Advanced Hybrid Water-Heater Using Electrochemical Compression (ECC)

2016 Building Technologies Office Peer Review

XERGY

GE Appliances

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

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Project Summary: Phase II SBIR

Timeline:
Start date: May 19th, 2014
Planned end date: May 19th, 2016

Key Milestones:
1. Design and build 10 test stands 06/15
2. Construct component production lines; 06/15
3. Design and build scale ECC device for GE testing; 09/15
4. Design and build Prototype Heating System 12/15
5. Design and build Commercial Scale System 03/16
6. Operate & Test Commercial Scale System 06/16

Key Partners:

Xergy, Inc.	GE Appliances

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GE Appliances

Budget:

Total DOE $ to date: 1,033,481
(5/19/2015 to 2/17/2016)

Total future DOE $: 73,944
(2/17/2016 to 5/19/2016)

Project Goal:

Develop a heat pump water heater utilizing electrochemical compression technology with an installed cost and real world efficiency that will enable widespread adoption in US residential markets

Target Market/Audience:

Residential electric water heating.

TRL:

Start: 3 End: 6 (system), 8 (ECC)

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Purpose and Objectives

Problem Statement:

- Heat pump water heaters can reduce energy use of electric hot water heaters by 66% +, but mechanical heat pumps are noisy and use high GWP refrigerants.
- Electrochemical compression (ECC) is a transformative solid state technology that can be applied to different refrigeration cycles for this application.
- ECC is

Variable	Efficient
Scalable	Noiseless with no moving parts

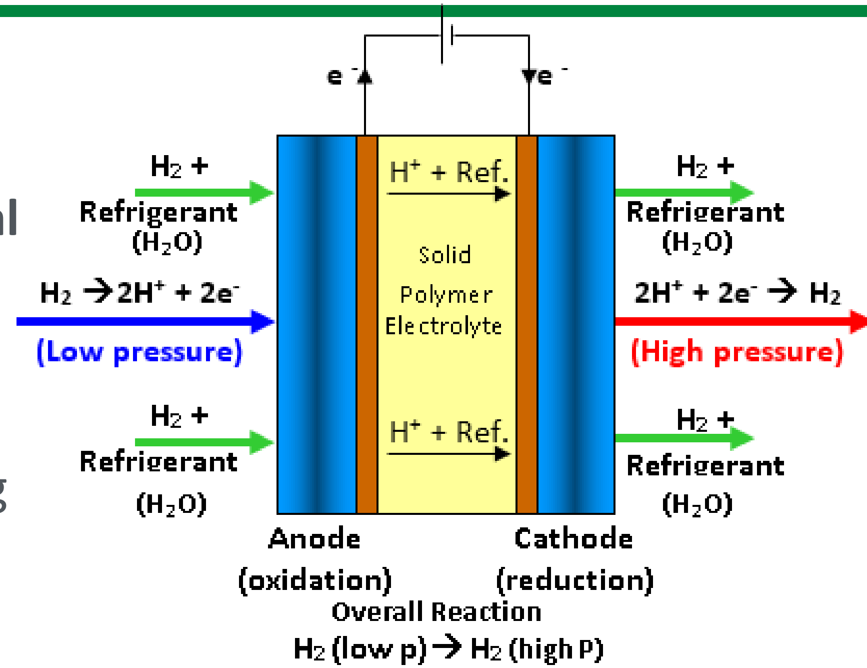
Target Market and Audience: Approximately 15% of electric demand is for hot water production using 1.4 Quads/yr.

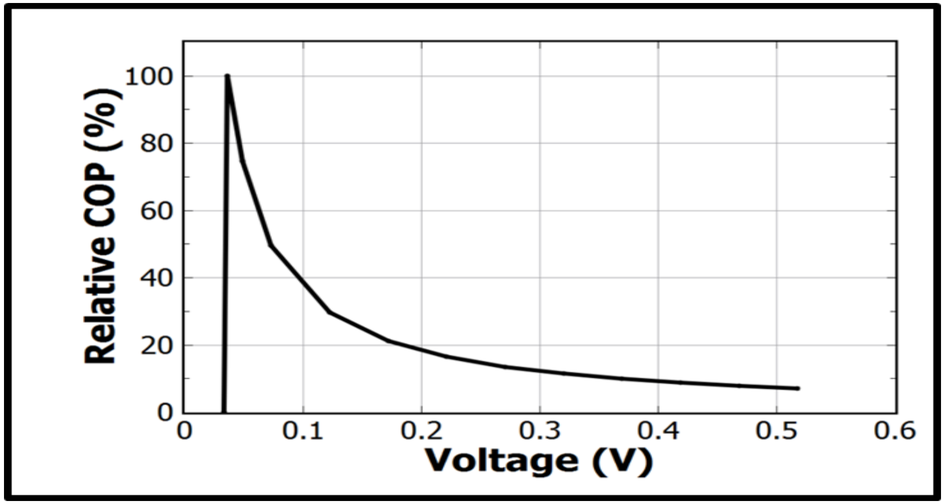
Impact of Project:

- Near Term (1-3 years)
  - Demonstrate and produce high efficiency ECC HPWH 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 HVAC applications
  - Potential savings of 5 Quads/year

Approach - Technology

- 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



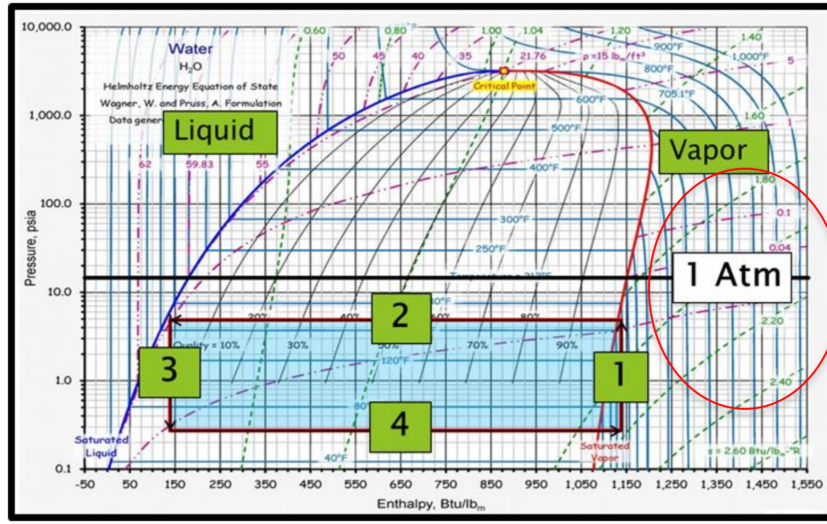


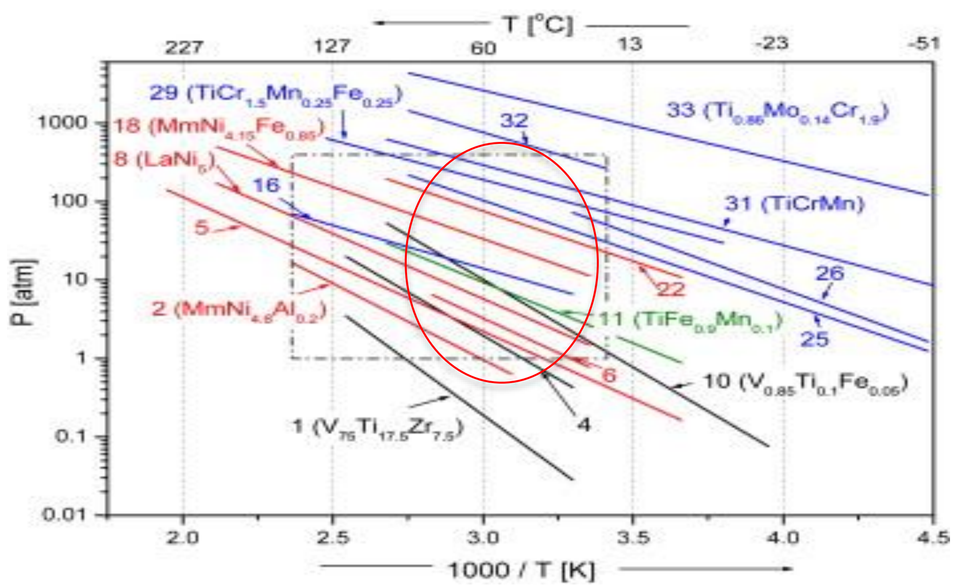
Xergy, Inc. is the world leader in ECC technology

Approach - Technology

- Water VC: Water compression requires **low pressure** operation (~2 kPa to 26 kPa) which is impractical using ‘traditional’ EC compressors

- ECC + metal hydride heat exchanger, requires ultra dry compressed hydrogen, but high efficiency means **low pressure** operation





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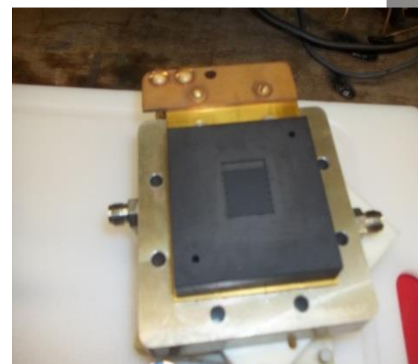
Approach – Key Components

- **Key Components:**
  - Polymer Electrolyte Membranes
  - Low Pressure Electrode Systems
  - Low Pressure Cell Plate Designs
  - Compressor Assembly

- **Critical Requirements:**
  - COP >3
  - Unit price < $500 at commercial volumes
  - Low cell voltage leads to higher cell efficiency but lower cell pumping throughput
  - Creating high **volumes** of low cost components is required to meet commercial unit targets



Approach

Goals of this program:

- Establish Testing Capability
- Achieve system cost targets (high volume installed premium < $500) by developing advanced cell components and manufacturing methods
- Achieve cycle performance target (COP>3) through advanced compressor system integration
- Build and Demonstrate prototype and commercial system based on advanced components and design (2, 10, and 50 gallon ECC HPWH)

Key Issues:

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

Distinctive Characteristics:

ECC driven heat pump water heater

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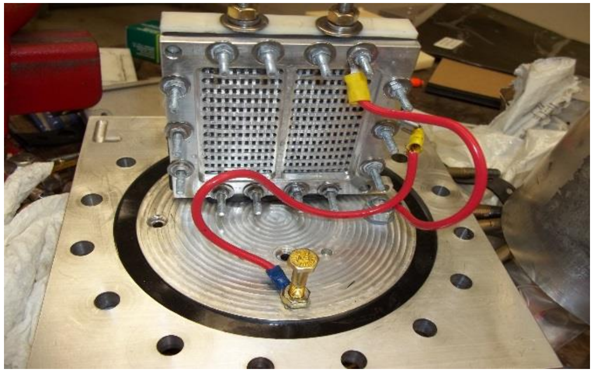
Major Tasks and Accomplishments: Summary

- Year 1: Build ten test stands & Testing capability - DONE
- Year 1: Build & Deliver scale model prototype ECC device – DONE
- Year 1 and Year 2: Develop and set up manufacturing for advanced components for commercial ECC's – DONE
- Year 2: Select Cycle, and Integrate ECC prototype into a complete heating system – Done
- Year 2: Scale up & Test ECC System into a working 50 gallon working HWH – IN PROCESS

Xergy, Inc. has full confidence that the final task will be fulfilled. We are delivering our 50 gallon HHWH system based on ECC compressor before end of the program. System analytics i.e. COP etc. will be provided.

However, performance testing @ GE will be extended beyond the program, with no financial impact on budget

Progress and Accomplishments: Design & Testing Capability



A) Compressor test cell

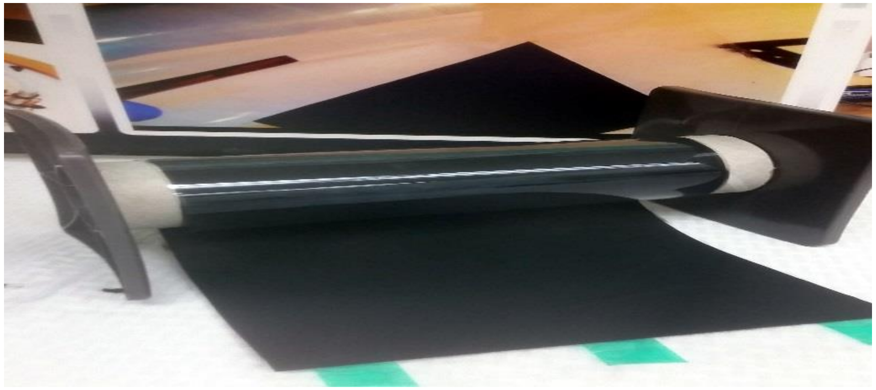
B) Pressure test station.

C) Assembled test stand

- Ten test stands have been built to test performance of new cells designs
- Membranes, Electrodes, and Plates testing capability established

D) Multi-cell Compressor Test Unit

Progress and accomplishments: Membrane & Electrodes



- Ultra-thin, Ultra-strong, high performance Continuous Composite membranes and MEA's produced in Year 1

- Membranes & MEA's **commercially available** (since Nov 2015)
    - Initially created 6 full-time manufacturing positions, ramping up to 12 by mid-year (with orders)

- Established multiple strategic sources for **LOWER** cost raw materials and high activity catalysts. 3+ Technology Generations

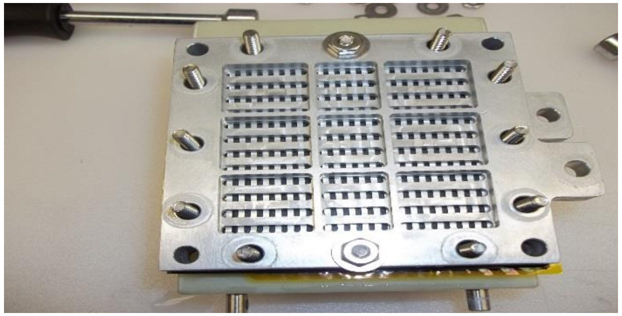
- External Validation: 3rd Generation Xergy membranes & MEA's show excellent performance vs other commercial products

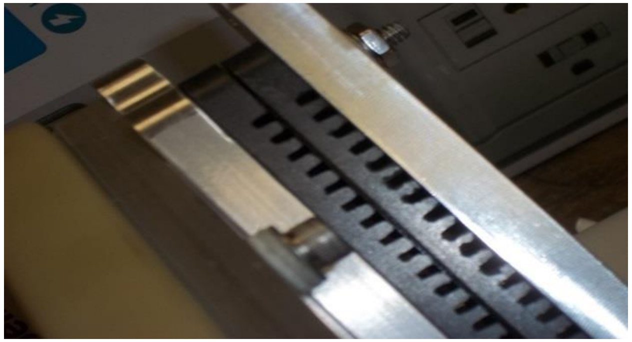
Progress and accomplishments: Plate fabrication

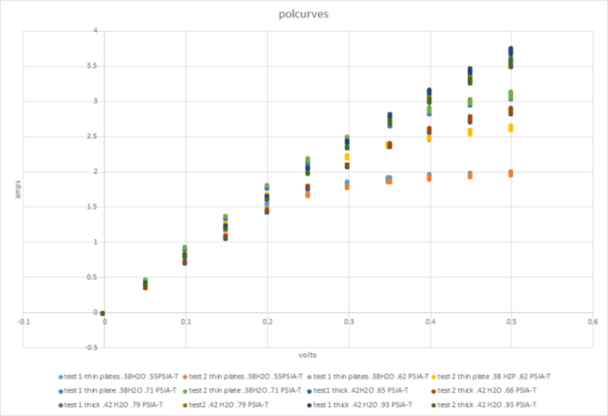
- 3+ Generations of Plate Technologies were designed & tested
  - Back vs Edge vs Internal Ported,
  - Graphite vs Metal
  - Scaled up Gen Production Process

- Tooling Systems to support designs have been established

- Production Capacity has been established
  - Beginning to produce literally hundreds of plates now
  - System cost reduced by factor 10x







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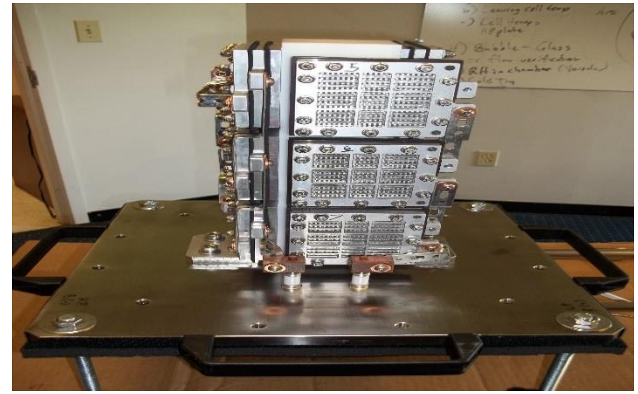
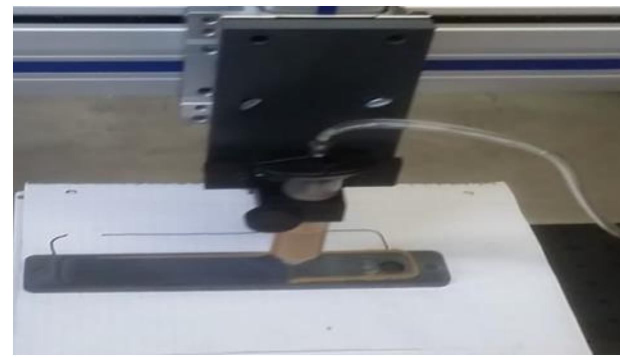
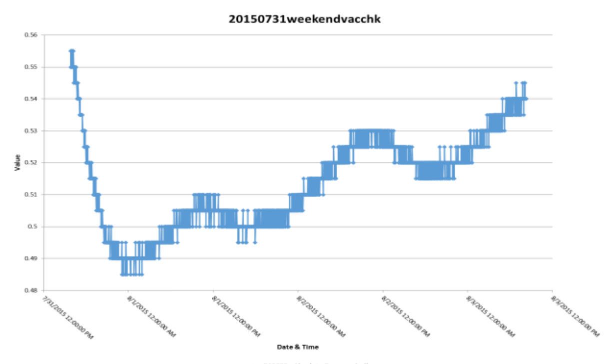
Progress and accomplishments: Compressor Assembly

- Robotic Gasket Application Systems have been established
- Assembly jigs have been established
- Stack testing systems have been established
- Quality Assurance systems are in place
  - Testing methodologies have been established
  - No Bad Cells in delivered units
  - System Vacuum have been held
    - No Hydrogen leaks







Progress and Accomplishments: Prototypes

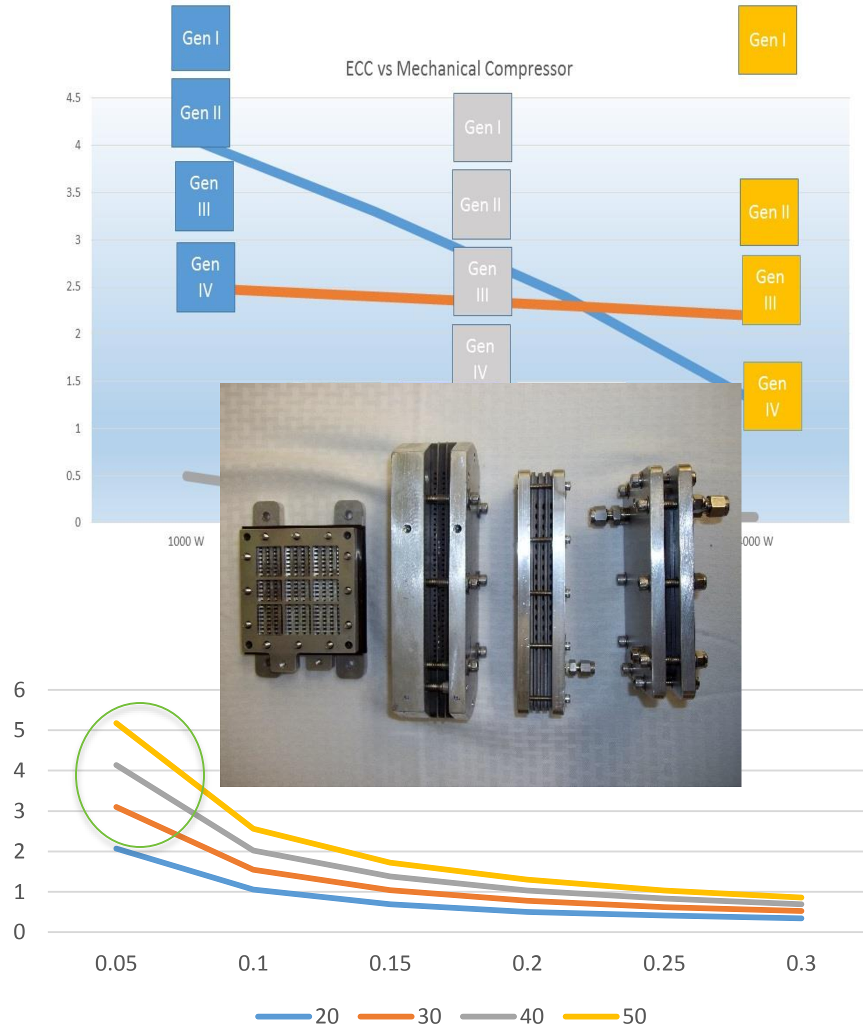
- Delivered prototype Electrochemical Compressor ECC
- Evaluated ECC cycles, and selected best cycle for operating HHWH
- Performed system comparisons and analysis – COP >3
- Demonstrated prototype Operating Cycle (ECC + MHHX selected)
- Assemble 50 Gallon HHWH System & Testing – Now
  - Will use membranes and MEA's developed under this program – not BENEFIT award – i.e. with desiccants
  - Will use Gen I – MHHX system

Progress and Accomplishments: Performance

1. 3+ Generations of Compressors developed over 2 years
   - Cell area & number reduced by an order of magnitude

2. Compressors are close to meeting program commercialization goals in terms of g/Wc, cc/Wc and $/Wc.

3. Operated ECC's with MH Heat Exchangers. System can exceed program COP goal; also, discovered: (a) MH formulation options, (b) rapid heat exchange feature; and (c) system modulation feature



Progress and Accomplishments

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

- **ECC operate with Low Current densities and Low operating pressures**,
  - imply **creative** designs / fluid flow considerations
  - imply mass transport limitations lead to large active areas (i.e. **cost issues**)
- **System packaging and integration is key**

Market Impact:

- Target Market: Electric WH, approximately 50% of 8.5 million new WH
- Demonstrated Higher Efficiency cycles for ECC based HPWH
  - No GWP, No direct environmental impact, recyclable
  - Noiseless, vibration free operation
  - Project targets met – payback period is less than 2 years
- **Economic attributes are NOW compelling**
  - **Lower operating cost than even Gas Fired Water Heaters!**
  - **Thermal Battery – a compelling case for utility /DOE 'push'**

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**

- Worked closely with GE project managers and engineers
- Established Strategic agreements with major (global) suppliers
- Sponsored related work at the University of Delaware

Partners, Subcontractors, and Collaborators:

- Xergy, Inc.
  - Dr. William Parmelee, PI
  - Bamdad Bahar, President Xergy, Inc.
- General Electric Appliances
  - Dave Beers, Manager, Heat Engines R&D

Communications: Currently have 40+ patents in process, presented numerous papers including ACEEE Hot Water Forum 2015/16, exhibited at Fuel Cell Seminar 2015, ECS 2015, AHR 2016, Art of Compression Colloquium 2016

Next Steps and Future Plans

- Develop and Build a More advanced Integrated ECC+MHHX System
- Taking Commercial Order(s) for Gen II Compressor Systems Now
- Perform Endurance testing, validate long-term performance with Partners
- Consider projects with others in this area, per DOE

Also, separately, immediately leverage capabilities developed under this award, to assist other DOE programs:

  - New Anionic Composite Membranes & MEA's - LANL/RPI/GT
  - New Cationic Composite Membranes & MEA's – UD/USC
  - Supplying Gen II ECC to DAIS/ORNL Membrane Water Evaporative Chiller Cycle

- Opportunities to leverage this know how in other product areas:
  - Micro-Climate Control Systems (humidifiers) – Appliance Applications
  - Advanced Metal Hydride Systems – re-establish U.S. Capability & R&D
    - Metal Hydride Heat Exchanger capability lags ECC development

REFERENCE SLIDES

Project Budget

Project Budget: To date, Xergy Inc. has stayed within our budget
Variances: The only planned variance (which we described in our year end report was that we decided to add a mechanical engineer, so we have shifted some payroll around to cover this).
Cost to Date: 93% has been spent as of 2/17/2016
Additional Funding: none

Budget History					
5/19/2014– FY2015 (past)		FY2016 (current)		FY2016 – 5/19/2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
908,739.62	99,961.36	22,324.08	2,455.65	66,616.30	7,327.79

Project Plan and Schedule

Project Schedule		
Project Start: May 19th, 2014		Completed Work
Projected End: May 19th, 2016		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

	2014		2015				2016		
Task	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)
Past Work									
Fabricate cells for test stands									
Build five test stands									
Develop commercially viable membranes									
Current/Future Work									
Build five endurance test stands									
Build scale HPWH (10 gallon)									
Build Prototype HPWH (50 gallon)									
Test Prototype HPWH									