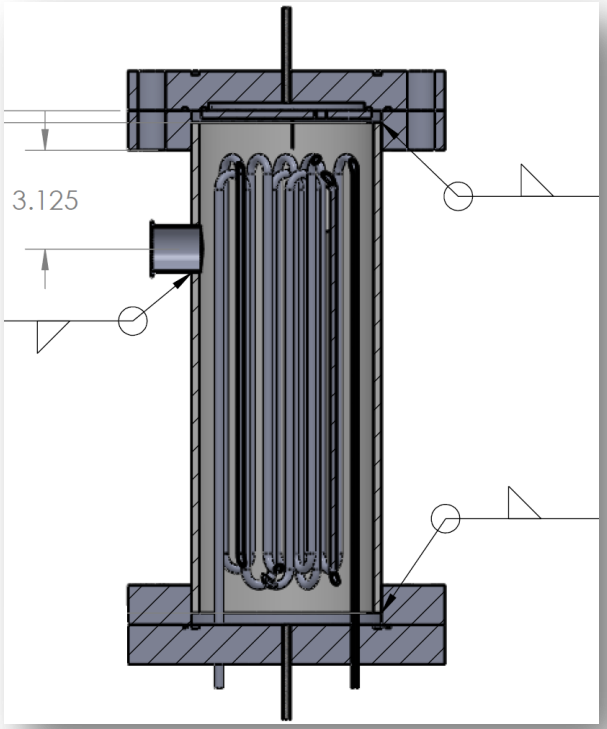
Development of High Performance Residential Gas Water Heater



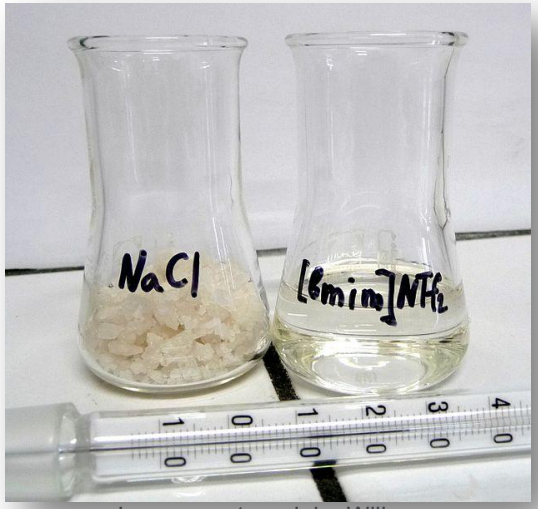


Image courtesy John Wilkes

Absorption Heat Pump Water Heater

CRADA - GE

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April 3, 2013

Purpose & Objectives

Problem Statement: Absorption technology could greatly boost water heater efficiency, but faces barriers of high first cost and working fluid challenges.

Impact of Project: Energy factor of gas storage water heating increased from ~0.65 to >1.0, with zero GWP and zero ODP.

Project Focus: The 1.29 Quads/yr of primary energy currently used in gas water heaters could be reduced by more than 0.45 Quads/yr when fully adopted.

Approach

Approach:

- Use validated system modeling tools to develop conceptual designs
- Design, build, and test a series of progressively enhanced prototypes to achieve required performance targets
- Conduct market assessment to identify optimal price point for acceptable market penetration

Key Issues:

- Working fluid challenges:
  - LiBr additive (1,3-propanediol)
  - Optimized ionic liquid as an alternative working fluid
- High system cost: novel system configuration

Distinctive Characteristics: Achieving primary energy efficiency exceeding 100% for residential gas fired water heaters

Accomplishments and Progress

Accomplishments:

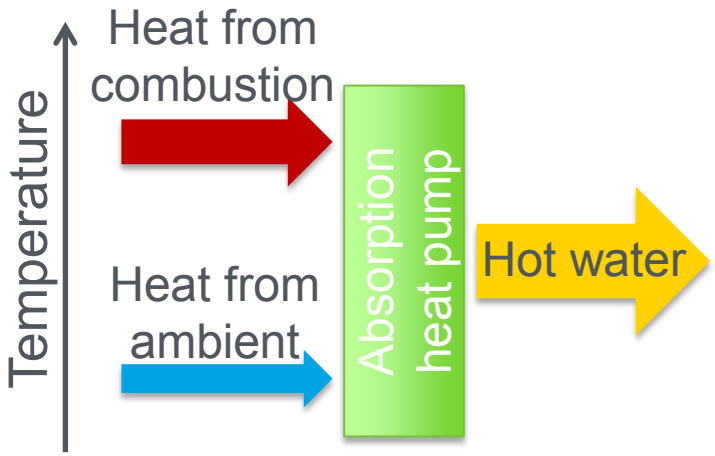
- Investigated several LiBr water additives (3 publications)
- Developed patent-pending cycle configuration
- Designed and built second generation prototype
- Drafted market assessment report
- GE has also achieved target performance with batch process

Progress on Goals:

- Beta prototype incorporates numerous improvements
- Established subcontracts to investigate alternative paths

Awards/Recognition: Invited to present at the AIAA 10th Int. Energy Conversion Engineering Conference (IECEC)

Accomplishments and Progress: Prototype

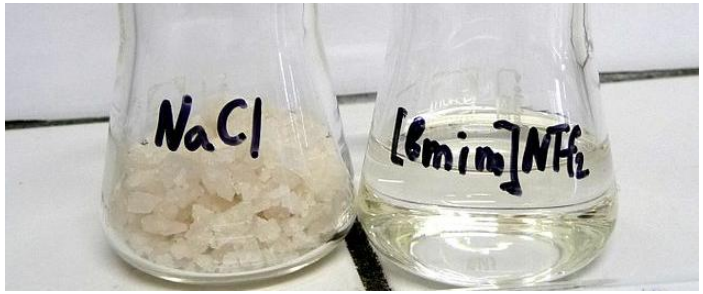


An absorption heat pump transfers heat to the water from fuel *and* ambient air

Prototype will be shakedown tested in early April

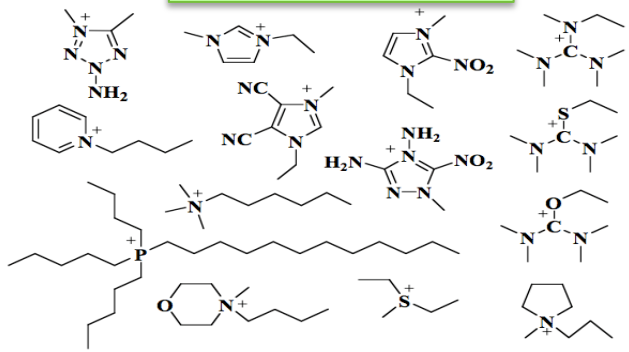
Accomplishments and Progress: Ionic Liquid Development

Ionic liquid: an organic salt, liquid at room temperature.

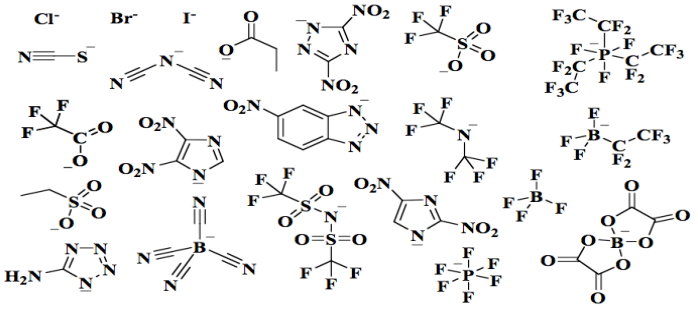


- Represent unique opportunity to advance absorption technology
  - Safe, environmentally benign
  - Less corrosive than typical fluids
  - No crystallization risk
- 10^{10} possible combinations of cations and anions
  - 10^3 described in literature
  - 10^2 commercially available
  - Need to explore options through modeling

Common cations

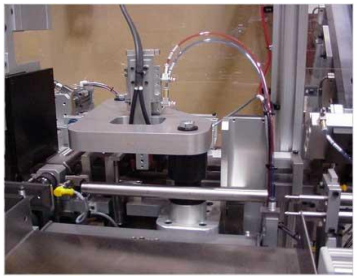


Common anions

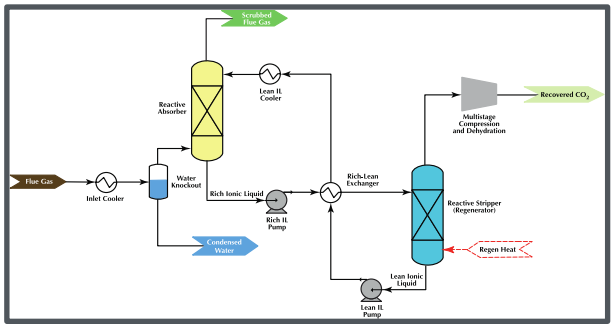


Accomplishments and Progress: Ionic Liquid Development

Ionic liquid development is in progress. Physics-based modeling is coupled to process model and guided synthesis.

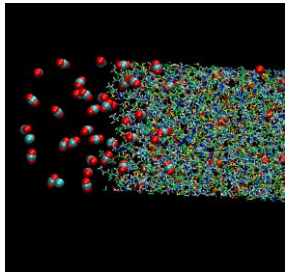


Precise lab characterization



Process modeling / life cycle analysis

Guided synthesis

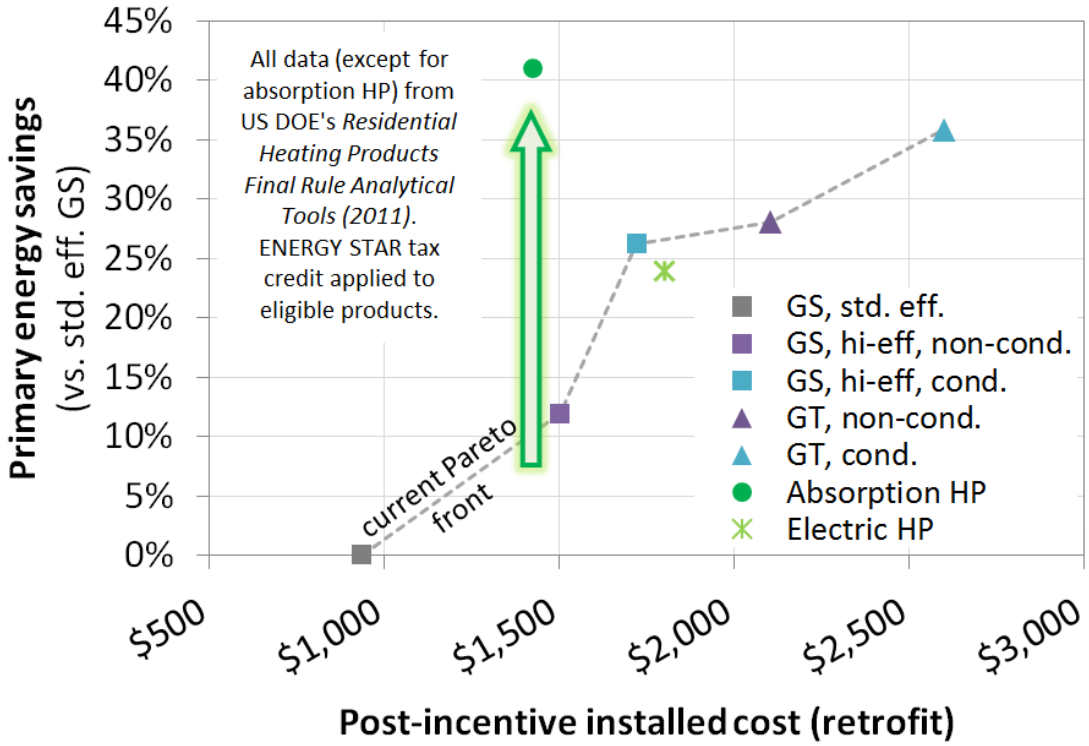


Computational property predictions

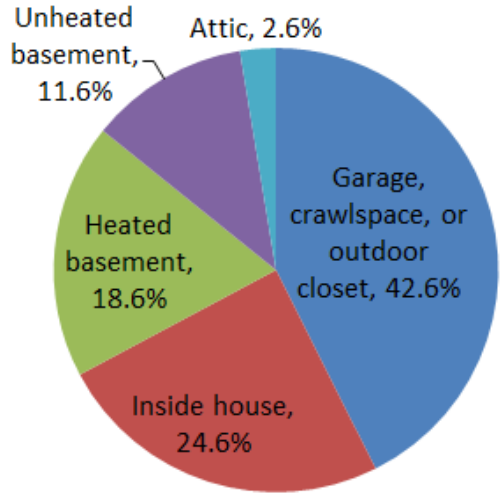
Accomplishments and Progress: Membrane Based Absorption Systems

- Work with Prof. Saeed Moghaddam (UFL) to implement membrane-based technology developed through ARPA-E funding
  - Higher heat and mass transfer coefficients result in compactness and less likelihood for crystallization
  - Ceramic membrane results in cost savings
- Developed novel absorption heat pump cycle configuration
- System modeled using ABSIM
- Component design is underway
  - Absorber, desorber and internal heat exchanger manufactured on one sheet
  - Condenser and evaporator using plate heat exchanger designs

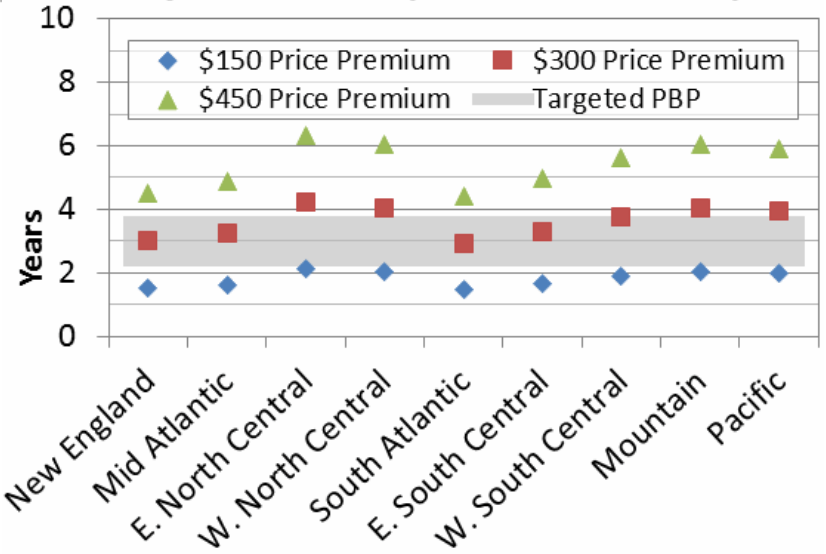
Accomplishments and Progress: Market Assessment



Water heater install location:



Payback Period (Conditioned Area)



Retrofit payback period favorable with ~$300 price premium (compared with standard efficiency gas storage)

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Original initiation date: October 1, 2009
Planned completion date: September 30, 2014
Project delayed in FY12 due to fabrication of beta unit

Go/No-Go decision plans:
July 2012 – proceed to beta unit; passed
July 2013 – proceed to field unit

Summary	
WBS Number or Agreement Number	
Project Number 18810	
Agreement Number 6800	

Legend	
	Work completed
	Active Task
◆	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Name: Gas Fired Absorption Water Heater Development												
Milestone: Complete breadboard unit testing		◆										
Milestone: Publish results of working fluid additive tests				◆								
Current work and future research												
Milestone: Design, fabricate and initiate beta unit testing				◆		◆						
Milestone: Complete testing of beta unit							◆					
Milestone: Testing of optimized ionic fluid										◆		
Milestone: Design, fabricate and intiate field unit testing										◆		
Milestone: Complete testing of field prototype												◆

Project Budget

Project Budget: Total - $2420k

Partner Cost Share: Total - $1450k

Variances: None

Cost to Date: $1605k

Additional Funding: FY14 - $300k

Budget History					
FY2011		FY2012		FY2013	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$800k	$250k	$475k	$300k	$300k	$300k

Project Integration, Collaboration & Market Impact

Partners, Subcontractors, and Collaborators:

CRADA partner is GE.

Other collaborators are:

- Yankee Scientific, Inc. – breadboard prototype
- Ionic Research Technologies, LLC – ionic liquids
- Purdue University – update of ABSIM
- University of Florida – membrane systems
- Sentech/SRA International, Inc. – market assessment

Technology Transfer, Deployment, Market Impact:

Target is a commercialized residential unit with energy factor >1.0 at <$300 price premium over standard gas technology, introduced in 2015.

Project Integration, Collaboration & Market Impact

Patent applications:

- Abdelaziz, O., Vineyard, E., Zaltash, A. (2010). US Patent application 12/829,940, filed July 2, 2010. "Absorption heat pump system and method of using the same." UT-Battelle ID 201002389.

Communications (pg 1/2):

- Abdelaziz, O., Maginn, E., Morrison, D. (2013). "Ionic fluid design for absorption heat pump applications." Seminar 58 of 2013 Winter ASHRAE Conference, Dallas, TX, USA.
- Sikes, K., Blackburn, J., Abdelaziz, O. (2012). "Market assessment for high-performance gas absorption water heaters." November 2012.
- Wang, K., Abdelaziz, O., Kisari, P., Vineyard, E. (2011). "State-of-the-art review on crystallization control technologies for water/LiBr absorption heat pumps." International Journal of Refrigeration, vol. 34, pp. 1325-1337.

Communications (pg 2/2):

- Wang, K., Abdelaziz, O., Vineyard, E. (2011). "The impact of water flow configuration on crystallization in LiBr/H2O absorption water heater." International Journal of Energy Technology and Policy, vol. 7, pp. 393-404.
- Brownell, D., Stevenson, A., Guyer, E. (2011). "Absorption heat pump water heater prototype, design report B." Submitted by Yankee Scientific, Inc., under subcontract number 4000101964, May 24, 2011.
- Kisari, P., Wang, K., Abdelaziz, O., Vineyard, E. (2010). "Crystallization temperature of aqueous LiBr solutions at low evaporation temperature." *Road to Climate Friendly Chillers*, Cairo, Egypt.
- Wang, K., Kisari, P., Abdelaziz, O., Vineyard, E. (2010). "Testing of crystallization temperature of a new working fluid for absorption heat pump systems." *Road to Climate Friendly Chillers*, Cairo, Egypt.

Next Steps and Future Plans

- Finalize second generation prototype assessment
  - Complete instrumentation and develop controls
  - Characterize performance (24-hour and first-hour ratings)
- Continue working fluid evaluation
  - Characterize working properties of optimized ionic liquid
  - Complete characterization of propanediol properties
- Test promising alternative working fluids using prototype
- Continue development of membrane-based components
  - Investigate performance tradeoff
  - Develop a cost model
- Work with GE, CRADA partner, towards developing cost-effective, reliable, and efficient absorption heat pump water heater for new and **retrofit** markets