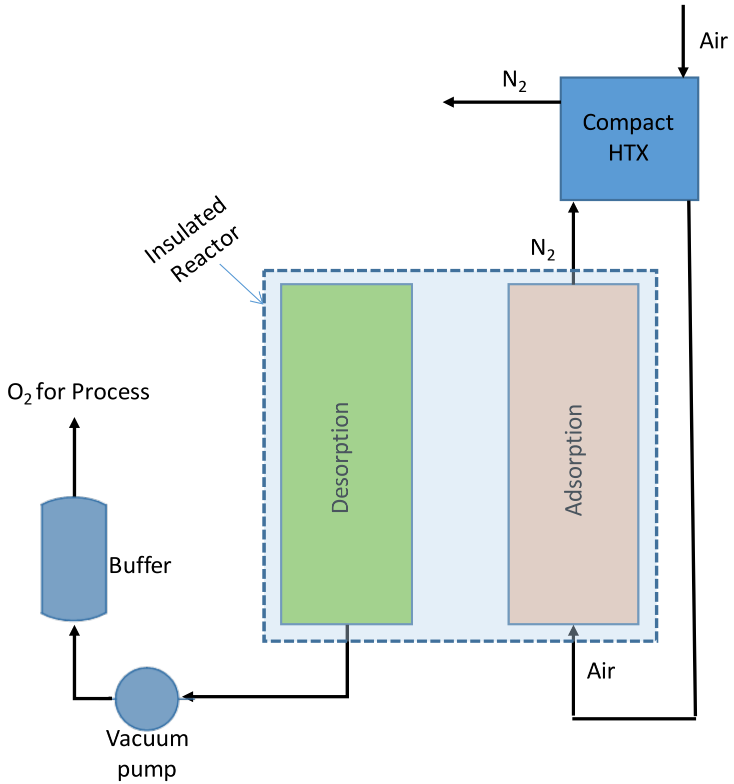
Scope of Work

- Upgrade an existing bench-scale test setup to include provisions for modified rinse and desorption steps.
- Optimize the adsorption, rinse, desorption cycles as a function of operating temperature and pressure.
- Based on the results from bench-scale testing, develop a simulation model
- Using the model design a reactor and oxygen process of nominal 1-ton/day capacity
- Construct, debug and operate the 1-ton/day oxygen production facility to perform parametric tests
- Perform long-term performance tests to establish sorbent durability and service life
- Develop credible process economics for small-scale modular coal gasification power plants in the less than 5MW size range.

Project DE-FE0028002

Low-cost Oxygen for Small-scale Modular Gasification

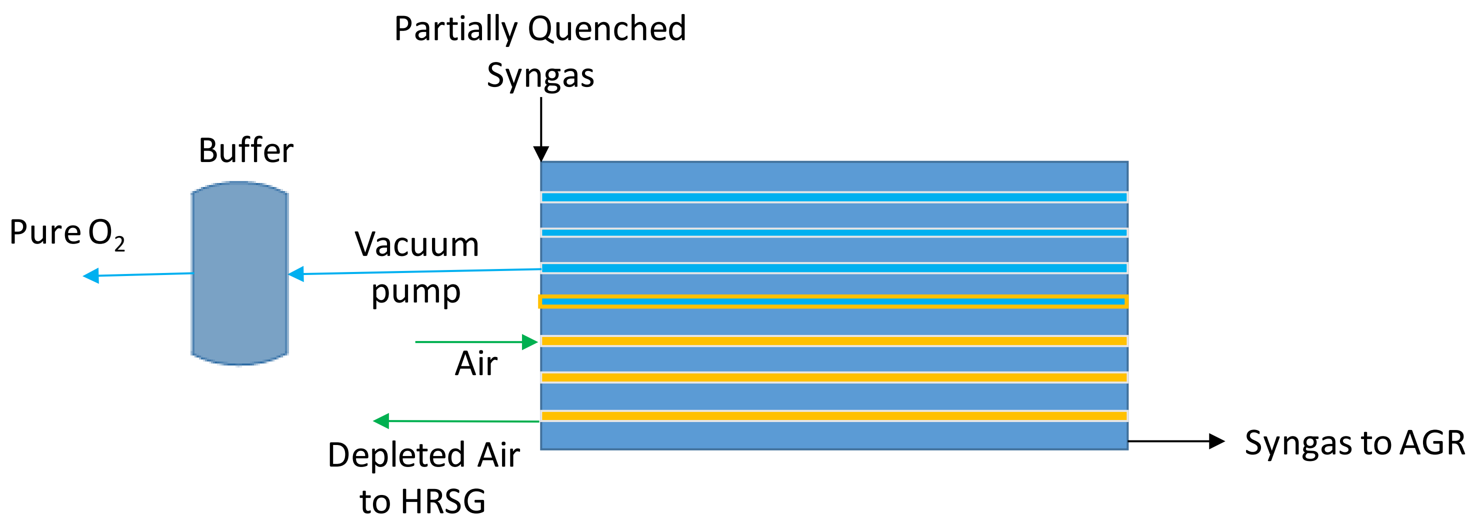
- Stand-alone >95% purity oxygen process for small-scale modular < 5MW coal gasification plants
- Design, build and operate a 1-tpd Oxygen Plant



Project DE-FE0028002

Full integration within a plant is possible

- Nearly adiabatic cycle
- Low pressure process reduces CAPEX and OPEX



THERMOSOLV LLC

Process Design

Important Properties/Variables…

- Sorbent Capacity, Kinetics, Density

Material Properties

- Sorption Pressure
- Pressure Swing
- Cycle Time
  - Sorption
  - Desorption
  - Rinse
- Packing Length
- Packing density

Plant/Equipment Design

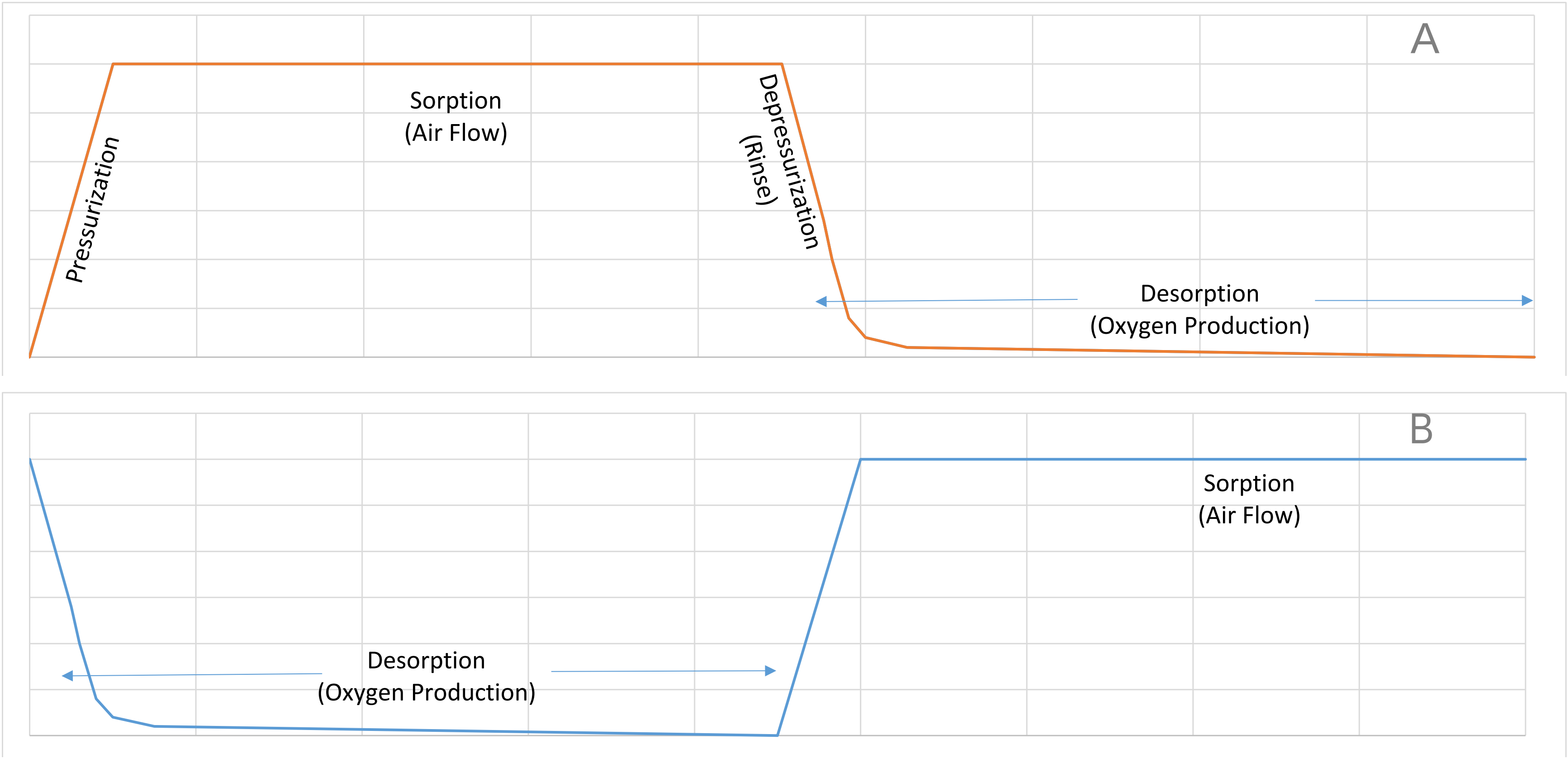
- Temperature

Integration

THERMOSOLV LLC

Project FE28002

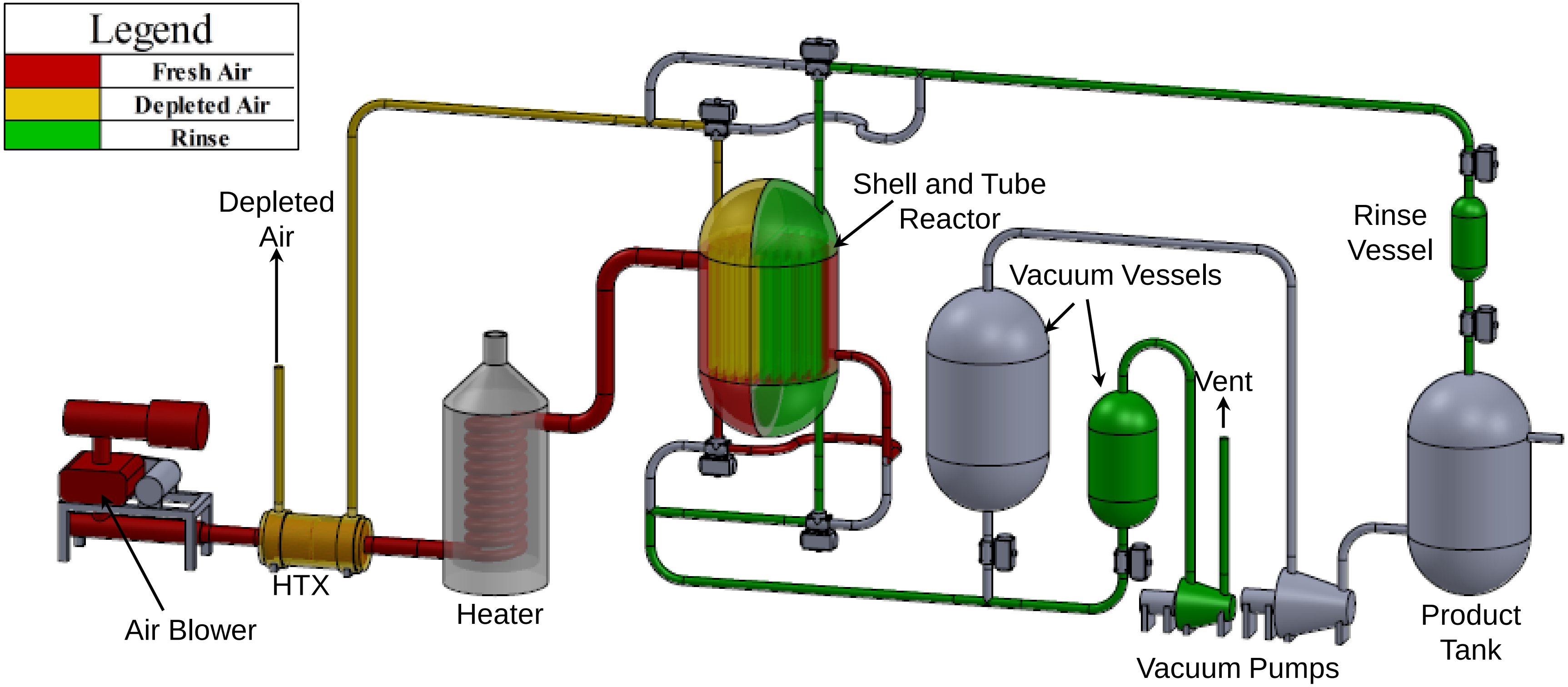
Two-Bed VPSA Cycle



THERMOSOLV LLC

Project FE28002

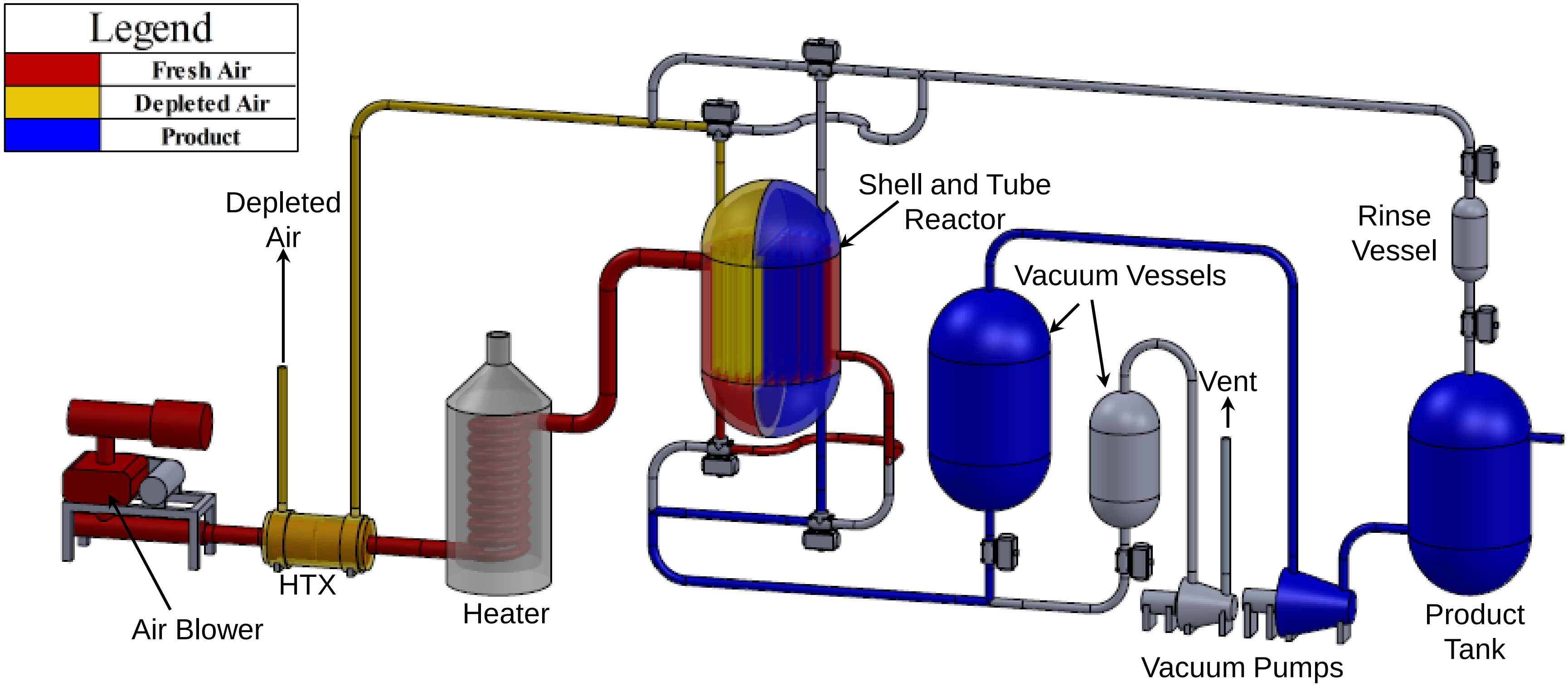
Two-Bed VPSA Cycle



THERMOSOLV LLC

Project FE28002

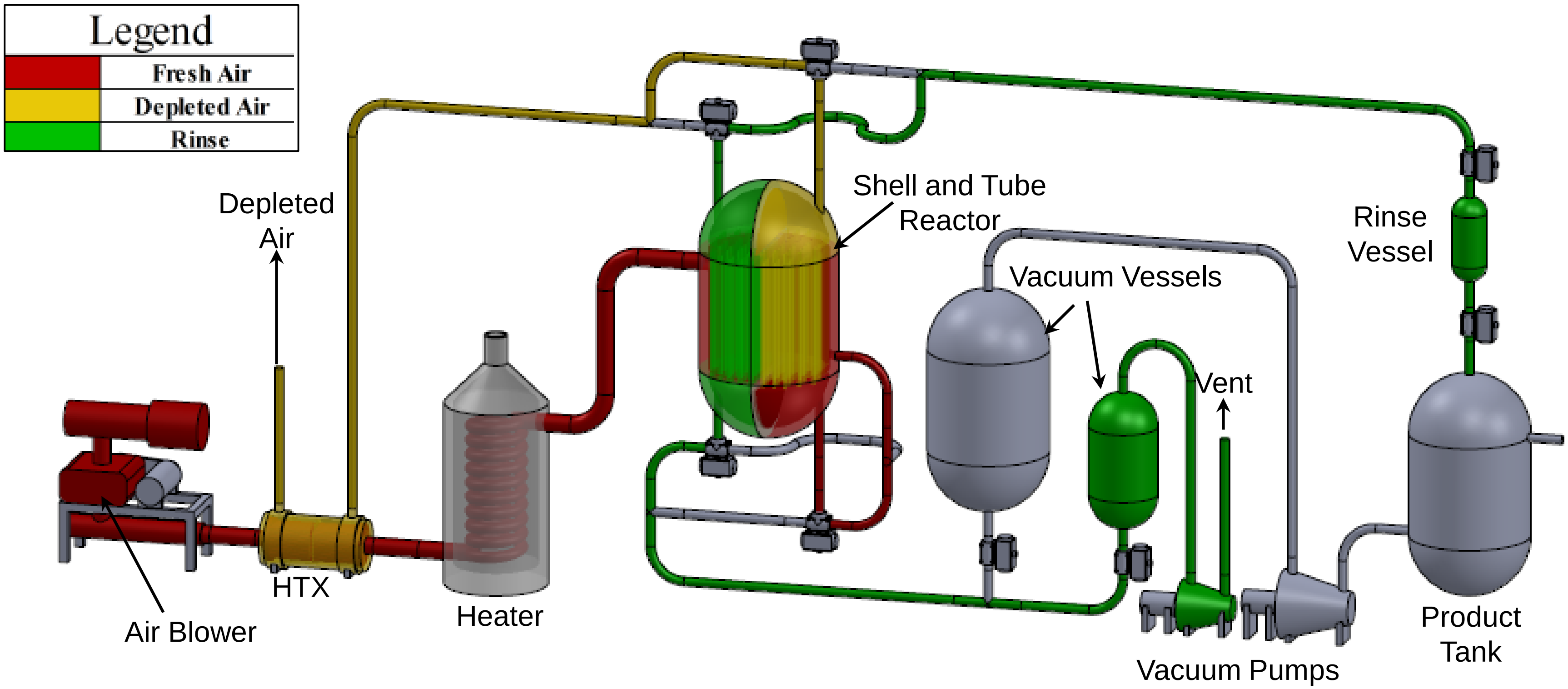
Two-Bed VPSA Cycle



THERMOSOLV LLC

Project FE28002

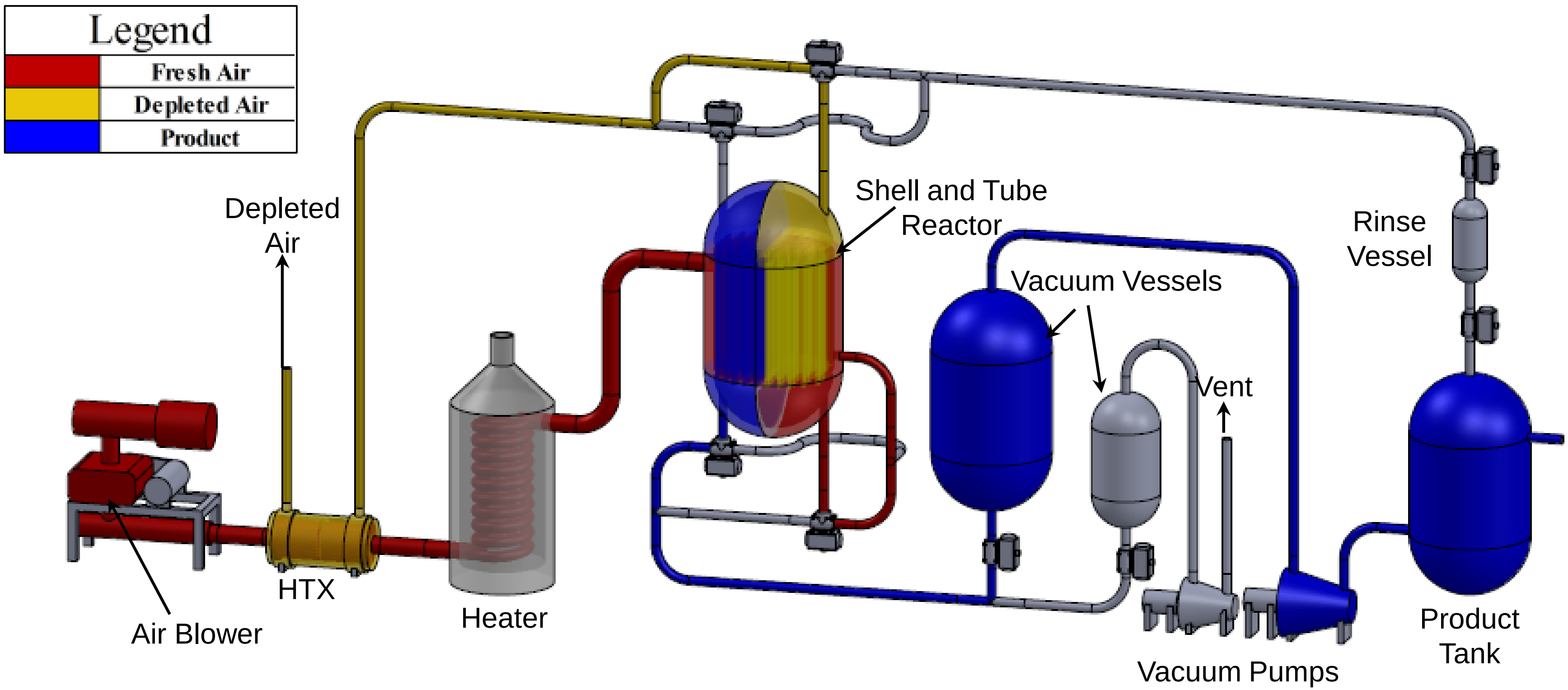
Two-Bed VPSA Cycle



THERMOSOLV LLC

Project FE28002

Two-Bed VPSA Cycle



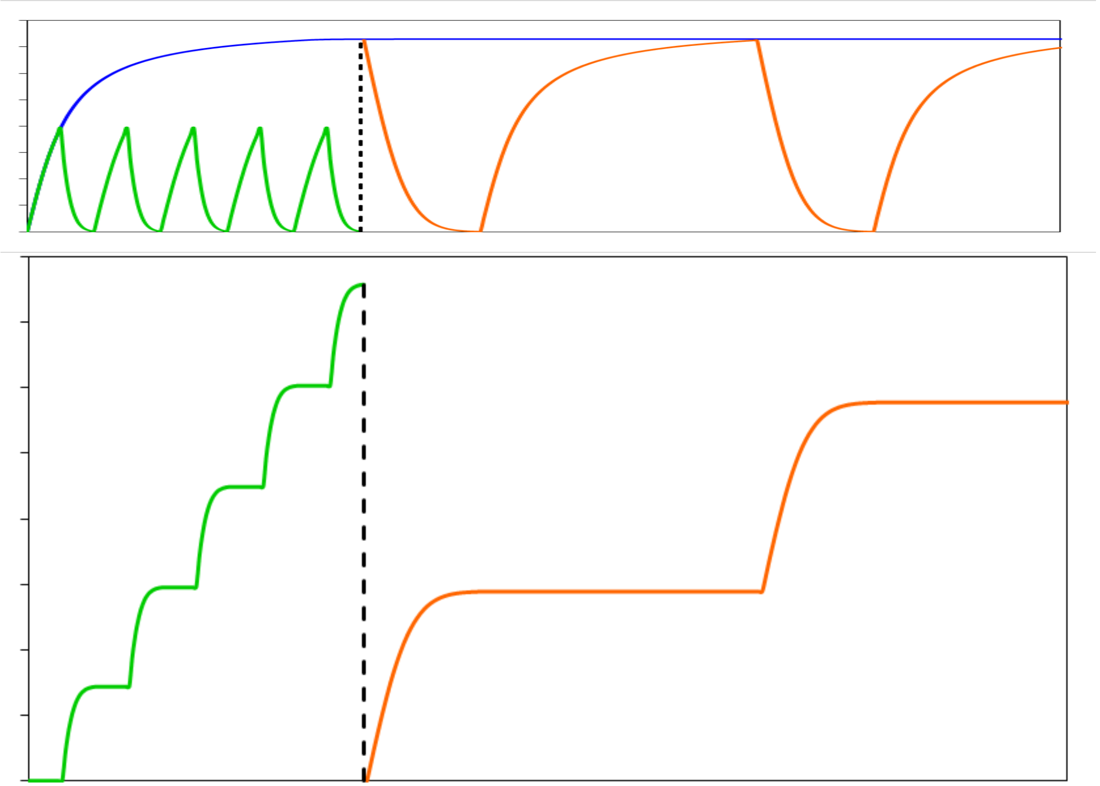
THERMOSOLV LLC

Process Design

Cycle Optimization

- Faster cycle times increase production

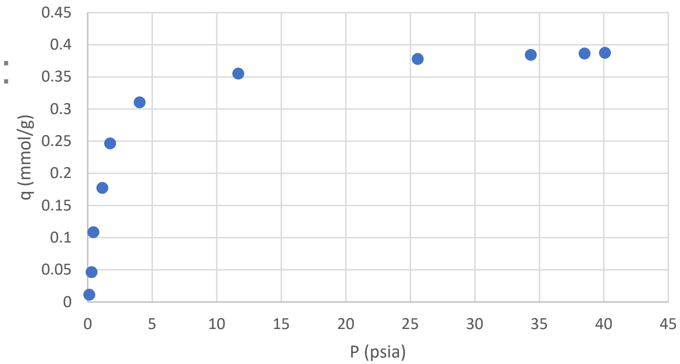
  (*equipment limitations and sorbent pack (ΔP) limit how fast)*

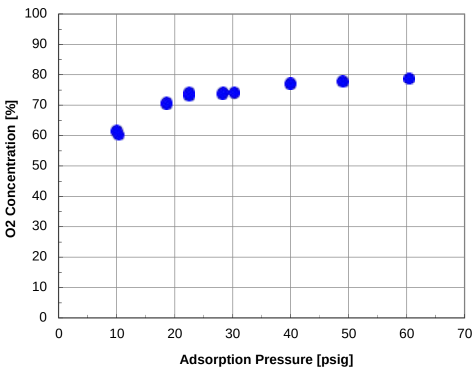


One Ton/Day Plant

Design Basis

- Sorption Pressure:
  - Use PD blowers
  - 20 psig





- Blower Capacity:
  - 300 SCFM

3X Theoretical

- Reactor :
  - 0.8 m^3 (~1,500 kg Sorbent)
  - Shell and Tube
  - 2” dia. 40” long tubes
  - Refractory-lined

Bench Data

- Cycle Time:
  - 2:1 sorption to desorption time (three sorbent beds)
  - 180 to 270 s/cycle

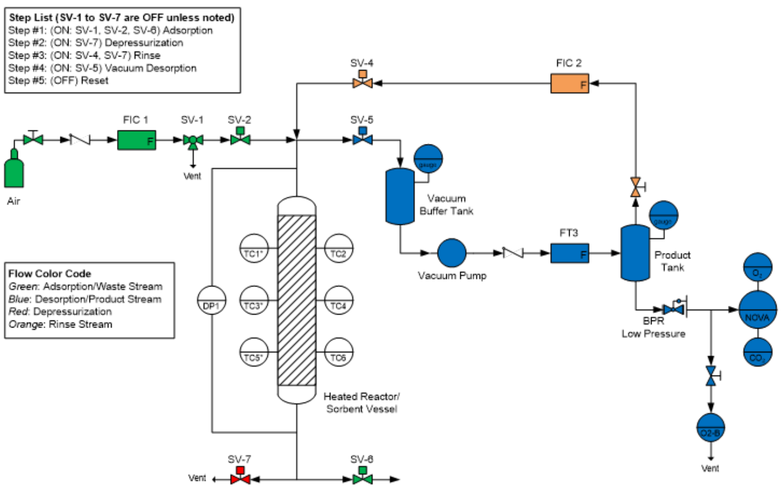
Bench Data

THERMOSOLV LLC

Bench-Scale Testing

- Bench-scale unit operated to determine optimal cycle structure, temperature, pressure, and required sorbent quantity
- Utilized to determine efficacy and stability of multiple sorbent samples
- Generated isotherm data for modelling purposes

- Bench testing completed successfully
- Through testing, determined that required sorption time is longer than desorption time
- Determined that pelletized sorbent is stable for several thousand hours
- Guided the design of the pilot to a 3-bed system which should give the highest chance of project success



THERMOSOLV LLC

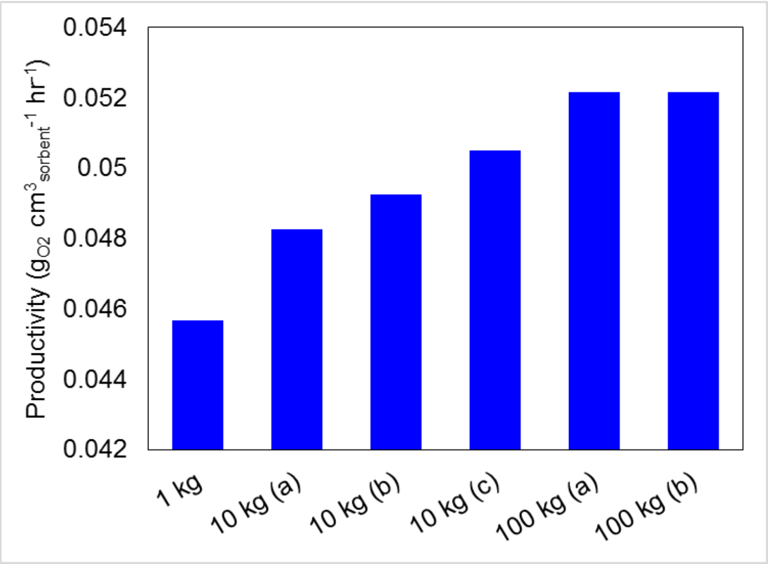
Sorbent Manufacturing

- Sorbent manufacturing was scaled from gram quantities to kilogram quantities
- Methods and procedures were transferred to a commercial partner for scaling to hundreds of kilograms
- Sorbent manufactured at scale has similar productivity to lab-synthesized sorbent
- Final pelletized sorbent has required mechanical properties and sorption kinetics
- Final manufacture of the sorbent is complete

THERMOSOLV LLC

Sorbent Manufacturing

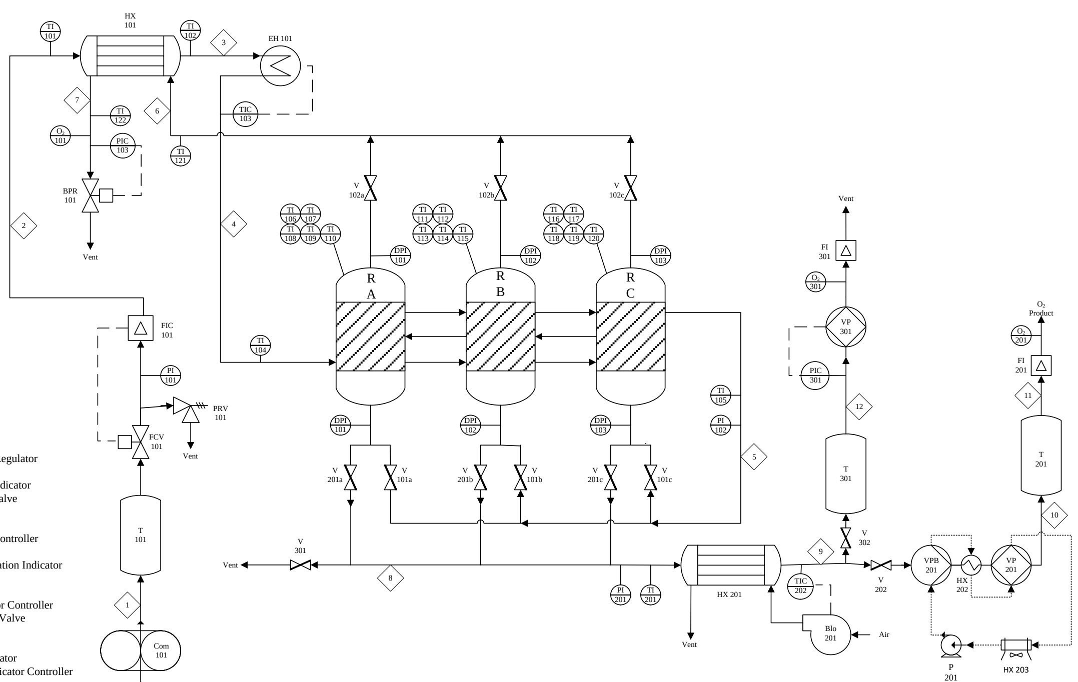
- Sorbent manufacturing was scaled from gram quantities to kilogram quantities
- Methods and procedures were transferred to a commercial partner for scaling to hundreds of kilograms
- Sorbent manufactured at scale has similar productivity to lab-synthesized sorbent
- Final pelletized sorbent has required mechanical properties and sorption kinetics
- Final manufacture of the sorbent is complete



THERMOSOLV LLC

Equipment and Process Design

- Required instrumentation located and specified
- Cycle structure mapped and simulated
- Safety review conducted to determine safe operational envelope
- Emergency mode operations designed and programmed into process logic



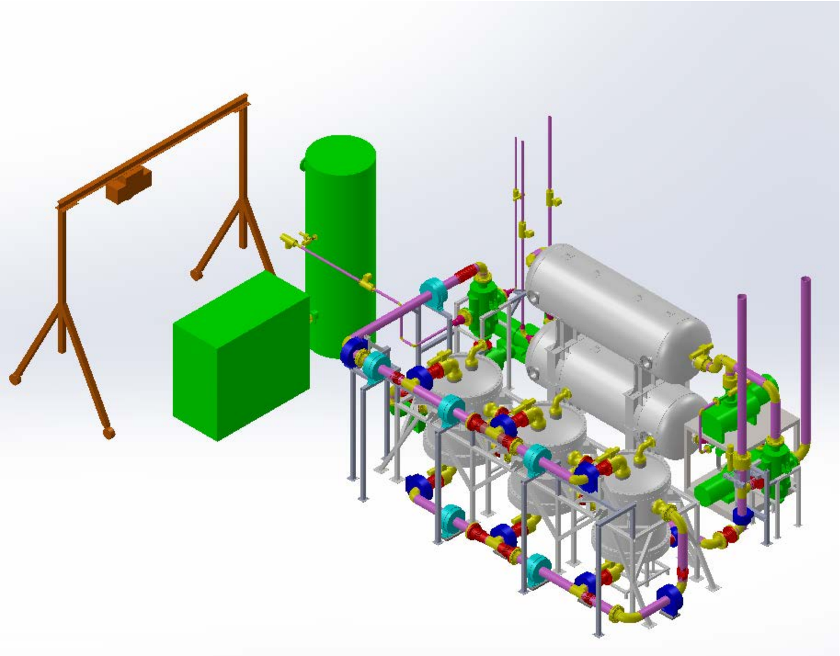
Blo = Blower
BPR = Back Pressure Regulator
Com = Compressor
DPI = Pressure Drop Indicator
FCV = Flow Control Valve
EH = Electric Heater
FI = Flow Indicator
FIC = Flow Indicator Controller
HX = Heat Exchanger
O_2 = Oxygen Concentration Indicator
P = Coolant Pump
PI = Pressure Indicator
PIC = Pressure Indicator Controller
PRV = Pressure Relief Valve
R = Reactor
T = Tank
TI = Temperature Indicator
TIC = Temperature Indicator Controller
V = Butterfly Valve
VP = Vacuum Pump
VPB = Vacuum Pump Booster
◇ = Pipe ID
100 Series = Air Path
200 Series = Product Path
300 Series = Purge Path

Proprietary and Confidential	Title:	Oxygen Plant	Rev 8
The information contained in this drawing is the sole property of Thermosolv. Any reproduction in part or as a whole without the written permission of Thermosolv is prohibited.		Name	Date
	Drawn	Bryce Dutcher	3/2/2018
	Checked	Garrett Wilson & Beau Braunberger	3/2/2018

THERMOSOLV LLC

Equipment and Process Design

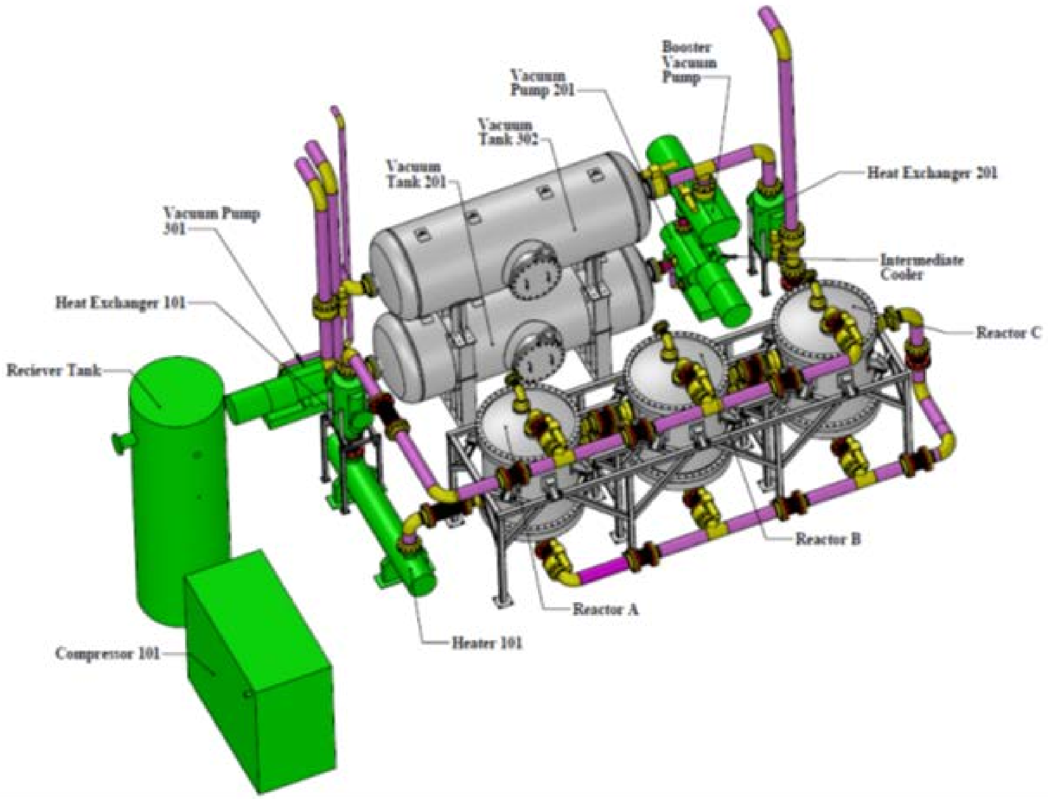
- Entire plant designed
- Sorption vessels require 0.8 m3 pelletized sorbent to achieve project goals
- Controls architecture and programming designed
- Metallurgy examined for temperature and oxygen stability
- Major and minor equipment items specified



THERMOSOLV LLC

Equipment and Process Design

- Simulations of final design operations show capable of successfully meeting project goals



THERMOSOLV LLC

Plant Fabrication

Current Status

- Plant is undergoing final shakedown
- All equipment has been tested and programmed
- Refractory has been cured up to reaction conditions
- Reactor loading and operation scheduled

Key Challenges

- Fabricated sorption reactors did not meet specified tolerances and required repair
- Commercial sorbent did not meet initial performance requirements

THERMOSOLV LLC

Risk Management

- Remaining major risk is to the schedule due to equipment unsuitability
- Tongue and groove seal between reactor shell and tube sheet was too long. This would result in excessive sealing pressure to the sealing faces when thermally cycled
- Refractory lining of shells was out of specified range and not concentric within the vessel
- All affected parts have been returned to the fabricator, and repairs have been completed

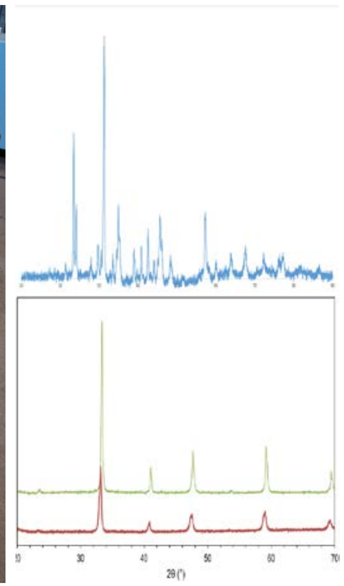
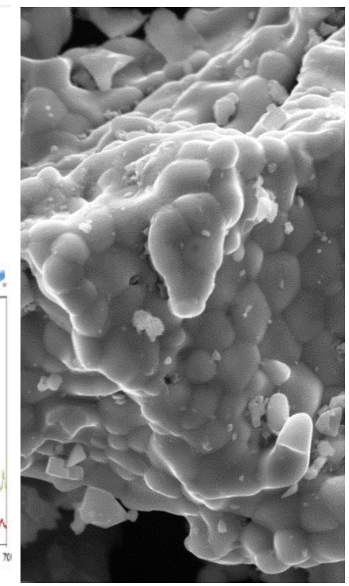




Risk Management

- Major risk to project due to low initial performance of sorbent
- After characterization, it was found that the phase purity was inadequate
- Testing showed that additional calcination would restore the material to satisfactory performance
- ¼ of the material was sent back to the manufacturer for repair
- Remaining material is being processed at Thermosolv



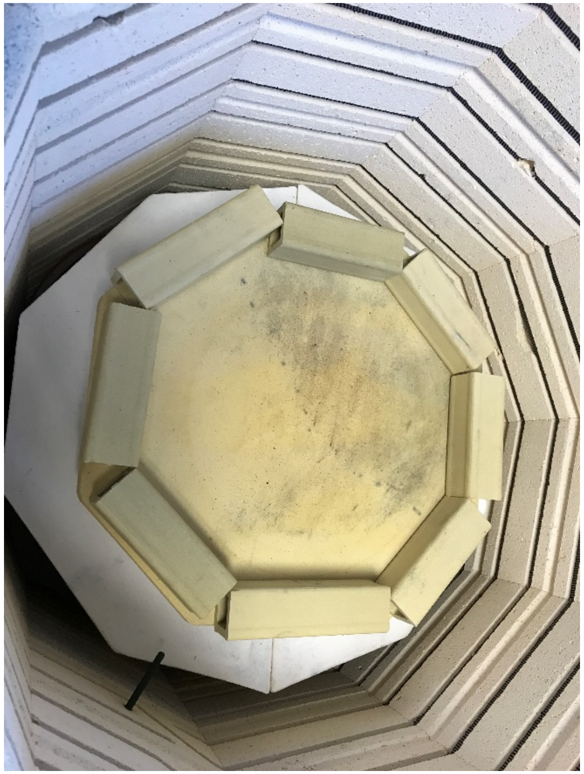
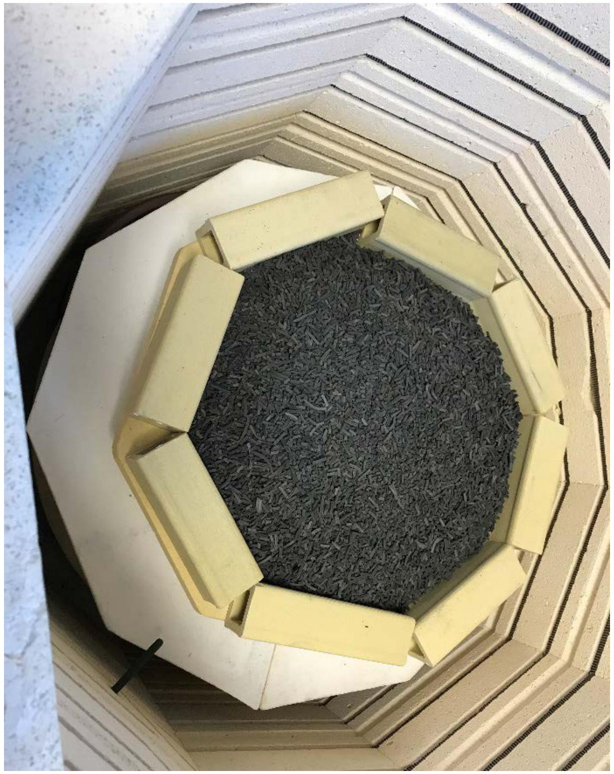




Risk Mitigation - Reactors

- Sent bottom reactor heads back to the fabrication shop for alterations
- Removed some of the refractory lining to make concentric for the tube bundles
- Shell/tube seal face modified for higher compression seal material
- Thermal imaging being utilized to ensure even temperature distribution throughout the shell

Risk Mitigation - Sorbent

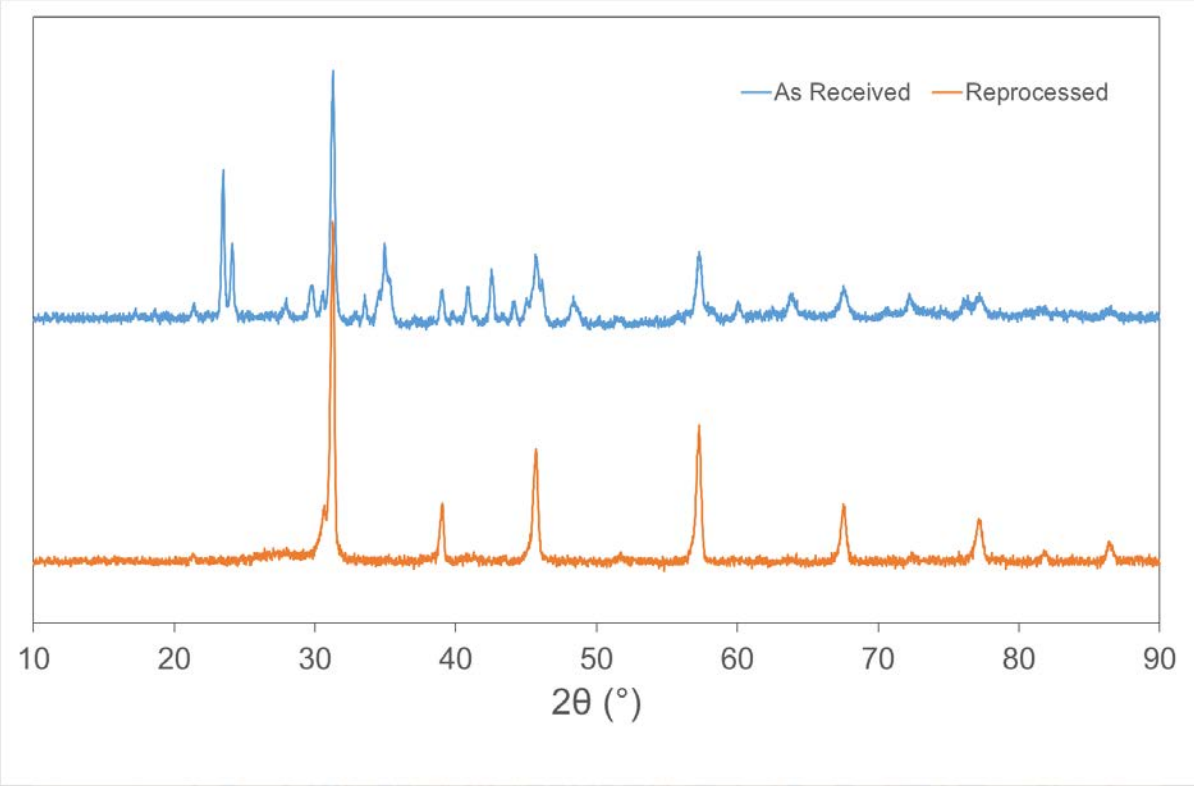
- Testing showed that 8 hours at 1100C would improve material performance by 35%-50%
- Two kilns are being operated around the clock to reprocess the material
- Manufacturer took back ¼ of the material for processing
- Full thermal treatment of the necessary fill volume will be completed next week


THERMOSOLV LLC

Analytical Results - XRD

- XRD reveals phase purity



THERMOSOLV LLC

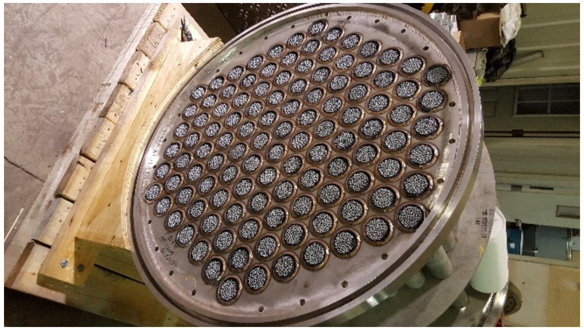
Plant Construction and Design Features




THERMOSOLV LLC

Plant Construction and Design Features

- **Tubesheet constructed of 304H SS for thermal stability**
- **Support plate utilized to maintain tube integrity**
- **SiC filter material utilized to keep sorbent in place**
- **Baffles allow for even thermal distribution throughout system**
- **Support struts to maintain bed integrity on top tubesheet**



THERMOSOLV LLC

Plant Construction and Design Features

- **Reactors hung from reactor shell to allow for vertical thermal expansion**
- **Roller-pad supports for horizontal thermal expansion**
- **Strain relief at all major joints to protect rigid plumbing**
- **Shells of all reactors linked to allow for even heating across all reactors**

Plant Construction and Design Features

- **Fully integrated support system for reactors and plumbing**
- **Access for floor crane for reactor and tubesheet maintenance**

THERMOSOLV LLC

Plant Construction and Design Features

- **Insulated piping guides and strain relief for safety and longevity**
- **Flanged construction for ease of maintenance and alterations**

THERMOSOLV LLC

Plant Construction and Design Features

- **Electrical heat for main process heating**
- **Heat exchange for recovery from depleted air**
- **Fully insulated system for process efficiency and safety**
- **All subsystems have been commissioned**

Path Forward

- Final thermal testing – This week
- Intermediate reactor seal testing – Next week
- Begin reactor fill and tuning – Anticipated April 22nd
- Final sintering of sorbent material – Anticipated April 22nd
- First full shakedown run – Anticipated April 29th

Acknowledgements

- **Department of Energy – Advanced Energy Systems Team**
- **Steven Markovich – Project Manager**
- **LP Amina – Modelling and Economic Analysis**
- **Western Research Institute**

Questions?