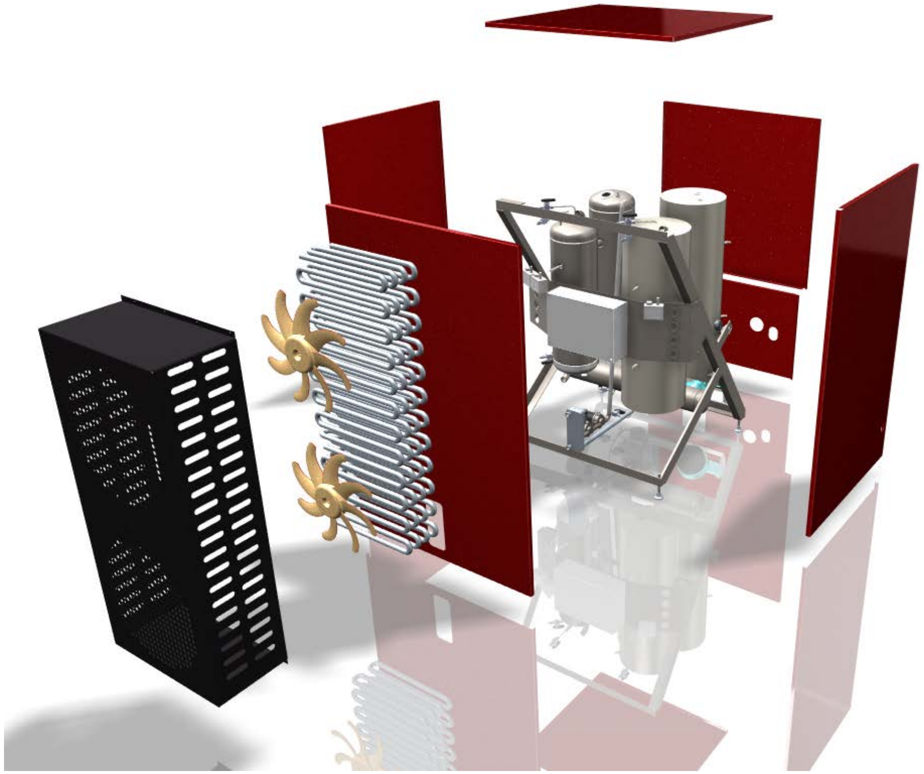
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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. Model evaluation: heating capacity >20 kBtu/hr @–11°F ambient, SGCOP>1.2; June 30, 2017
2. Resorption configuration eliminated; June 30, 2017
3. Reactors evaluated at 22.3 W/L heating capacity at entering glycol temperature of -13.4°C (+8°F); Nov 15, 2017.

Budget:

Total Project $ to Date:

- DOE: $2000k
- Cost Share: $59k

Total Project $:

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

Key Partners:

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

Project Outcome:

Validate the performance of gas-fired sorption heat pump with 1.4 seasonal gas COP at acceptable price premium

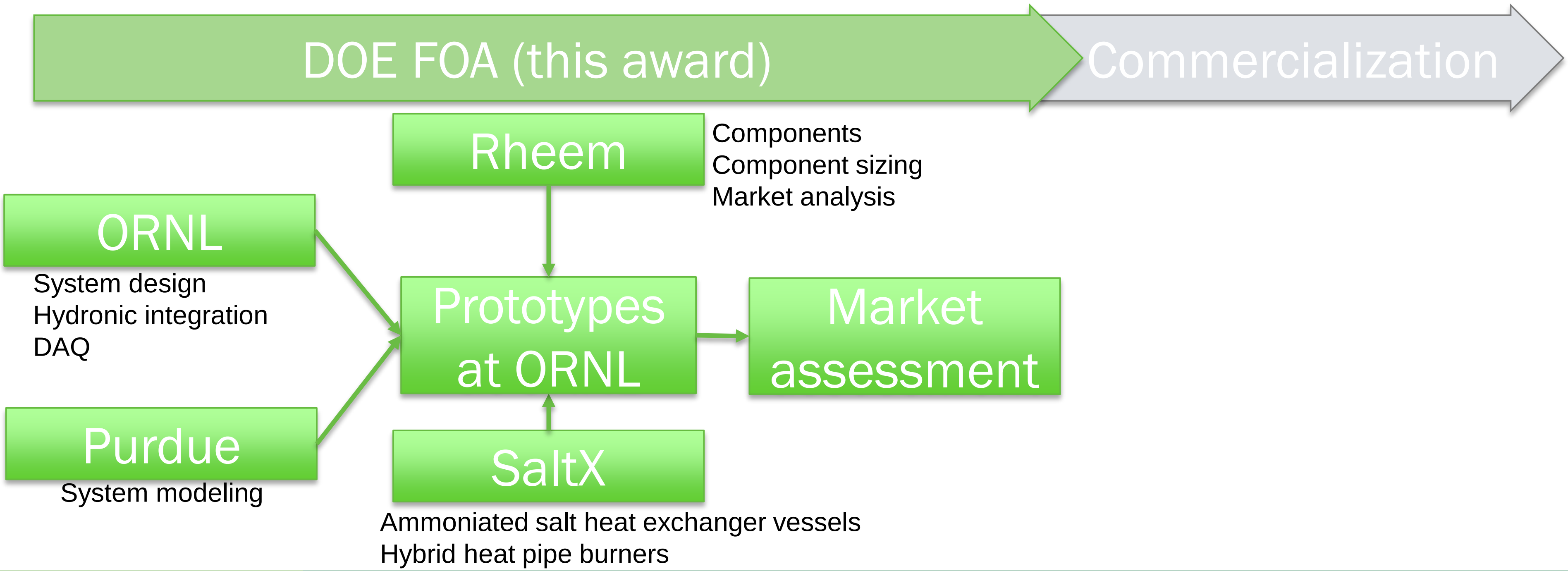
Proposed Goals

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
R&D Staff, Project PI

Anthony 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

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

Rheem

Troy Trant
Sr. Mgr, 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:

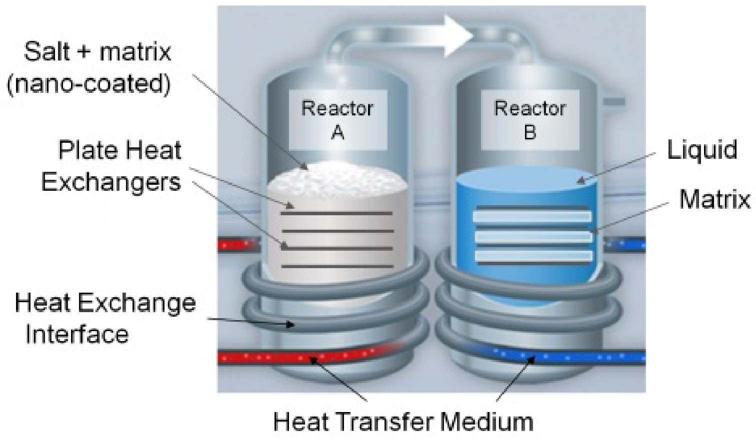
- High cost of residential space heating: ~$9,000 of gas over typical furnace lifetime

Maximum thermodynamically feasible furnace efficiency: 98%

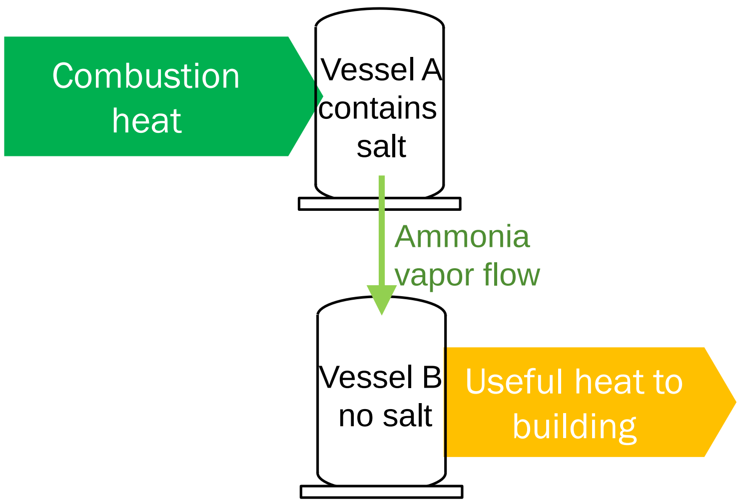
- Current furnaces are approaching thermodynamic maximum!
- Gas technologies with efficiency >100% have been too expensive for mass market
  - Absorption
    - Rotating seals (pump)
    - Ammonia expansion valve (specialty item)
    - Non-standard steel-tube heat exchangers
    - Periodic in-field charging 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

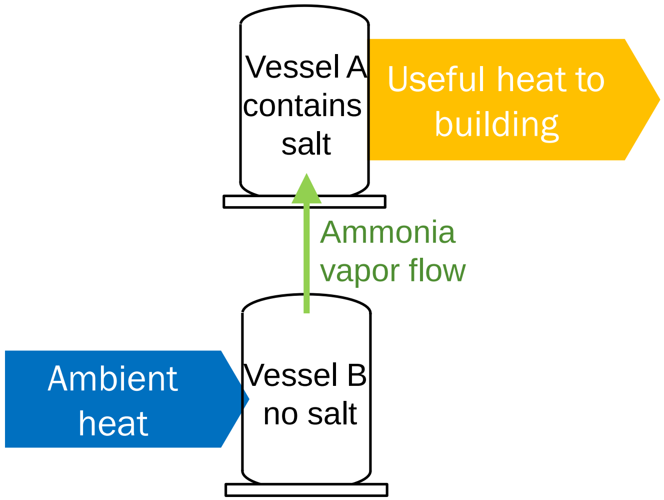
- Gas-fired heat pump extracts heat from ambient
- Novel nano-coated matrix suspends ammoniated salt and ammonia in heat exchange vessels
- Continuous heating by cyclic vessel operation
  - Vessel A: desorption (fuel) – absorption (heating)
  - Vessel B: evaporation (extract ambient heat) – condensation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



Heat flows in desorption mode:

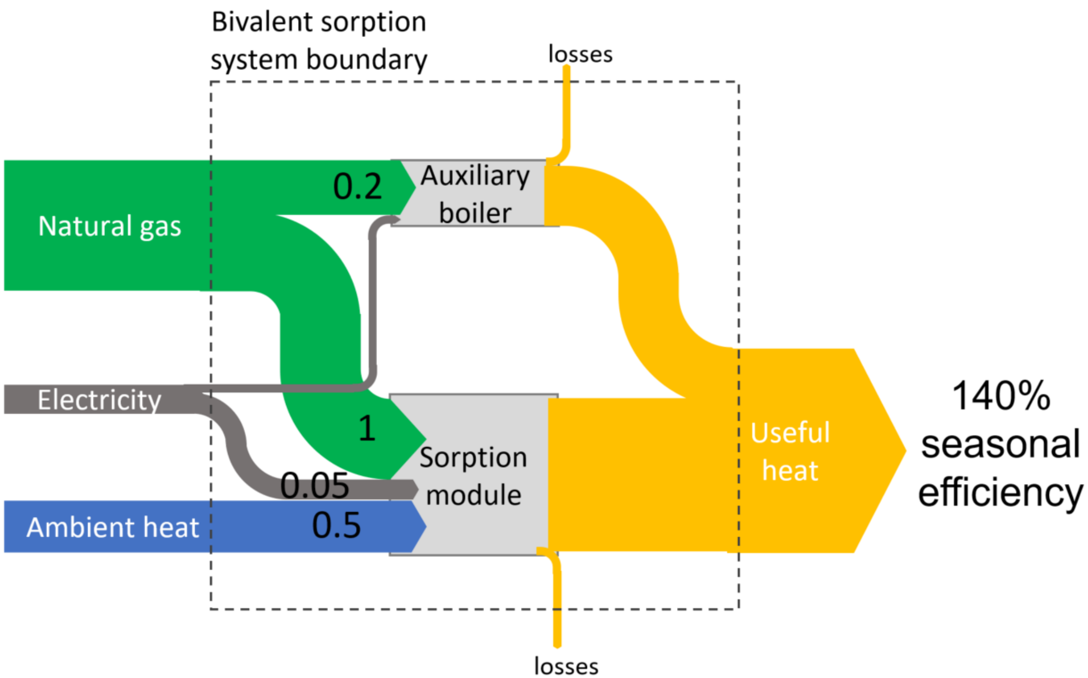


Heat flows in absorption mode:



Approach – Benefits

- Reduce cost of gas to consumers by 34% (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 ambients
  - Ammonia is housed entirely in outdoor unit, in fully hermetic vessels
  - No specialty ammonia components required
    - no expansion valve
    - no regulating or shutoff valves
    - no pump
    - no flexible seals
    - no sliding or rotating seals



Approach – Uniqueness

SaltX design eliminates problematic components in other gas fired heat pump

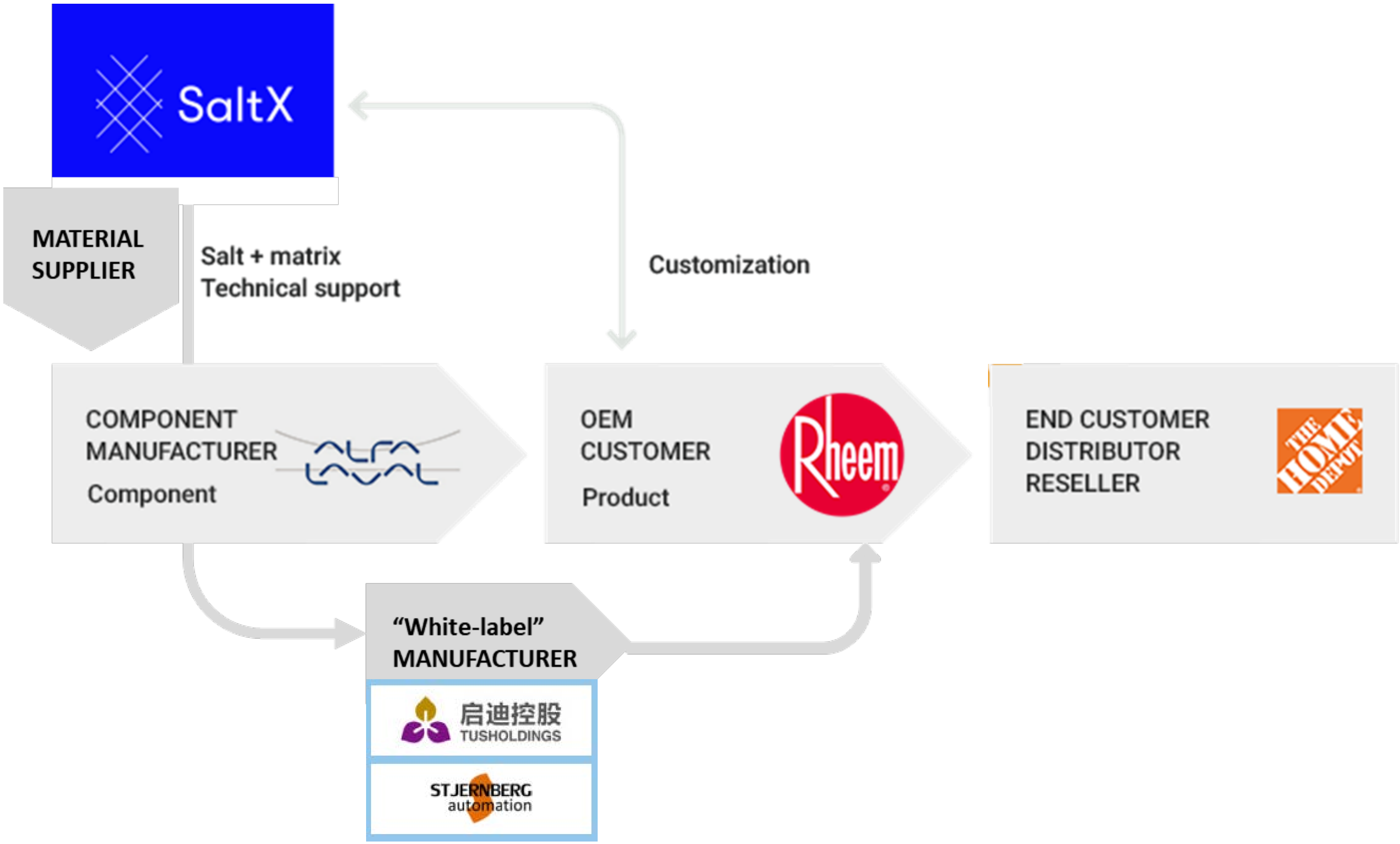
	SaltX	Ammonia/ water absorption	Adsorption	Gas engine driven vapor compression
Rotating seals	**None**	Pump	None	Compressor
Flex lines	**None**	None	None	Compressor
Expansion valve	**None**	Specialty item	Specialty item	Standard item
Switching valves	**None**	None	Specialty item	None
Specialty pumps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

*only require readily-available hydronic pumps with common specifications

Impact

- MYPP: compared with 2010 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 climate zones 1-2
- **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

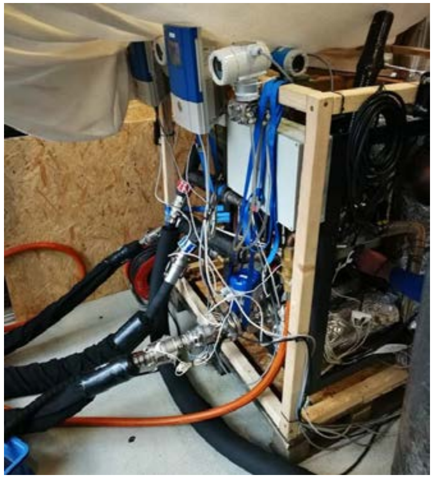


Progress – Vessel Fabrication and Evaluation

Experimental test results acquired: single vessel pair delivered 22.3 W/L heating capacity at entering glycol temperature of –13.4°C (+8°F). This is 64% of the target volumetric capacity. We are increasing volumetric capacity with improved burner controls, to:

- Increase heat pipe temperature
- Improve modulation during end of desorption phase

Vessels mounted on a skid with the burner, hybrid heat pipe, and controls



Vessels connected to the glycol loop and heating fluid loop at the testing facility

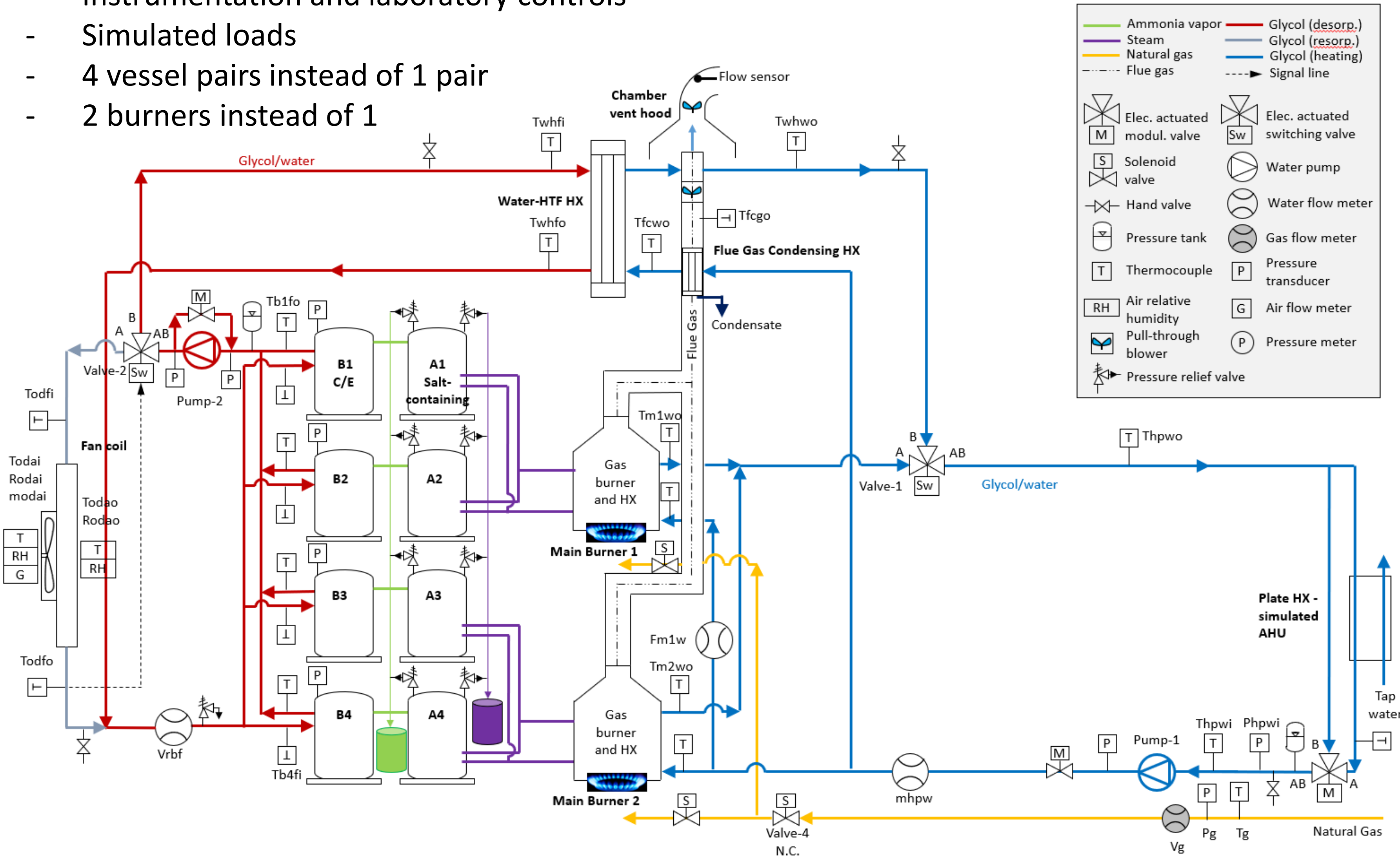
Progress – Breadboard Fabrication

- Target heating capacity: 12.5 – 50 kBtu/hr @ 47° F ambient (modulating)
- At current heat exchanger and vessel production capacities, this requires 4 pairs of vessels

Progress – Breadboard Design

Breadboard is more complicated than eventual product:

- Instrumentation and laboratory controls
- Simulated loads
- 4 vessel pairs instead of 1 pair
- 2 burners instead of 1



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
- Publications:
  - Blackman, Corey; Kyle R. Gluesenkamp, Mini Malhotra, 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, Andrea Frazzica (2017). "Database of Equilibrium Vapor Pressures for Sorption Materials." *International Sorption Heat Pump Conference*, August 7–10, 2017, Tokyo, Japan.
  - Zhu, Chaoyi; Kyle R. Gluesenkamp, Zhiyao Yang, Corey Blackman. "Unified Model Applicable to Diverse Sorption Heat Pumps: Adsorption, Absorption, Resorption, Multistep Crystalline Reactions, and Combined Condenser/Evaporator" *Manuscript in preparation*.

Remaining Project Work

- FY18
  - Evaluate breadboard prototype – standard conditions
  - Evaluate breadboard prototype – extended conditions
  - Dissemination: Publish chemisorption review paper
  - Dissemination: Publish experimental results
  - Design packaged prototype
- FY19
  - Evaluate packaged prototype
  - Commercialization determination by industry partners (stage gate)
  - Dissemination: Publish experimental results and project learnings
- Beyond this project period of performance
  - Commercialization determination by industry partners
  - Continued development to address challenges identified in this project

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: $563k
Additional Funding: None

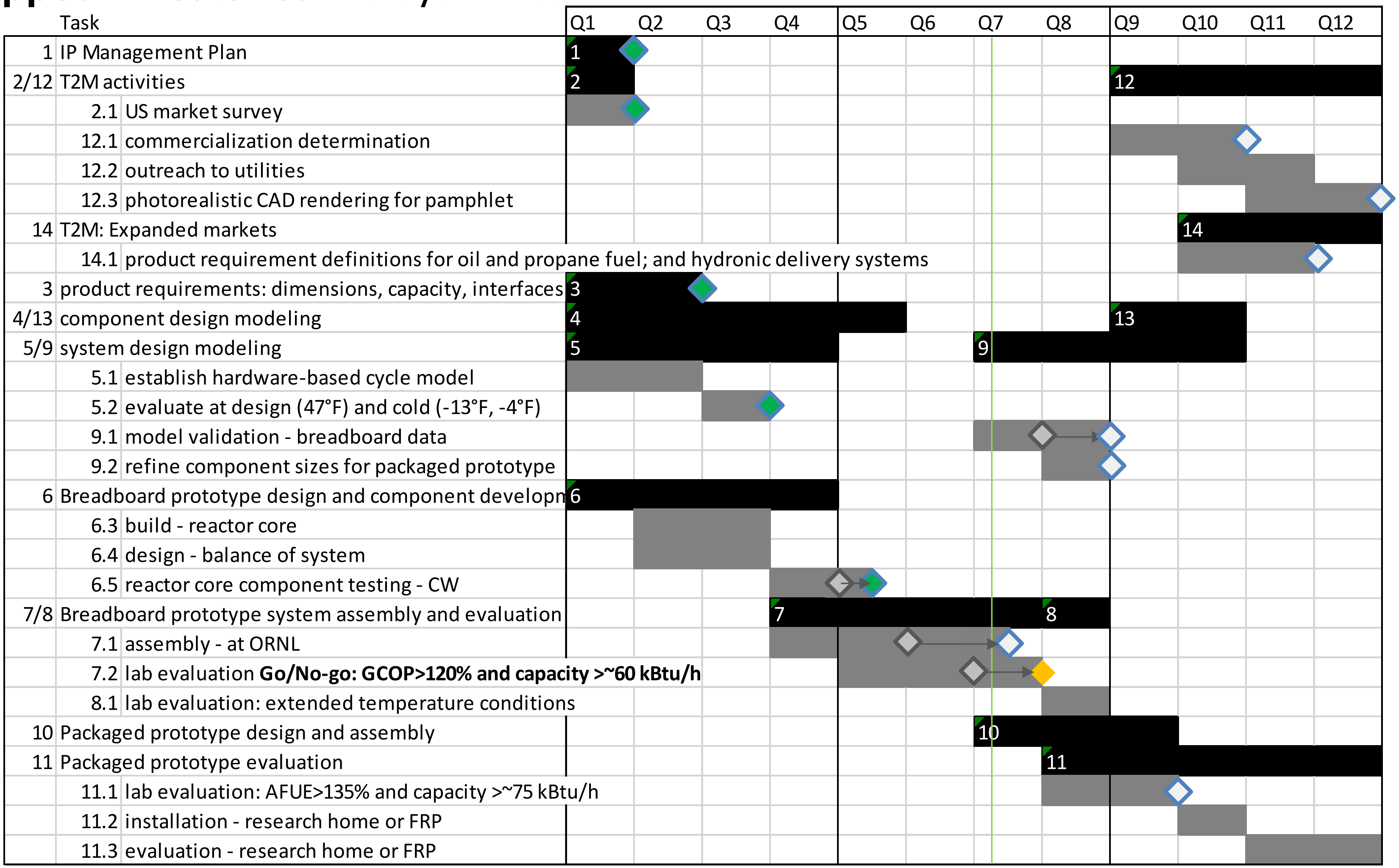
Budget History					
FY 2017 (past)		FY 2018 (current)		FY 2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
2,000k	47k	0	12k to date		

Project Plan and Schedule

Milestone - met
Milestone - planned
Go/No-go milestone

Project Initiation and End Dates: Oct 1, 2017 – Sep 30, 2020

Slipped milestones: Delays in vessel and HX fabrication



Note: not all subtasks shown