Advanced Hybrid Water-Heater Using Electrochemical Compression (ECC)

2015 Building Technologies Office Peer Review

XERGY

GE Appliances

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

Bamdad Bahar
bamdad.bahar@xergyinc.com
Xergy, Inc.

Project Summary: Phase II SBIR

Timeline:

Start date: May 19th, 2014

Planned end date: May 19th, 2016

Key Milestones:

1. Design and build five cell test stands; 02/15
2. Construct component membrane line; 01/15
3. Design and build scale device for GE testing; 06/15

Key Partners:

Xergy, Inc.	GE Appliances

XERGY

GE Appliances

Budget:

Total DOE $ to date: 454,892.94

(5/19/2015 to 3/3/2015)

Total future DOE $: 542,787.06

(3/2015 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.

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 allows for the use of water as the refrigerant in a vapor compression cycle.
- ECC is

Variable	Efficient
Scalable	Noiseless with no moving parts

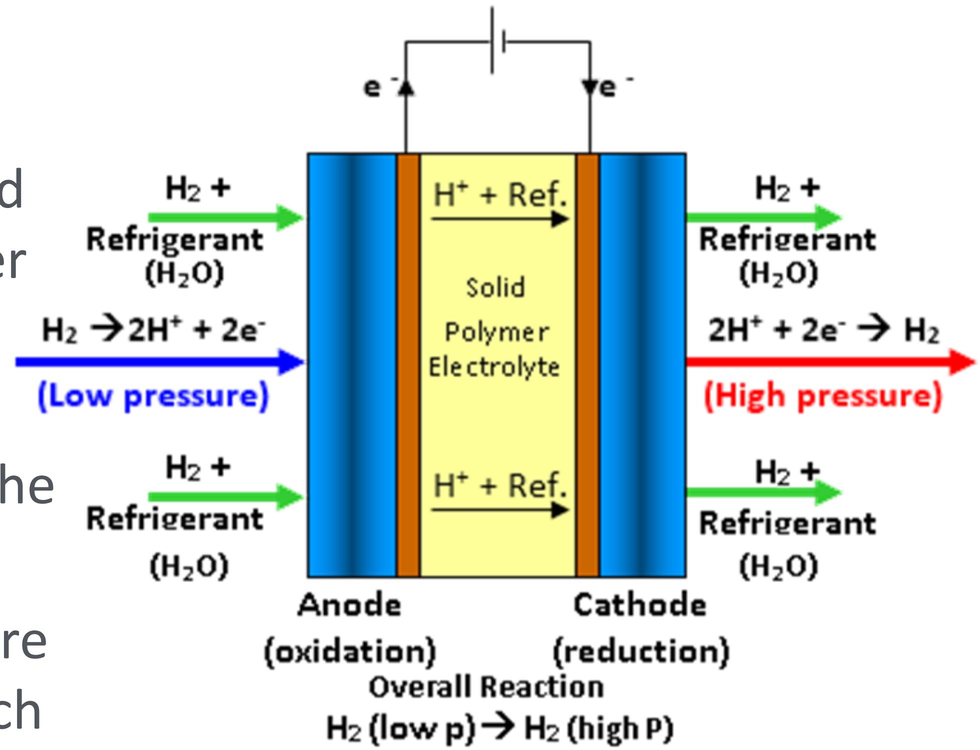
Target Market and Audience: Approximately 15% of electric demand is for hot water production using 1.4 Quads/yr.

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

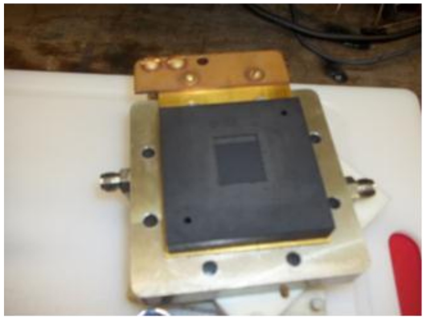
- Electro-Chemical Compression (ECC) uses an external voltage to **pump a water refrigerant**, carried by protons, across a solid polymer electrolyte membrane
- The driving force is an **electric potential gradient** governed by the Nernst equation and Ohm's Law
- ECC of water requires low pressure operation (~2 kPa to 26 kPa) which is impractical using traditional compressors
- Multiple **small cells are combined** to create units with the required pumping capability and efficiency



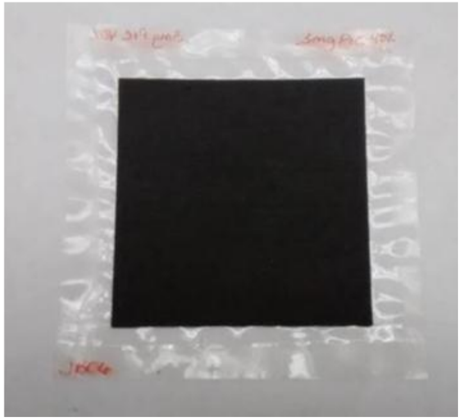
Xergy, Inc. is the world leader in ECC technology

Approach – Key Components

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



- **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
  - At phase 1 Targets: 6 m^2 of active area per 50 gallon unit



Approach

Goals of this program:

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

Key Issues:

- Low pressure operation (sealing)
- Cost of ECC components
- Long term performance
- System integration (design of heat exchanger and plumbing)

Distinctive Characteristics:

ECC heat pump water heater with water refrigerant

Progress and Accomplishments: Design and Testing

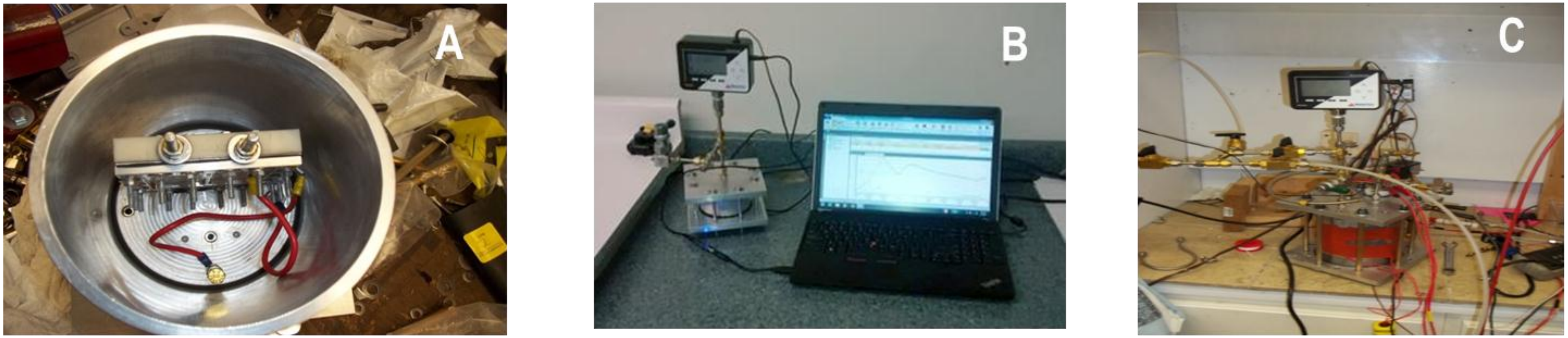


Fig. 1: A) Compressor test cell B) Pressure test station. C) Assembled test stand

- Five test stands have been built to test performance of new cells designs
- Five tests stands are being developed to test compressor durability
- 2 gallon and 10 gallon HPWH compressors have been designed and are under construction

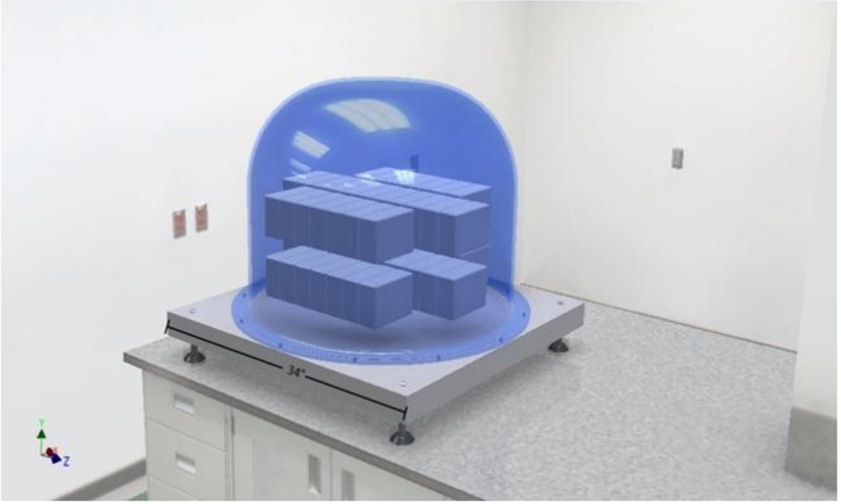
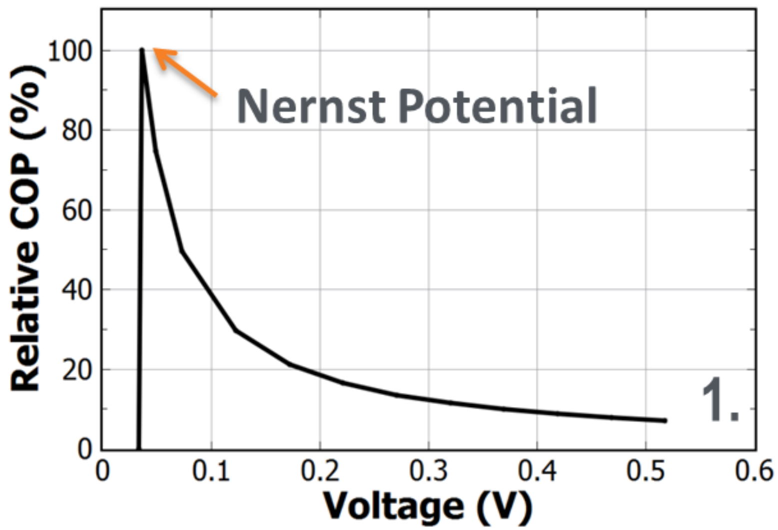


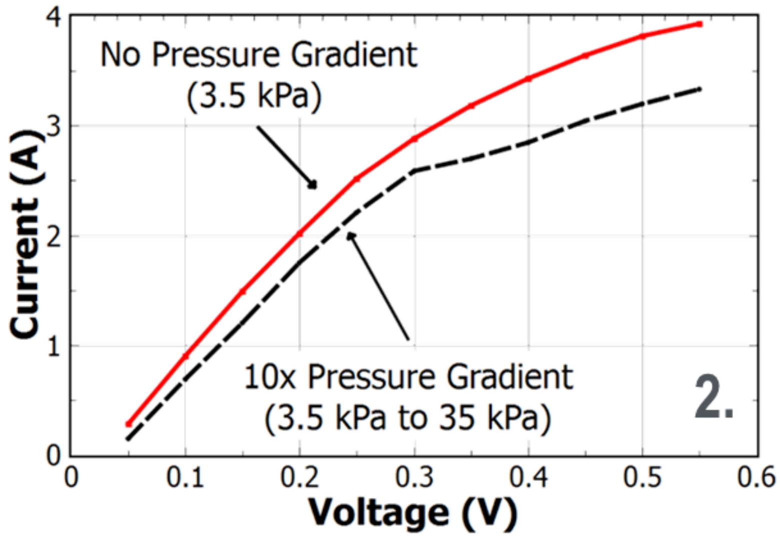
Fig.2: Simplified multi-cell compressor design

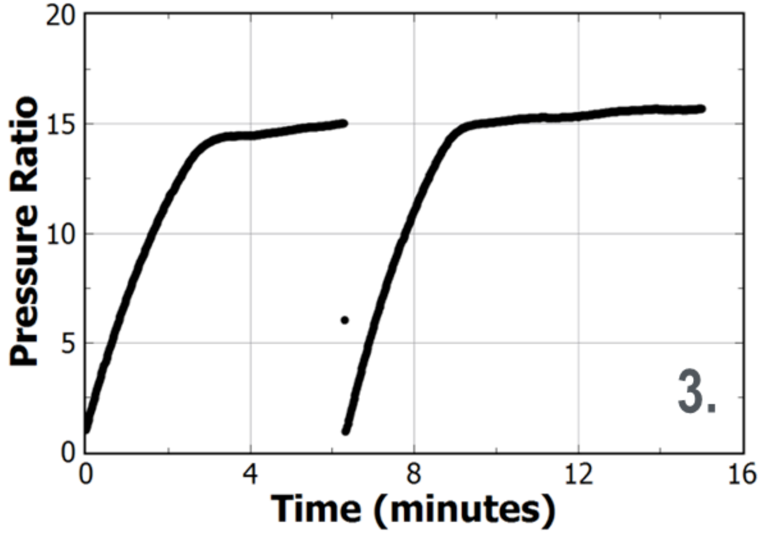
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Progress and Accomplishments: Compressor Performance

1. Heat pump water heater compressor performance. COP
   - Is highest at the Nernst potential
   - Decreases with increasing voltage
   - Goes to zero when the cell voltage is below the Nernst potential
2. The effect of pressure gradient on cell performance. ECC water compressors will require a pressure ratio of approximately 13
3. Pressure build-up and reproducibility in prototype compressors for HPWH







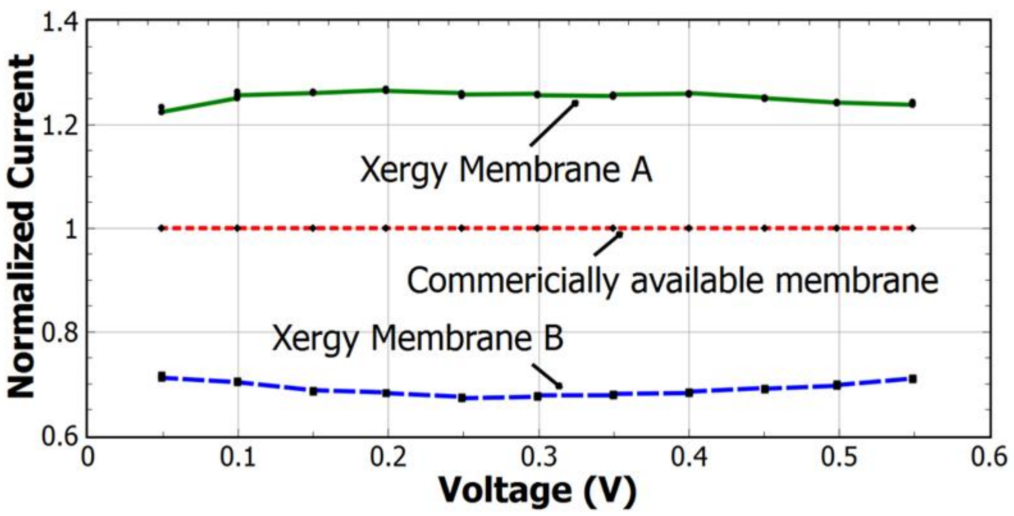
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

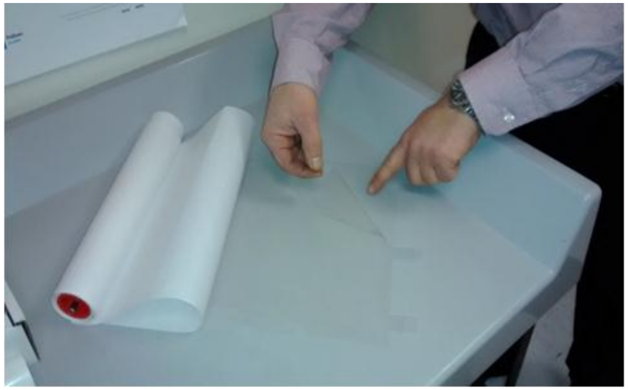
Progress and Accomplishments: HWH Prototype

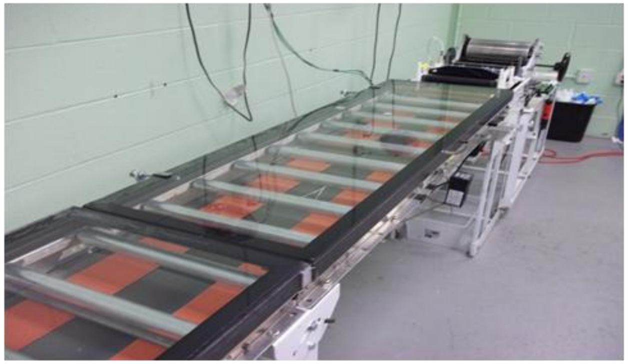
GE Appliances (Commercial Partner)

- Developed flow simulator
- Performed heat exchange analysis
- Acquired raw materials for prototypes

Progress and accomplishments: Membrane fabrication

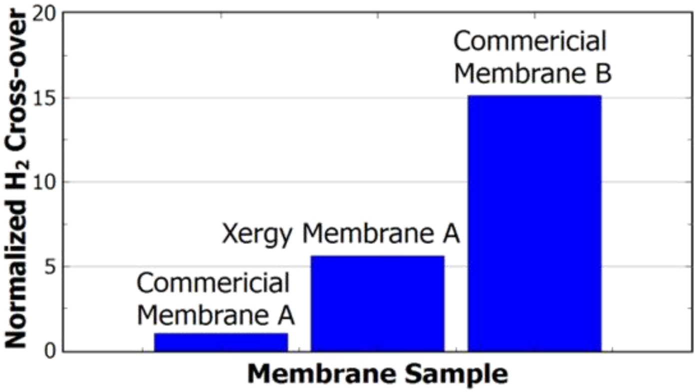






- Ultrathin, strong Composite membranes with thickness between 5 and 30 microns have been fabricated on a roll to roll line

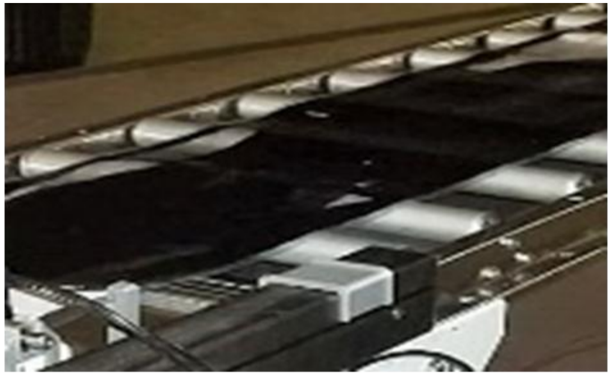
- Xergy membranes show good performance compared to commercial membranes

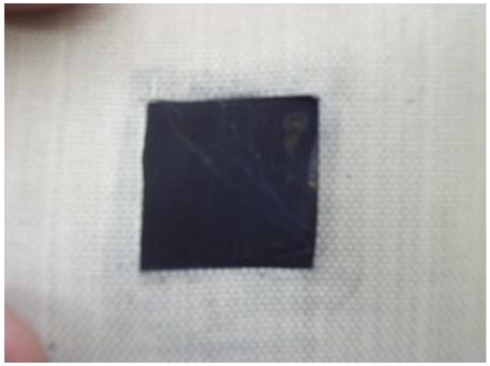


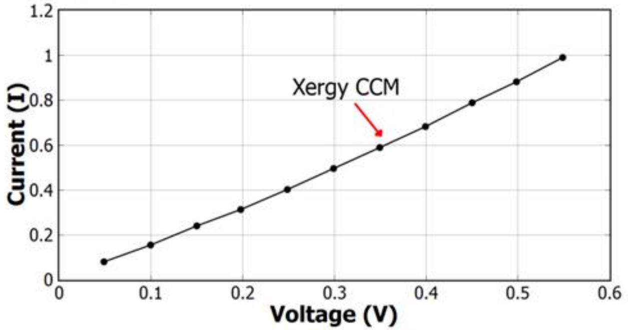
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Progress and accomplishments: Electrode fabrication

- Electrode Films have been produced on a roll to roll line
- Catalyst Loadings of 0.3 mg/cm2 and 0.1 mg/cm2
- Catalyst coated membranes are currently being tested
- New Catalyst formulations are being developed, both lower cost and lower quantity of precious metals in the system
- Gasket system has been developed to suit MEA features and provide sealing







Progress and Accomplishments: Summary

Major accomplishments include:

- Built five test stations, completing 5 more now (on schedule)
- Built continuous membrane and electrode production lines
- Determined multiple sources of raw materials
- Developed membrane and electrode formulations
- Tested prototype compressors showing requisite compression ratios
- Multiple cell redesigns improved performance by
    - Reducing component distortion under operating conditions
    - Eliminating canister leaking
    - Improving “cell breathing”
- Designed the 2 and 10 gallon water heater compressor and balance of plant
- Building first unit for system integration now (on schedule)
- GE Appliances has designed balance of plant, identified component requirements, and procured units.

Xergy, Inc. has full confidence that the remaining technical objectives of this project can be delivered in budget period two.

Progress and Accomplishments

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

- Low pressures needed for water vapor compression require intricate sealing and heat exchanger plumbing
- Mass transport limitations lead to large cell foot print

Market Impact:

- Demonstrated a ECC based HPWH with a water refrigerant
  - Low GWP
  - No direct environmental impact
- Approximately 8 million new WH are purchased yearly
- If project targets are met payback period will be less than 2 years

Awards/Recognition: GE Ecomagination Award 2011, Cleantech 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
- Obtained input from industry experts in membrane technology
- Sponsored related work at the University of Delaware and the University of Maryland

Partners, Subcontractors, and Collaborators:

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

Communications: Currently have 23 patents in process, and presented numerous papers including ACEEE Hot Water Forum 2013

Next Steps and Future Plans

Next Steps and Future Plans:

- Build 10 gallon HPHW prototype based on in-house membrane electrode assembly
- Optimize packaging: cell geometry and design
- Build capacity to produce low cost high volume molded cell plates
- Build full size 50 gallon HPHW prototype with all in-house components
- Perform endurance testing, validate long-term performance

Also, separately we plan to immediately leverage our capabilities to begin marketing sub-components

- Engage current capabilities to produce custom membranes
- Market MEA modules for niche applications
  - De-humidifiers
  - CO sensors
  - Etc.

REFERENCE SLIDES

Project Budget

Project Budget: To date, Xergy Inc. has stayed in compliance with 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: 45% has been spent as of 3/3/2015
Additional Funding: none

Budget History					
5/19/2014– FY2014 (past)		FY2015 (current)		FY2016 – 5/19/2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
386,947.09	42,994.12	67,945.85	7549.53	542,787.06	60,309.67

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									