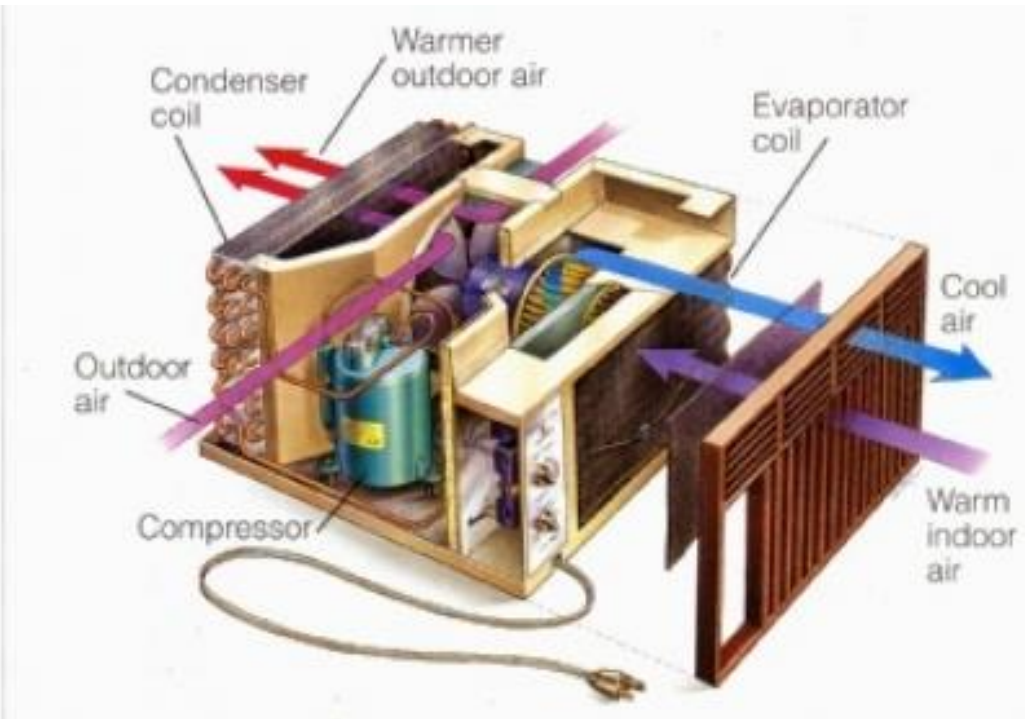
Low-Cost Electrochemical Compressor Utilizing Green Refrigerants for HVAC Applications

2016 Building Technologies Office Peer Review



XERGY

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Xergy, Inc.

Project Summary: DOE BENEFIT ECC BASED HVAC

Timeline:
Start date: June 1 , 2015
Planned end date: June 30, 2017

Key Milestones:
1. Test Novel (low cost) Membrane systems
2. Develop Advanced MEA based on Membranes
3. Design and build prototype ECC system for testing
4. Design and build (Liquid) Desiccant System
5. Design and build Commercial Scale Unit

Budget:

Total DOE $ to date: 303,542.06
(6/1/2015 to 2/17/2016)
Total future DOE $:1042437.94
(2/17/2016 to 6/30/2017)

Target Market/Audience:

Residential Window AC Units

Key Partners:

Xergy, Inc.	UD / ORNL / Haier

Project Goal:

Develop the most efficient, noiseless, and most environmentally friendly cooling system based on electrochemical compressors (ECC) to replace mechanical compressors for use in building heating, ventilation and air-conditioning (HVAC) applications.

TRL:
Start: 3 End: TBD

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Purpose and Objectives

Problem Statement:

- Electrochemical compression (ECC) is a transformative solid state technology.
- Overall objective is to develop and build a scalable 5,000 BTU/hr. ECC-based air conditioning system operating with a COP of 4.5, with a price premium of $70 installed per kBTU/hr.

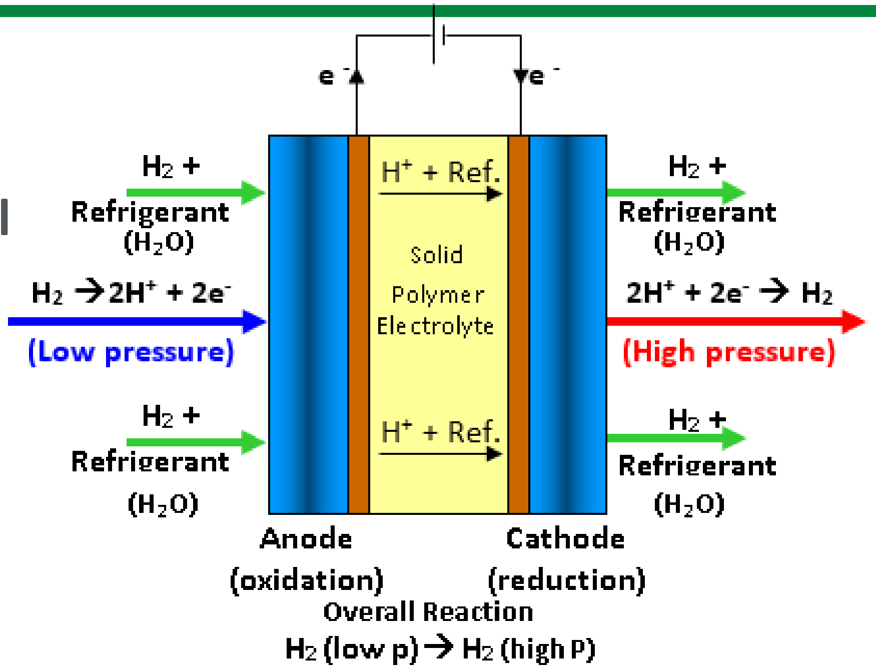
Target Market and Audience: HVAC systems account for approx. 14 Quads of primary energy annually, or nearly 30% of all energy used in U.S. commercial and residential buildings. ECC based HVAC systems could result in 40% less energy use.

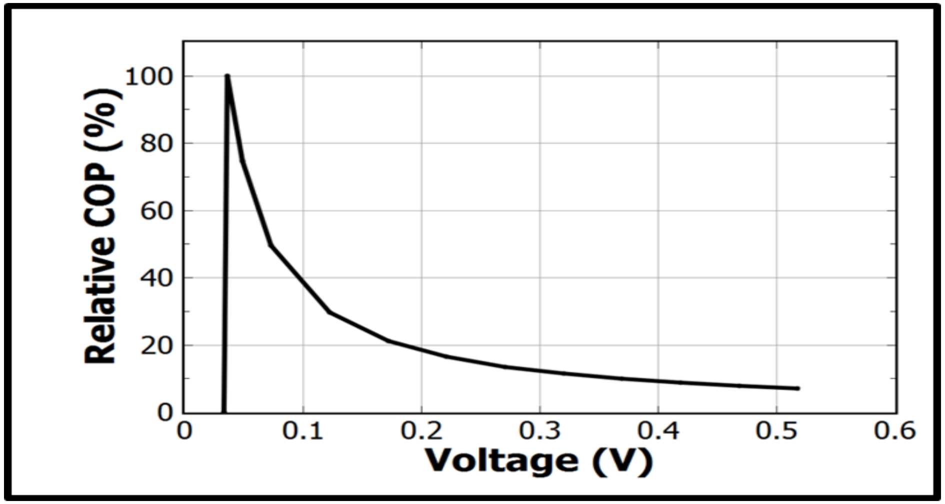
Impact of Project:

- Near Term (1-3 years)
  - Demonstrate and produce high efficiency ECC Window Air Conditioner at a price point viable for the US residential market
  - Potential of savings of 1 Quad/year
- Long Term (3+ years)
  - Experience will support ECC development to replace mechanical compressors in other appliance applications
  - Potential savings of 5 Quads/year

Approach – Technology - Electrochemical Compressor (ECC)

- ECC uses an external voltage to **pump hydrogen, water or other refrigerant.**
- The driving force is an **electric potential gradient** governed by the Nernst equation and Ohm's Law
- Multiple **small cells are combined** to create units with the required pumping capability and efficiency for **different refrigeration cycles**
- **Multiple Cycles Feasible:**
- Water VC Cycle
- Metal Hydride Heat Exchanger (Absorption) Cycle .. And others
- Select Best Cycle for client

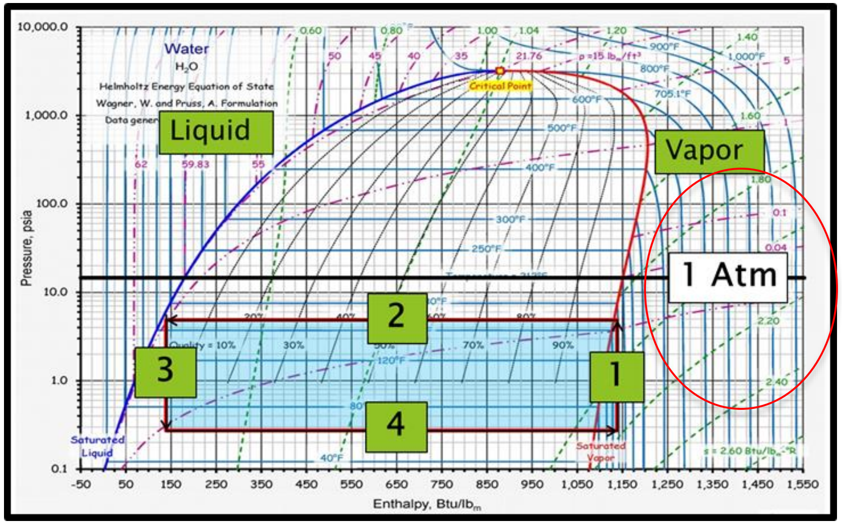




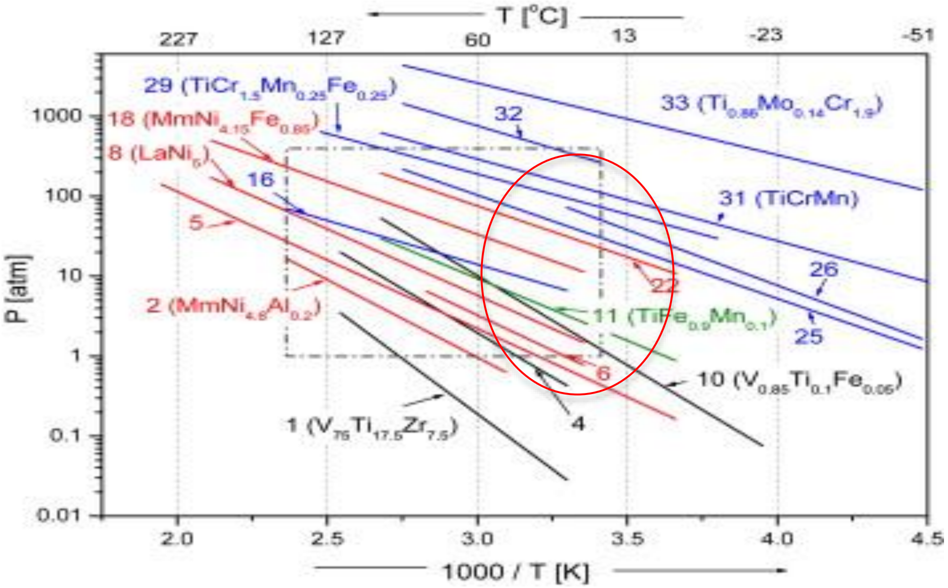
Xergy, Inc. is the world leader in ECC technology

Approach – Technology – ECC Driven Cycles

- Water VC: ECC water compressor requires **low pressure** operation (~2 kPa to 26 kPa) which is impractical using traditional compressors

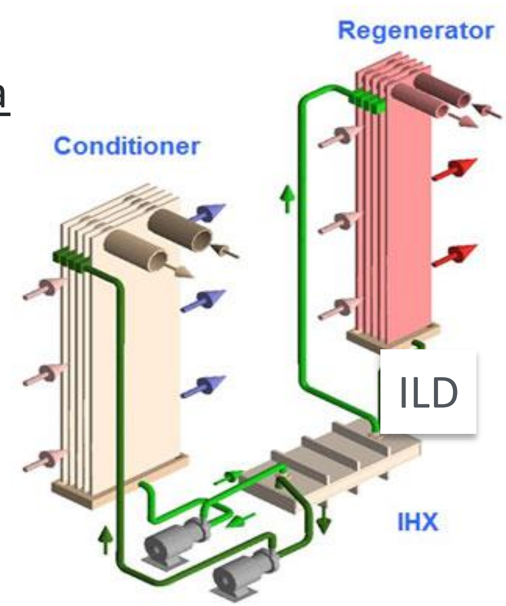


- ECC + metal hydride heat exchanger, requires ultra dry compressed hydrogen, and **low pressure** operation



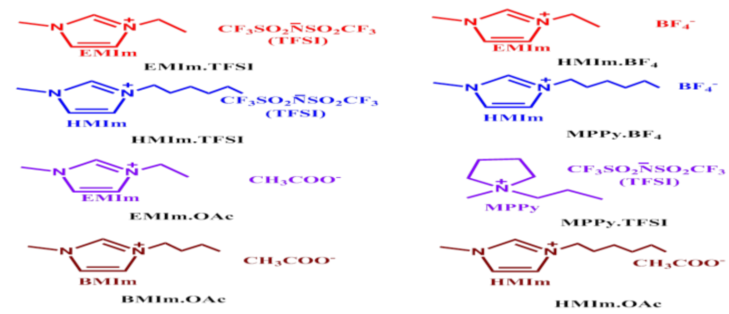
Approach – Technology – Ionic Liquid Desiccant(s) Integration

- Ionic Liquids are salts in liquid state at room temperature; they can be used as desiccant materials: Ionic liquid desiccants (ILD)
  - Bulky and asymmetric organic cations
  - Can be designed to optimize the temperature of desorption
  - Better performance than traditional salt solutions (e.g. Lithium Chloride) desiccant systems used in HVAC Applications
- Key is to creating <u>higher efficiency</u> cooling systems: <u>dehumidify a without over-cooling</u>.
  - Conventional HVAC systems achieve cooling and dehumidification by cooling the air below its dew point in order to condense the moisture and then reheat the air to provide it at the desired conditions
  - Separate sensible and latent cooling dehumidify air as close (adiabatic if possible) and then sensibly cool it at higher evaporating temperature.
- In this program, we are integrating novel ILD's with heat exchangers used in ECC cycles, to use the heat to regenerate ILD's
  - Goal is to improve COP by 25 to 40% with ILD integration

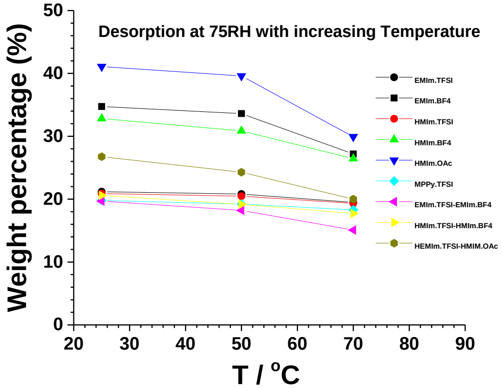


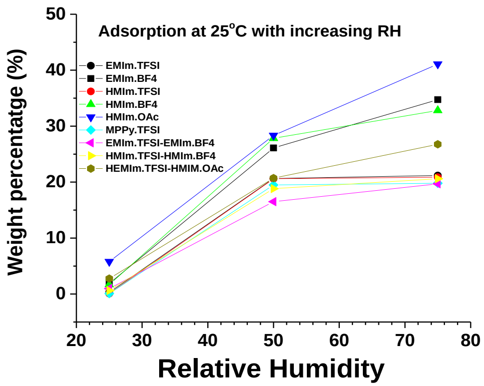
Progress and Accomplishments: Ionic Liquid Desiccant

- ORNL Synthesized 8 different ILD's
- Performed Absorption & Desorption test with candidates
- All tests under thermodynamic equilibrium conditions
- Complete Cycle Analysis
- Currently Synthesizing additional 'lower cost / Higher Performance ILD's
  - Will down select for commercial scale up in 3Q 2016
  - Then Integrate ILD's
  - Test and analyze overall System performance



Ionic Liquids (ILs)	Adsorption Maximum	Desorption Minimum	Working Range
EMIm.TFSI	21.2%	19.5%	1.7%
$EMIm.BF_4$	34.7%	19.2%	15.5%
HMIm.TFSI	20.9%	18.9%	2.0%
$HMIm.BF_4$	32.8%	21.6%	11.2%
MPPY.TFSI	19.8%	17.8%	2.0%
HMIm.OAc	41.1%	11.5%	29.6%
EMIm.TFSI(50)-$EMIm.BF_4$(50)	19.7%	12.8%	6.9%
HMIm.TFSI(50)-$HMIm.BF_4$(50)	20.6%	15.9%	4.7%
HMIm.TFSI(50)-HMIm.OAc(50)	26.8%	12.5%	14.3%

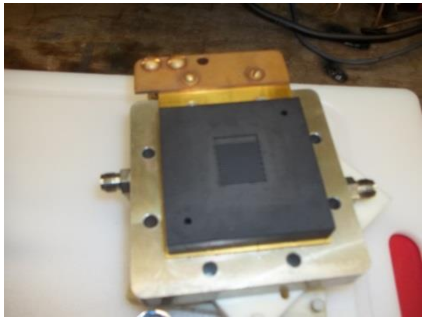


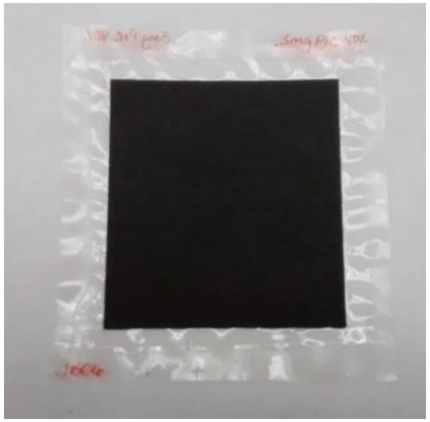


Approach – ECC Key Components

- **Key Components:**
  - Compressor Canister
  - Cell Plates
  - Polymer Electrolyte Membranes
  - Electrodes

- **Requirements:**
  - COP > 4
  - Unit price < $ 70/kBTU installed
  - Creating high **volumes** of low cost components is required to meet commercial unit targets
  - Innovative integration with other systems components (such as Heat Exchangers)





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Program Approach

Goals of this program:

- Establish Testing Capability
- Achieve system cost targets by developing advanced cell components and manufacturing methods
- Achieve cycle performance target (COP>4) through advanced compressor system integration & Liquid Desiccant System
- Build and Demonstrate prototype and commercial system based on advanced components and design (window AC system)

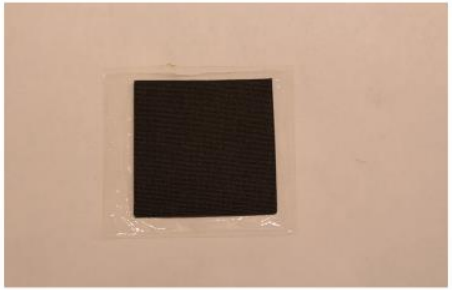
Key Issues:

- Cost of ECC components
- Long term performance
- System integration (integrating heat exchangers, controls and seals)

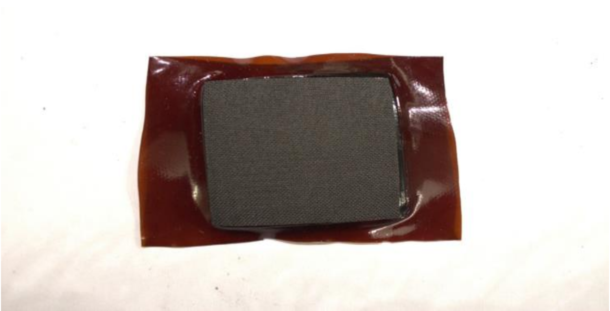
Distinctive Characteristics:

ECC driven heat pump

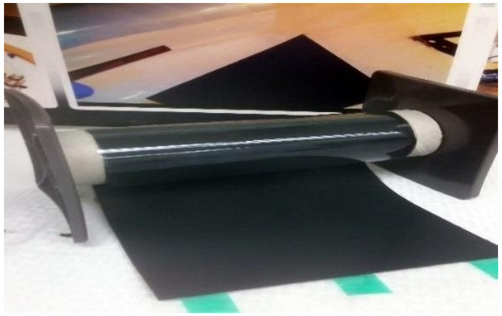
Progress and Accomplishments: Membrane Capability



A) SPEEK

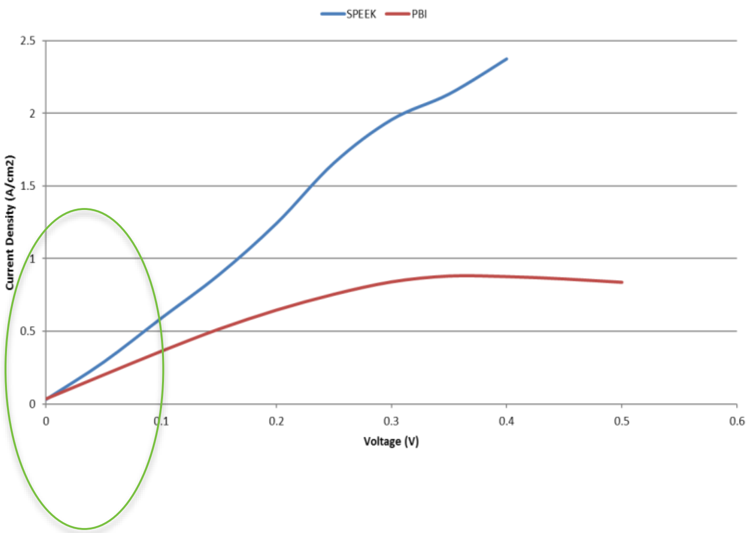


B) . PBI



C) SBIR Production MEA

- Polarization Data Provided
- Other Membranes in Process
  - SPPSU, LEW PFSA, other PBI's, etc.
- Composites Production in Process
- **Dry** Operation is feasible with PBI membranes
  - Metal Hydride Heat Exchangers systems (enabled)



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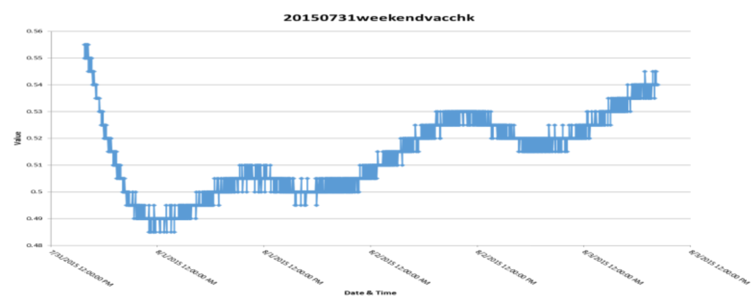
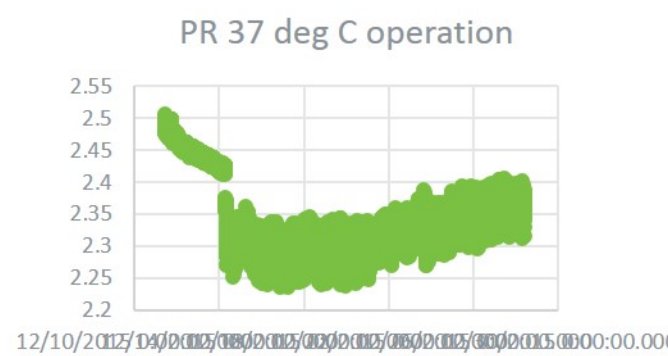
Progress and accomplishments: Endurance Testing

A modified test station has been built and tested to demonstrate the AC cycle can be achieved with ECC. Commercial units will be welded and sealed, but our laboratory test units must be openable.

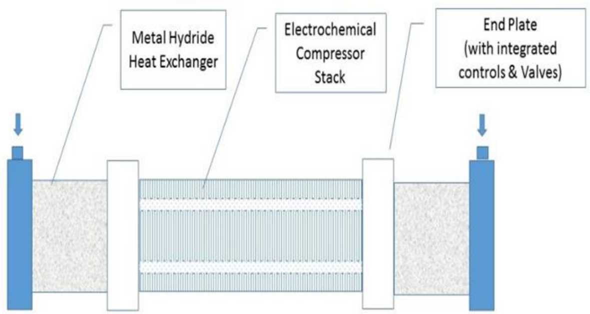
- Vacuum Checked the Device
- Extended operation at multiple temperatures was demonstrated
- Extended testing exceeded 2 weeks. All pressure changes were initiated or accounted for by changes in temperature.
- Working fluid Blend was adjusted at temperature
- Minimal change in Polarization post experiment





Progress and accomplishments: Compressor Design

- Gen IV & V ECC stack will integrate with MHHX & ILD systems
  - Schematic for "Cooling Cartridge"
- Gen IV ECC Stack Components have been specified, and 3D printed for debugging
- Gen IV Plate tooling is complete, and production has started
- Gen IV Membrane production has started
- Will use Gen IV stack for unified HVAC "cartridge" build in 3Q 2106
- Meanwhile we have a concept for Gen V ECC
- Projected Compressor COP:
  - Strongly depends on operating voltage
  - At .5V/plate ~1+
  - At .1V/plate ~4+
- Projected Cartridge COP ~ 5



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Progress and accomplishments: Gen II MHHX Development

- Performed fundamental system analysis
  - Verify COP potential, system requirements
- Set up testing facility for MH systems
- Identified global raw material sourcing
- Set up production infrastructure
- Testing multiple Metal Hydride Compositions, and down selecting specific Composition for Window AC Application
- Developed and patented Gen II Metal Hydride Heat Exchanger; currently under construction
- Developed integration concept to operate Metal Hydride Heat Exchanger with ECC and ILD's
- Goal is to build a unified HVAC "cartridge" in 3Q 2106 based on Gen II design
- Meanwhile we have a concept for Gen III MHHX

GEN II

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Progress and Accomplishments

Lessons Learned: **Packaging is 'the' critical issue**

- **Cycles operate at low pressures**,
  - imply **creative** designs / plumbing, and intricate sealing
  - imply mass transport limitations lead to large active areas (i.e. **cost issues**)
  - System integration is key – different components operate at different rates

Market Impact:

- Demonstrated Higher Efficiency cycle for HVAC is very significant
  - Low GWP, No direct environmental impact
- Target Market: HVAC units

Awards/Recognition: GE Ecomagination Award 2011, Clean-tech Award Finalist 2012, Defense Energy Technology Challenge Finalist 2014

Project Integration and Collaboration

Project Integration: **Xergy has**

- Established Strategic relationship with major (global) market leader
- Sponsored related work at the University of Delaware & Delaware State

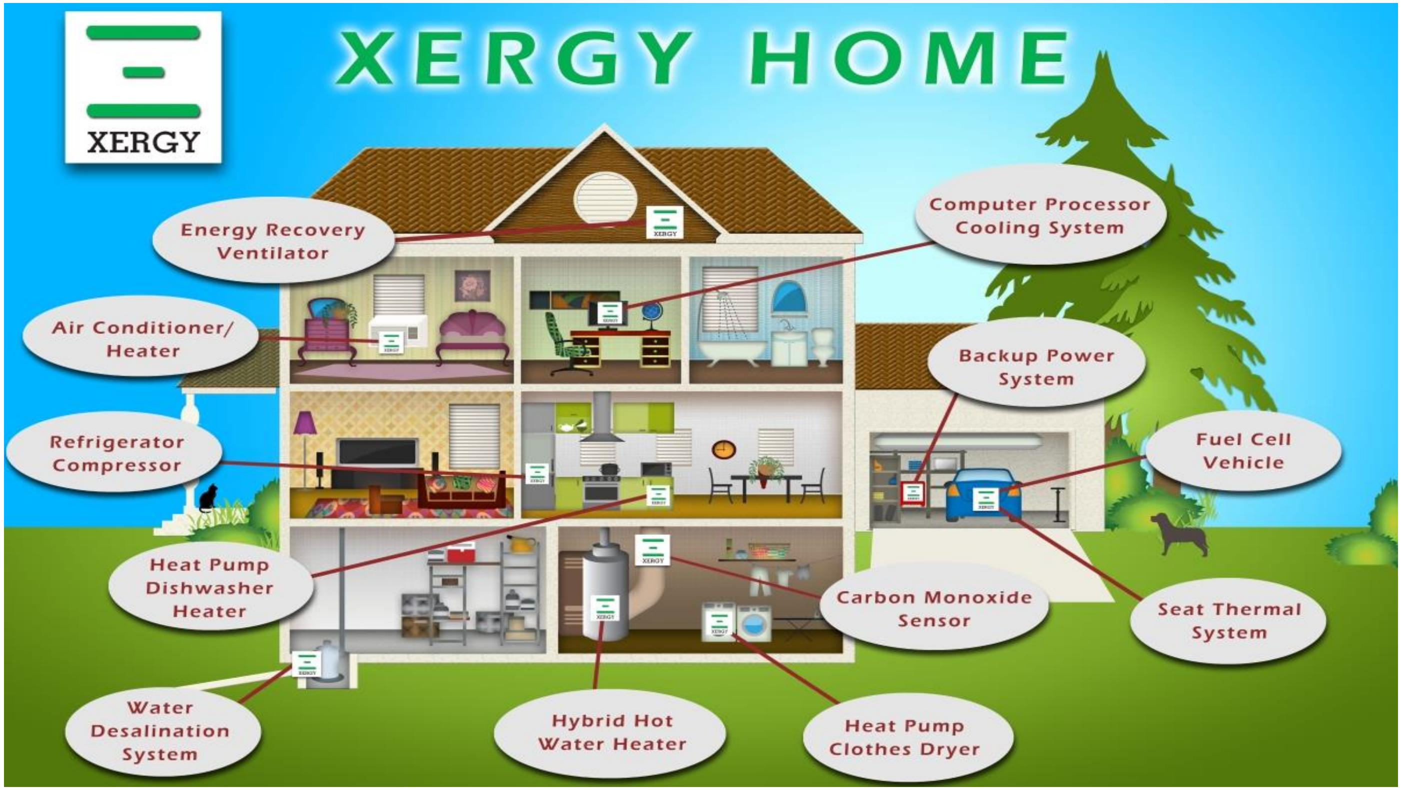
Partners, Subcontractors, and Collaborators:

- Xergy, Inc.
  - Dr. William Parmelee, PI
  - Bamdad Bahar, President Xergy, Inc.
- ORNL
  - Omar Abdelaziz
- University of Delaware
  - Ajay Prasad

Communications: Currently have 40+ patents in process, presented numerous papers including ACEEE Hot Water Forum 2013, exhibited at Fuel Cell Seminar 2015, ECS 2015, AHR 2016, Art of Compression Colloquium 2016

Next Steps and Future Plans

- Implement Gen IV System in other programs (i.e. HHWH system)
- Develop Gen V ECC, and Gen 3 & 4 MHHX in other programs
- Continue Endurance testing, validate long-term performance with Partners
- Leverage this technology to develop systems for other applications:



SAMSUNG

Panasonic

U.S.ARMY

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REFERENCE SLIDES

Project Budget

Project Budget: To date, Xergy Inc. has stayed within our budget
Variances: None
Cost to Date: 23% has been spent as of 2/17/2016
Additional Funding: none

Budget History					
6/1/2015– FY2015 (past)		FY2016 (current)		FY2016 – 6/30/2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
121,617.07	53,231.02	181,924.99	42,991.82	1,043,058.94	253,177.16

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Project Plan and Schedule

Name	Begin date	End date
Demonstrate AC cycle	7/1/15	11/30/15
Make composites from HC ...	1/1/16	5/25/17
Build ECC for full size AC u...	1/1/16	5/25/17
Build final AC unit based o...	7/1/15	7/19/16
Full size ECC cell built and ...	11/15/16	11/15/16
Develop cost model	11/1/16	4/17/17
Hydrocarbon ionomer prep...	7/1/15	7/1/17
Electrode prep	11/2/15	7/15/16
MEA prep	3/1/16	12/5/16
Pt electrodes preparation	4/1/16	11/30/16
MEAs tested	3/1/16	7/1/17
HC MEAs prepared	6/1/16	6/1/16
Design sensible & latent c...	7/1/15	7/15/16
Develop novel liquid and d...	1/1/16	1/18/17
Develop latent cooliing syst...	7/1/16	3/23/17
Experimental system evalu...	1/2/17	7/1/17