Residential Gas-fired Cost-effective Triple-state Sorption Heat Pump

Oak Ridge National Laboratory
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Project Summary

Timeline:

Start date: Oct 1, 2016

Planned end date: Sept 30, 2019

Key Milestones

1. First generation prototype evaluated in environmental chamber: Sept 30,2018
2. Model validation to breadboard experimental data: March 31, 2019

Budget:

Total Project $ to Date:

- DOE: $2000k
- Cost Share: $234k

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Key Partners:

SaltX Technology Holding, AB (formerly ClimateWell, AB)
Rheem Manufacturing Company
Purdue University

Oak Ridge National Laboratory

Rheem

SaltX

Purdue University

Project Outcome:

Validate the performance of gas-fired sorption heat pump with 1.4 seasonal gas coefficient of performance (SCOP) at acceptable price premium

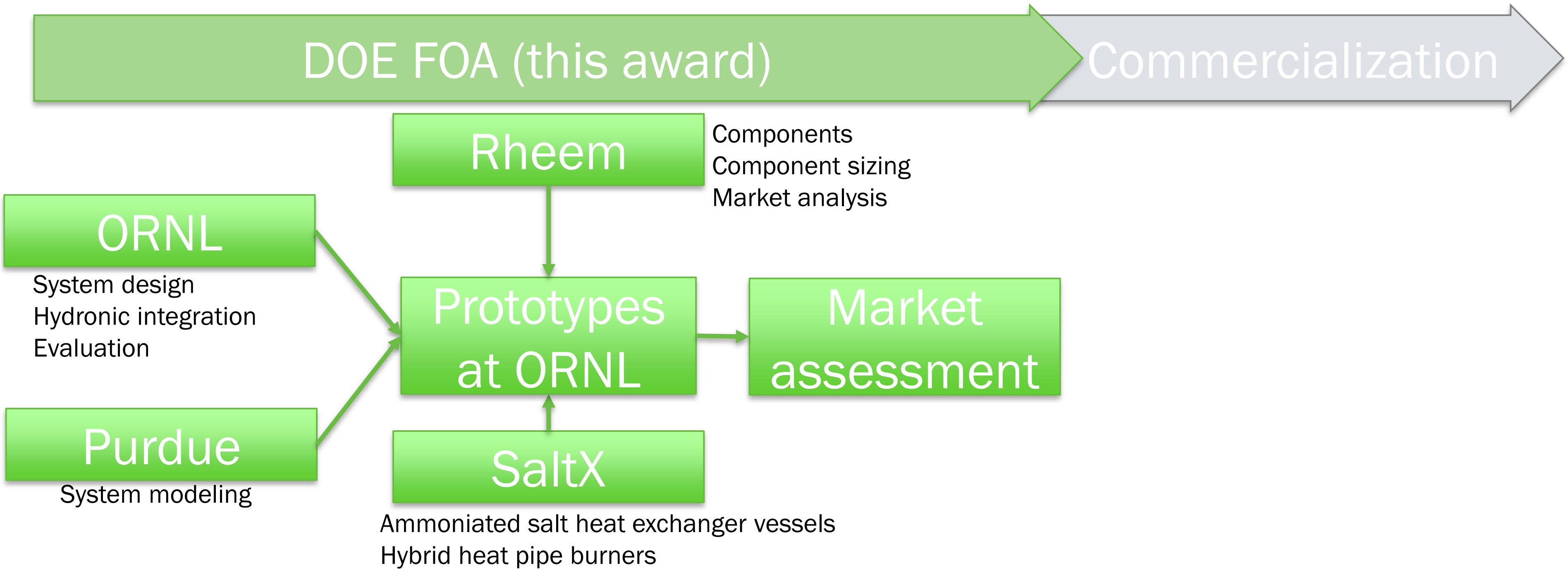
Proposed Goals

Metric	State of the Art	Proposed
Primary SCOP	*0.87 (furnace)* *0.83 (elec. HP)*	*1.4*
GCOP @ 0°F	*0.87 (furnace)* *0.30 (elec. HP)*	*1.20*

Team

Partners, Subcontractors, and Collaborators:

- Rheem Manufacturing Company: ensure market relevance, provide prototype materials
- SaltX Technology: develop reactor cores, sealed system
- ORNL: System-level integration and evaluation
- Purdue University (subcontract to ORNL): PhD student with GO! program



Team

Oak Ridge National Laboratory




Kyle Gluesenkamp
Sr. R&D Staff, Project PI

Tony Gehl
R&D Staff

Viral Patel
R&D Staff

Bo Shen
R&D Staff

- Experimental design and analysis
- Prototype fabrication, assembly, evaluation
- System modeling

SaltX



Ingemar Hallin
Project Manager

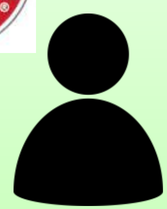
Corey Blackman
Chief Engineer

Michele Pressiani
Development Engineer

- SaltX matrix, salt, and vessel design and fabrication
- Burner design and fabrication

Rheem





Troy Trant
Director, Advanced Technology Analysis

Vishwanath Ardha
Combustion Research Engineer

Moatasm Ramli
Product Manager

- Components, component sizing
- Integration with space/water heating systems
- Market analysis

Purdue University


Zhiyao Yang
PhD student

Prof. Ming Qu
Advisor

- System modeling
- Experimental design support

All parties: biweekly teleconferences; periodic in-person meetings

Challenge

Problem Definition:

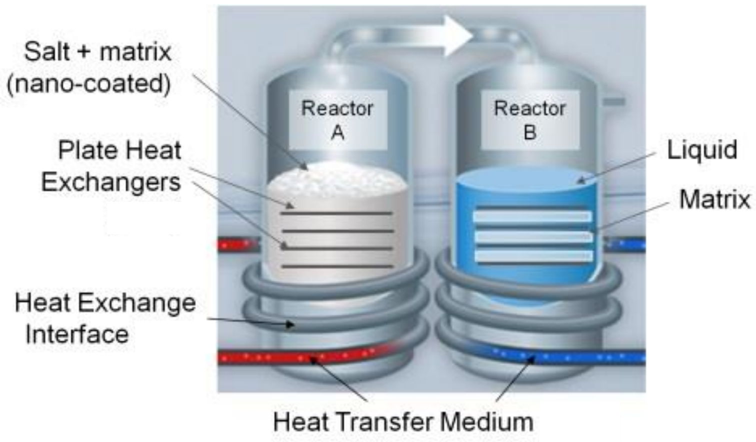
- High cost of residential space heating: ~$9,000 of gas over typical furnace lifetime

Maximum thermodynamically feasible furnace efficiency: 98%

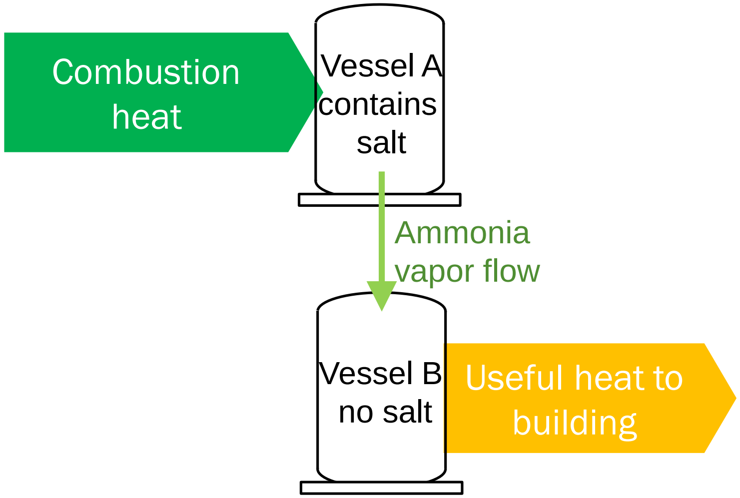
- Current furnaces are approaching thermodynamic maximum!
- Gas technologies with efficiency >100% have been too expensive for mass market
  - Absorption
    - Rotating seals (pump)
    - Ammonia expansion valve (specialty item)
    - Non-standard steel-tube heat exchangers
    - Periodic in-field charging in case of leakages through pump mechanical seals
  - Adsorption
    - Poor cold climate performance
    - Switching valves to regulate refrigerant flow
  - Engine-driven heat pump
    - Rotating seals (compressor)
    - Large parts count (engines)
    - Periodic in-field charging in case of leakages through pump mechanical seals

Approach – Working Principle

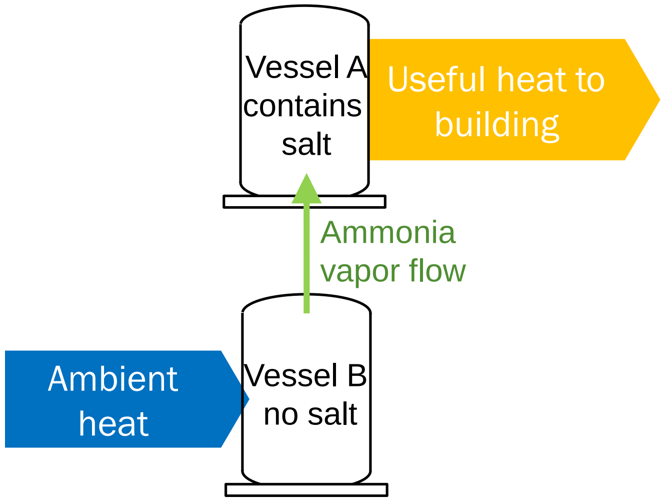
- Gas-fired heat pump extracts heat from ambient
- Novel nano-coated matrix suspends ammoniated salt and ammonia in heat exchange vessels
- Continuous heating by cyclic vessel operation
  - Vessel A: desorption (fuel) – absorption (heating)
  - Vessel B: evaporation (extract ambient heat) – condensation (heating)



Heat flows in desorption mode:

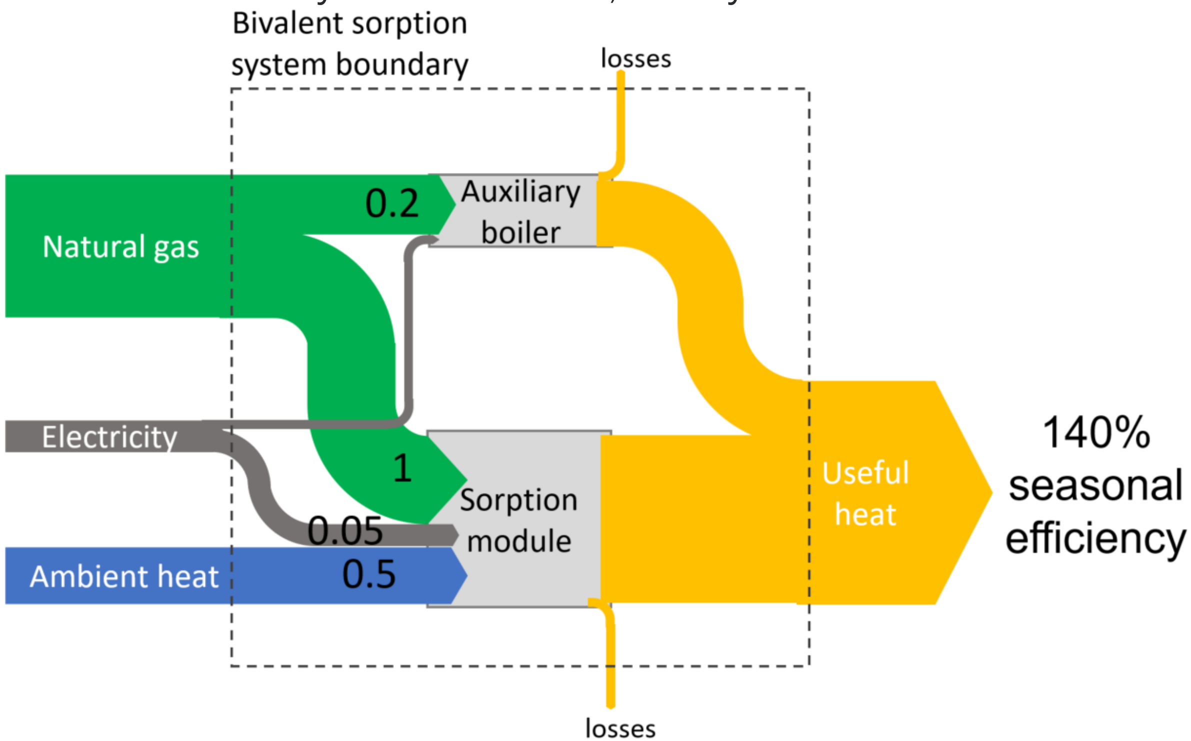


Heat flows in absorption mode:



Approach – Benefits

- Reduce cost of gas to consumers by 34% (annual fuel utilization efficiency [AFUE] of 140% vs 92%)
- Novel SaltX sorption heat pump addresses cost/complexity of traditional gas heat pump technologies:
  - No moving parts in sealed system (no pump, no valves)
  - High performance at cold ambient
  - Ammonia is housed entirely in outdoor unit, in fully hermetic vessels



Approach – Uniqueness

SaltX design eliminates problematic components in other gas fired heat pump

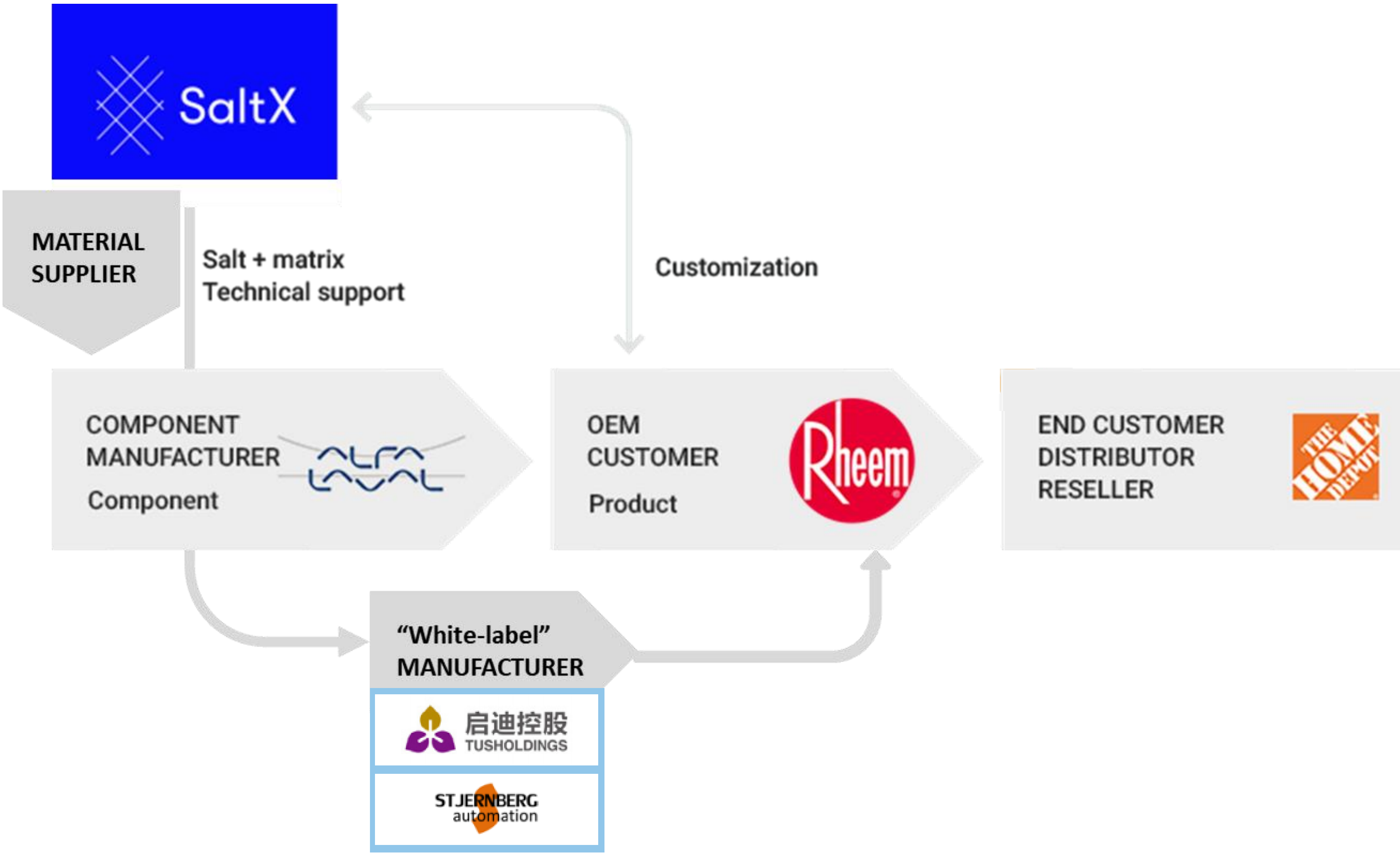
	SaltX	Ammonia/ water absorption	Adsorption	Gas engine driven vapor compression
Rotating seals	**None**	Pump	None	Compressor
Flex lines	**None**	None	None	Compressor
Expansion valve	**None**	Specialty item	Specialty item	Standard item
Switching valves	**None**	None	Specialty item	None
Specialty pumps	**None***	Specialty item	None*	None*
Cold climate	**Excellent**	Excellent	Poor	Good

*only require readily-available hydronic pumps with common specifications

Impact

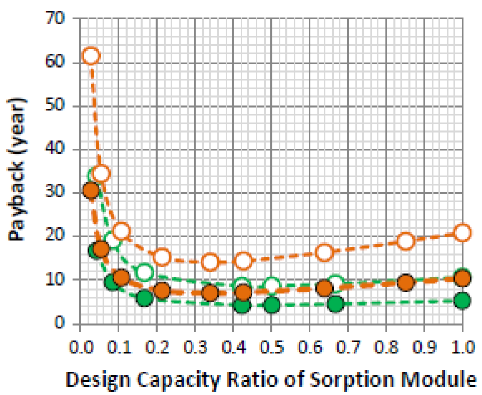
- Multi-Year Program Plan: compared with 2010 typical new technology (TNT – 0.78 AFUE), **44% cost of energy savings**
- Compared with 2030 TNT (0.92 AFUE condensing furnace), **34% cost of energy savings**
- 3-4 year simple payback for AIA climate zones 1 (>7000 HDD) and 2 (5,500-7,000 HDD)
- **1,037 TBtu/yr** technical potential
- Straightforward installation for existing HVAC contractor base, with outdoor combustion and hydronic coupling between indoor/outdoor units
- **Unique Characteristics:** Utilize innovative SaltX matrix technology to overcome the traditional product complexity of gas heat pumps
  - Fully hermetic sealed ammonia system (no rotating seals)
  - No pumped ammonia

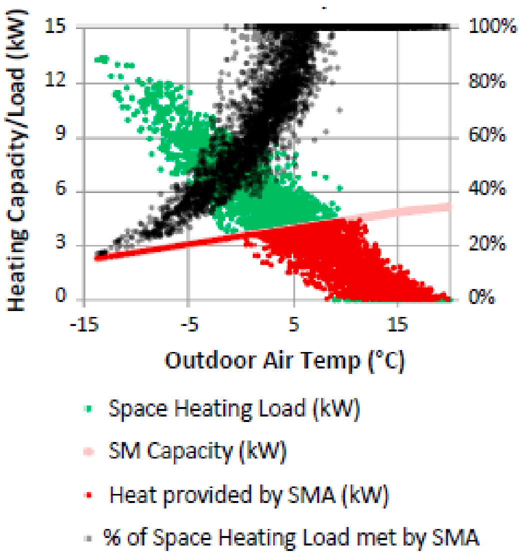
Impact – Commercialization Path

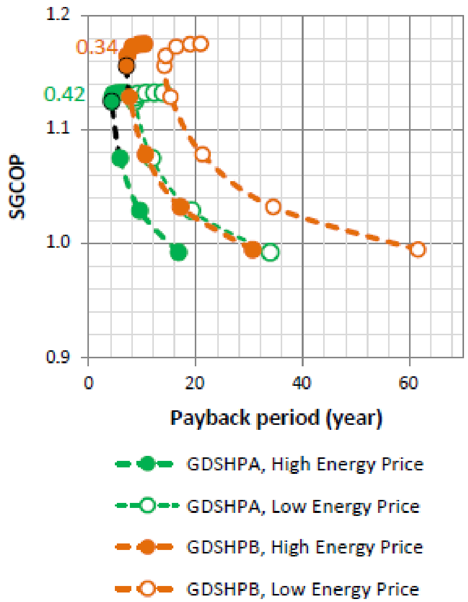


Progress – System Sizing

- Optimal sizing maximizes SGCOP and minimizes payback period
- Two hypothetical systems considered:
  - "GDSHPA" adsorption (lower cost, lower efficiency)
  - "GDSHPB" resorption (higher cost, higher efficiency)
- The optimum design heating capacity of GDSHP is between 22%-44% of peak capacity for the shortest payback
- Results below for NY climate location, notional sorption module cost scenario



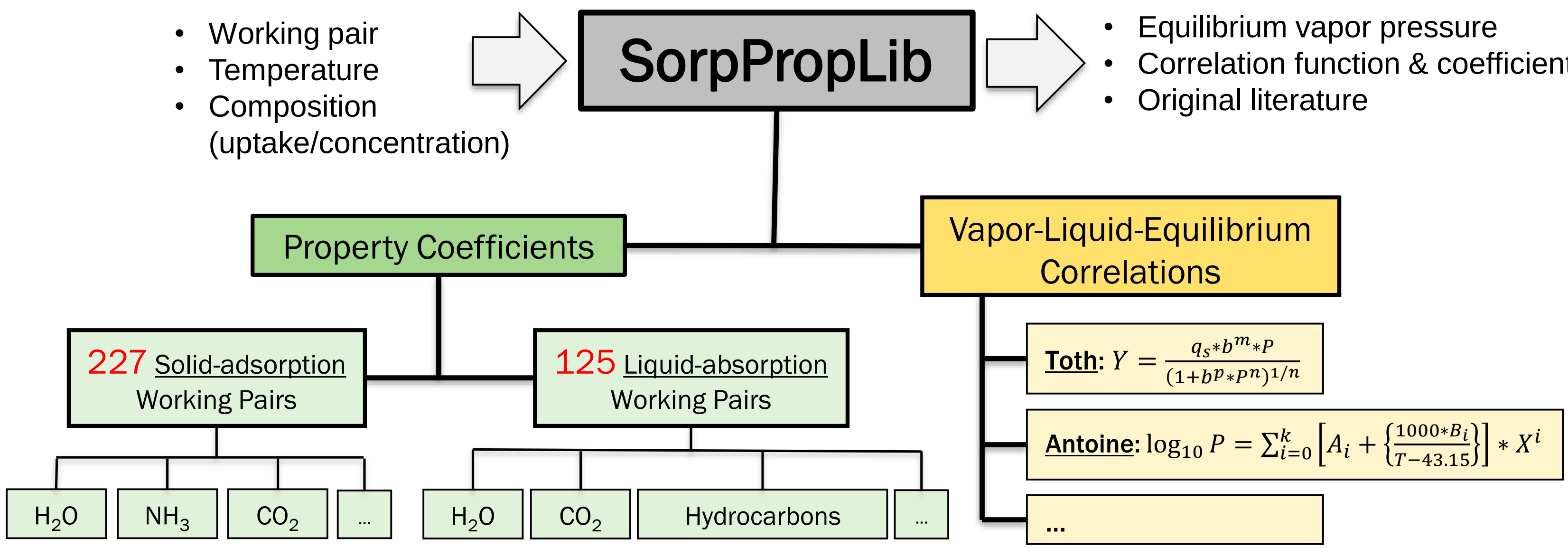




Blackman, Corey, Kyle R. Gluesenkamp, Mini Malhotra, and Zhiyao Yang (2019). Study of optimal sizing for residential sorption heat pump system. *Applied Thermal Engineering*, 150, 421-432.

Sorption Property Library (SorpPropLib)

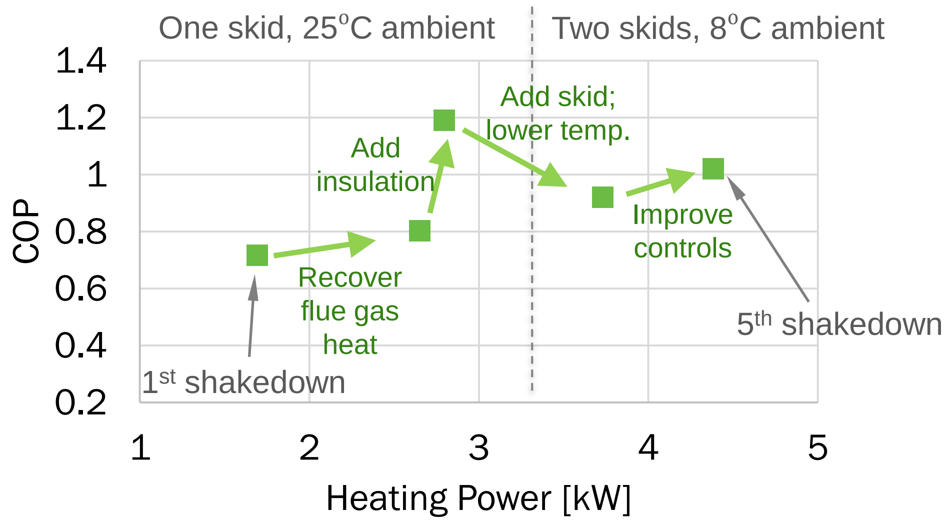
- Vapor-liquid-equilibrium (VLE) is critical to the performance of sorption-based heat pumps, energy storage, dehumidification, carbon sequestration, etc.
- The SorpProbLib database includes ***438*** generalized VLE correlations and coefficients for ***227*** solid-adsorption and ***125*** liquid-absorption working pairs
- The database is open-source to facilitate sorption research in various forms:
  - A standalone database program offering fast VLE inquiry of these working pairs
  - A compiled dynamic library (.dll) to support simulation in software such as Sorption system Simulation program (SorpSim), Engineering Equation Solver (EES), etc.
  - A JSON database to offer calculation in MATLAB, Python, and Web-based applications



https://github.com/zhiyaoyang/sorpproplib

Progress – Prototype Shakedown

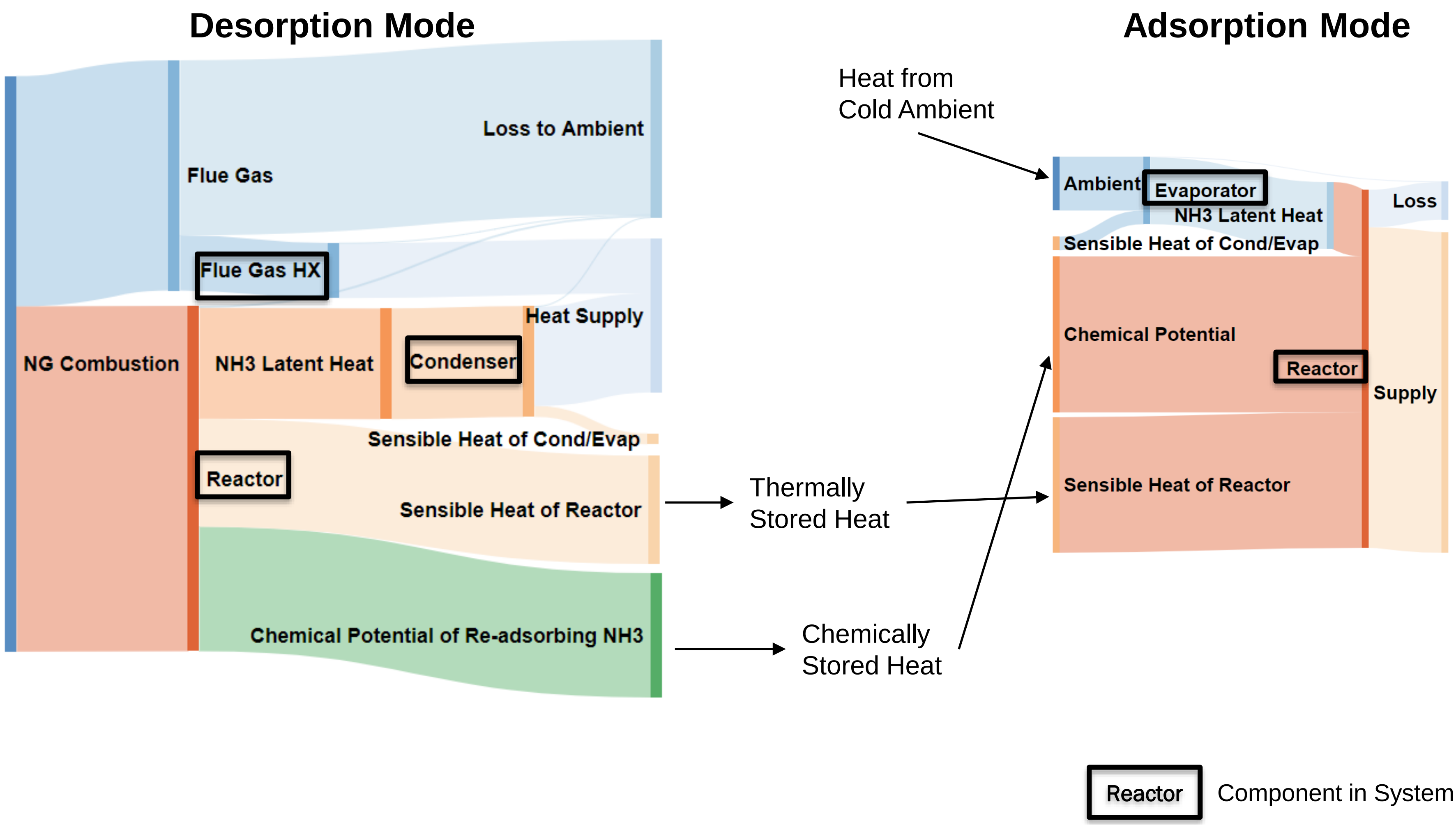
- Shakedown trials conducted: rapid increases in performance as team improves operation and control of prototype
  - Evaluation and development of breadboard resuming soon in FY19
- Performance matches model prediction, including shortcomings. Next prototype will address shortcomings of breadboard prototype:
  - Improve cycle COP with more complete ammonia desorption
  - Improve gas efficiency: improved boiler, heat exchangers
  - Address thermal losses with fundamental design change



$$GCOP = \eta_{comb}\left(\eta_{boiler}COP_{cycle} + (1-\eta_{boiler})\varepsilon_{FGHX}\right)(1-\lambda_{losses})$$

Progress – Prototype Test Summary

- Sankey diagram (to scale of the heat flux measured on Nov. 14th)



Stakeholder Engagement

- Collaboration among national laboratory (ORNL), industry (Rheem, SaltX), university (Purdue), and relevant component suppliers
- Active engagement with Rheem, US-based manufacturer of gas heating equipment
- Journal Publications:
  - Blackman, Corey; Kyle R. Gluesenkamp, Mini Malhotra, Zhiyao Yang (2019). “Study of Optimal Sizing for Residential Sorption Heat Pump System,” ***Applied Thermal Engineering***, v. 150, 421-432. (March 2019) https://doi.org/10.1016/j.applthermaleng.2018.12.151
  - Zhu, Chaoyi; Kyle R. Gluesenkamp, Zhiyao Yang, Corey Blackman (2019). “Unified Thermodynamic Model to Calculate COP of Diverse Sorption Heat Pump Cycles: Adsorption, Absorption, Resorption, and Multistep Crystalline Reactions”, ***International Journal of Refrigeration***, v. 99, 382-392. https://doi.org/10.1016/j.ijrefrig.2018.12.021

Stakeholder Engagement

- Publications – conference papers and presentations:
  - Yang, Zhiyao, Ming Qu, and Kyle R. Gluesenkamp. 2018. "Performance Comparison of Chemisorption Heat Pump Cycles Using a Generalized Analytical Model," ***17th International Refrigeration and Air Conditioning Conference***, Purdue University, West Lafayette, IN, July 9-12, 2018.
  - Yang, Zhiyao, Kyle R. Gluesenkamp, and Andrea Frazzica. 2018. "Database of sorption material equilibrium properties," ***Heat Powered Cycles***, Bayreuth Germany, 16-19 September 2018.
  - Gluesenkamp, Kyle R., Zhiyao Yang, and Andrea Frazzica. 2018. "Database of Vapor Equilibria for Sorption Materials". Presented to ***8th Expert Meeting of the IEA HPP Annex 43***, May 16, 2018, Stockholm, Sweden.
  - Blackman, Corey, Kyle R. Gluesenkamp, Mini Malhotra, and Zhiyao Yang. 2017. "Study of Optimal Sizing for Residential Sorption Heat Pump System." ***International Sorption Heat Pump Conference***, August 7–10, 2017, Tokyo, Japan.
  - Yang, Zhiyao, Kyle R. Gluesenkamp, and Andrea Frazzica. 2017. "Database of Equilibrium Vapor Pressures for Sorption Materials." ***International Sorption Heat Pump Conference***, August 7–10, 2017, Tokyo, Japan.

Remaining Project Work

- FY 2019 (Oct 1, 2018 – Sep 30, 2019)
  - Address issues leading to low prototype efficiency:
    - Reduce heat loss from uninsulated components
    - Balance the water flow between skids, which has led to reduced performance
    - Improve flue gas heat exchanger effectiveness
    - Improve control of steam temperature to maximize COP
  - Evaluate breadboard prototype – standard conditions
  - Utilize breadboard prototype to investigate chemical kinetics
  - Dissemination: publish experimental results
  - Design and fabricate packaged prototype
- FY 2020
  - Evaluate packaged prototype
  - Commercialization determination by industry partners (stage gate)
  - Dissemination: Publish experimental results and project learning
- Beyond this project period of performance
  - Continued development to address challenges identified in this project
  - EU and NEEA funding granted – growing interest in gas heat pumps

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: $2000k DOE plus $234k cost share, beginning in FY 2017
Variances: None
Cost to Date: $1113k
Additional Funding: None

Budget History					
FY 2017 (past)		FY 2018 (current)		FY 2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
2,000k	234k	0	0k	0	0k

Project Plan and Schedule

- Initiation: 10/1/2016
- Planned completion: 9/30/2019 (now 5/31/2020)
- Initial delays in prototype shakedown (7.1) due to leaks. Resolved and evaluation began.
- Further delays (7.2) due to retroactive change in DOE pressure system safety rules