# Advanced Hybrid Water-Heater Using Electrochemical Compression (ECC)

2017 Building Technologies Office Peer Review

XERGY

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

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**Xergy, Inc.**

# Project Summary: Phase IIB SBIR

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

**Key Partners**:

| | |
|---|---|
| Xergy, Inc. | HAIER / GEA |

**Key Milestones:**

1. Develop advanced Metal Bi-Polar Plates for ECC's
2. Integrate New Membranes & MEA's
3. Build State of the Art Metal Hydride Heat Exchangers
4. Develop Advanced System Integration & Controls
5. Meet ultimate cost targets
6. Meet Long-term Durability Requirements

**Budget**:
2013 (2/2013 thru 11/2013)-Phase 1 - $149,856.00
2014-2015-(5/2014 thru 5/2015)-Phase II - $997,680
2016-2017-(8/2016-present) Phase IIB - $408,922.39
Present – 8/2018 Phase IIB - $ 576.110

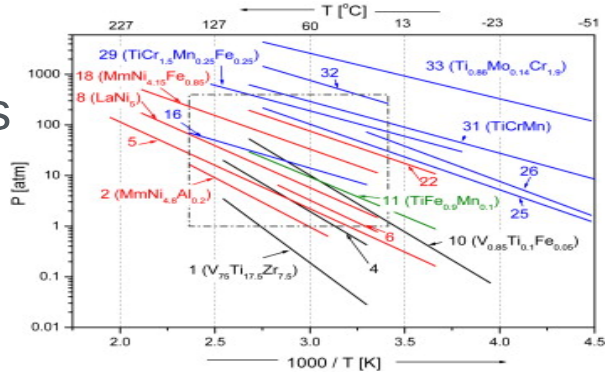
**Project Goal**:
Develop a heat pump water heater utilizing electrochemical compression technology with an installed cost and real world efficiency that will enable widespread adoption in US residential markets

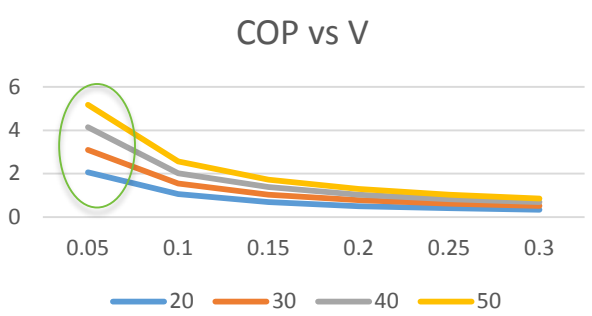
**Target Market/Audience**:
Residential electric water heating.

**TRL**:
Start: 7 End: 9 (system)

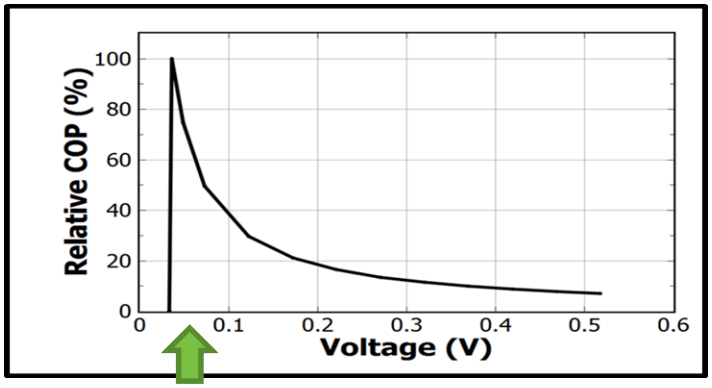
# ECC + Metal Hydride Heat Exchangers System Efficiency

ECC + metal hydride heat exchanger, requires ultra dry compressed hydrogen – at controlled pressures



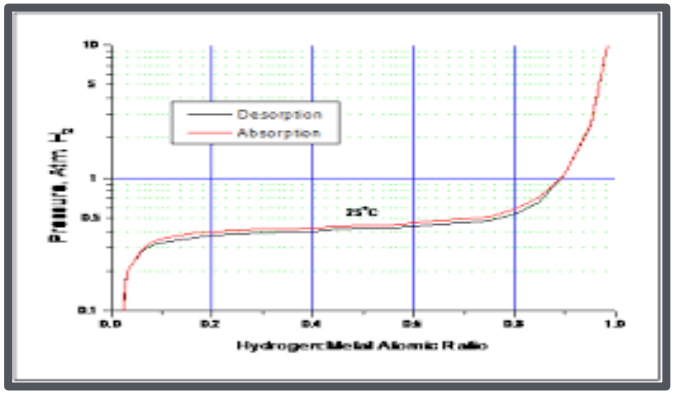




## Compressor




Operating Point (0.05 V)

## Heat Exchanger




Almost Reversible Reaction
Difference Between Curves is called Hysteresis
< 5% Loss For “Right Hydrides”

# 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** |

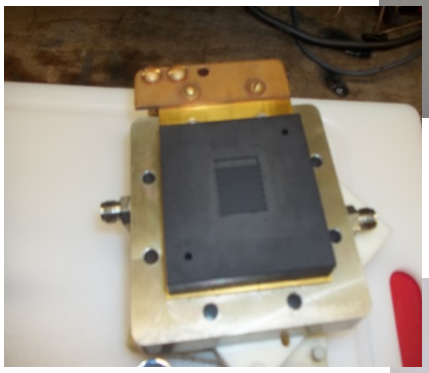
**Target Market and Audience:** Approximately 15% of electric demand is for hot water production using 1.4 Quads/yr.

**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 – Key Components

- **Key Components:**
  - Polymer Electrolyte Membranes & Electrode Systems (MEA's)
  - Cell Plate Designs
  - Compressor (Stack) 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:**

- 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 and heat pump system integration
- Build and Demonstrate prototype and commercial system based on advanced components and design (50 gallon ECC HPWH)

**Key Issues**:

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

**Distinctive Characteristics**:

ECC driven heat pump water heater

# Major Tasks and Accomplishments: Summary

Major Tasks

- Year 1: Develop, produce and integrate low cost advanced Metal Bi-Polar Plates
- Year 1: Develop, produce and Integrate New low cost Membranes & MEA's
- Year 1: Develop, produce and integrate advanced MHHX's
- Year 2: Develop Advanced System Integration & Controls
- Year 2: Meet ultimate cost targets
- Year 2: Meet Long-term Durability Requirements

Accomplishments

- Established Advanced Composite Membrane capability, now used for multiple DOE programs – achieved cost reduction goals
- Established automated electrode and gasketing capability – achieved cost reduction goals
- Achieved critical industry metrics for EC Compressor
- Built first prototype combined ECC + MHHX (Heat Pump) Hybrid Hot Water Heater

Working On

- Working on more advanced plate production capability
- Working on more advanced Metal Hydride production capability
- Working on system integration concepts
- Working on durability requirements

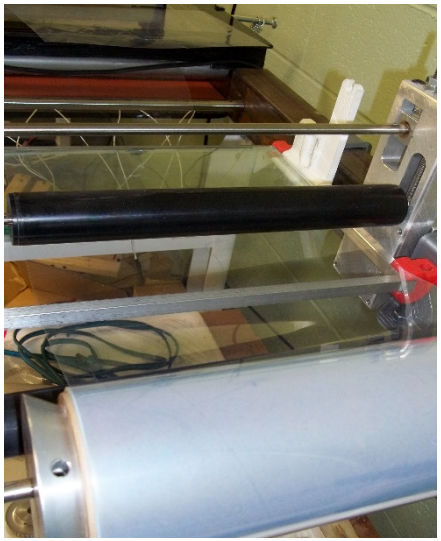
# Progress and accomplishments: Membrane & Electrodes

- Ultra-thin, Ultra-strong, Ultra-high performance pilot scale continuous Composite membranes and MEA's production capability in SBIR II

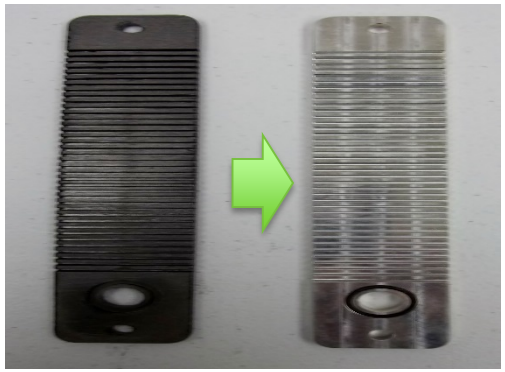
- In SBIR IIB:  Advancing MEA's production capacity further, with next generation robotic electrode production (no longer using transfer roll), and investing in more advanced membrane production capability
  - Able to process 'low cost' ionomers, very efficiently with high uniformity

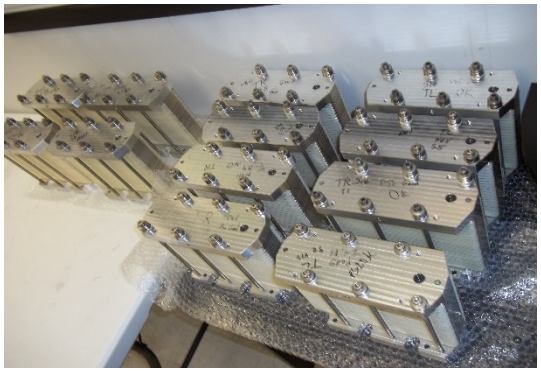
- Established new strategic source for catalysts

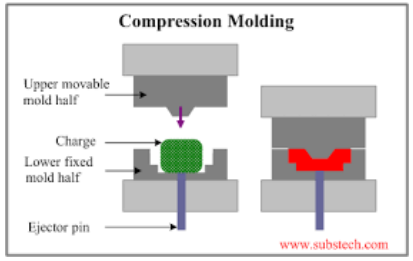
- Current Production capacity – literally hundreds / thousands of different types of MEA's a week

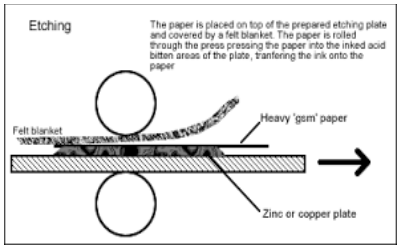


# Progress and Accomplishments: ECC Components (Plates)

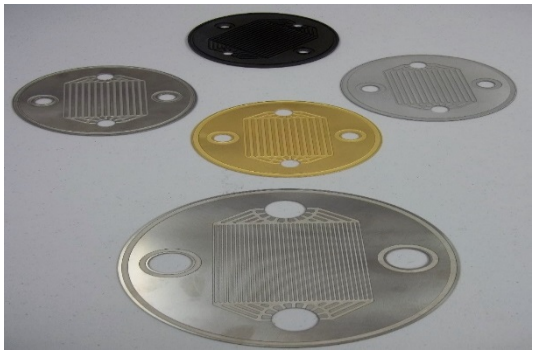


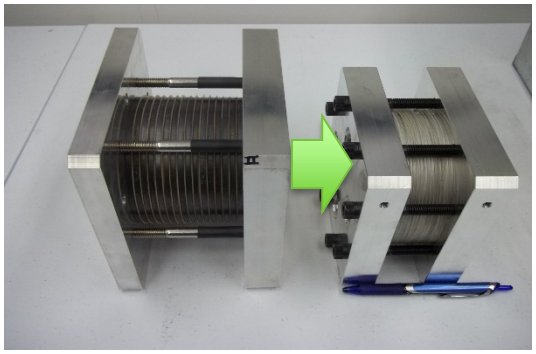


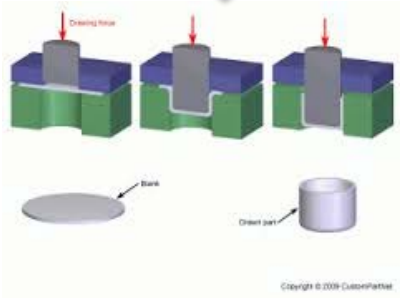



- Developed prototyping, piloting and large scale plate production capability
- Note, stamping dies are not cheap, and ordered only when final designs are validated; this work is in process (plates have to be produced for pennies to achieve cost targets



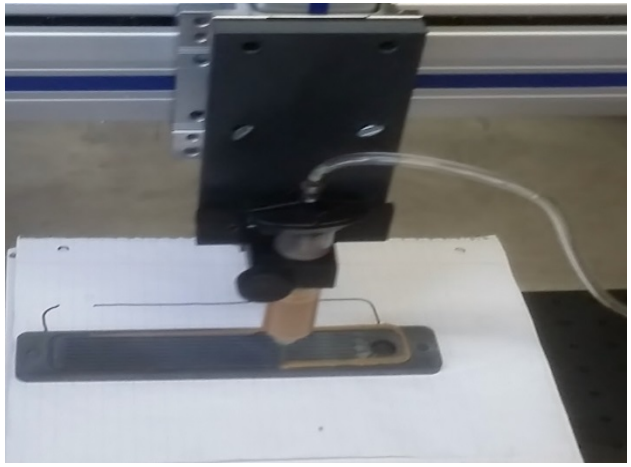


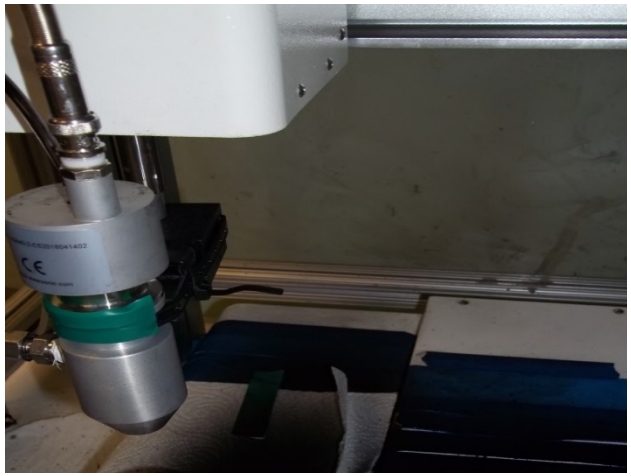


# Progress and accomplishments: Automation

- Robotic Gasket Application Systems installed in SBIR II
  - Gasket application upgraded – new programming and temperature controlled facility
  - Able to finish literally hundreds/thousands of plates a week.
  - Quality Assurance systems are in place

  QA systems to test gasket/electrical integrity
- Robotic Electrode Production
  - Moved away from Roll to Roll Systems
  - Much higher accuracy – especially with lower catalyst loadings
  - More efficient deposition, less waste
  - Customizable

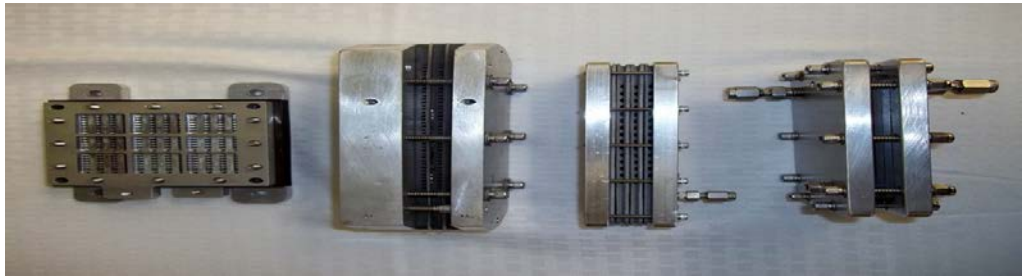


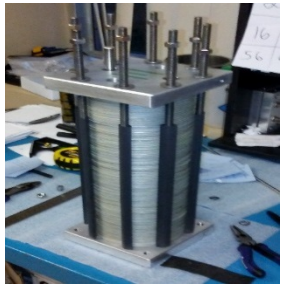


# 7 Generations of ECC's

**Commercial Sale (H2 compressors) Started**

| DOE SBIR PHASE 1 | DOE SBIR PHASE 2 Design Freeze | DOE SBIR PHASE 2 Advanced Learnings | DOE BENEFIT 2015 Design Freeze | DOE SBIR PHASE 2B Advanced Plates | DOE BENEFIT 2016 Anhydrous | DOE SBIR 2B 2017 Large Plates |
|---|---|---|---|---|---|---|
| GEN 1 | GEN 2 | GEN 3 | GEN 4 | GEN 5 | GEN 6 | GEN 7 |





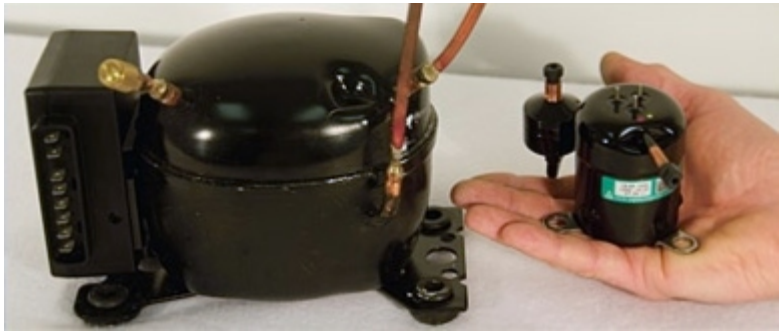
| Single Cell H2O | Multi-Cell H2O Graphite | Multi-Cell H2O Metal | Graphite Plate – H2 Internal Porting | Metal Plate – H2 3 x Smaller | Coatings Simpler System | Large Area 3 X Lighter |
|---|---|---|---|---|---|---|

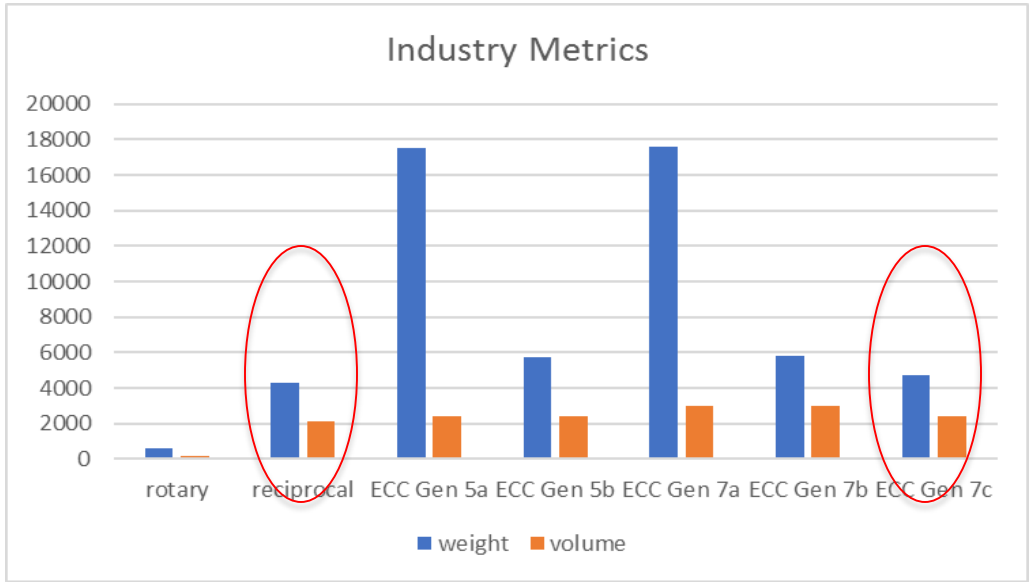
**Commercial Sale (Water Compressor) Dais / ORNL**

# ECC Comparison to Industry Metrics @ Nominal 150 Watts (Cooling) – Current State of the Art

- 5th & 7th Generation, C Variant ECC, within 10% of best reciprocal compressor system!
- Next stage is to work on cost, (while improving performance)

| Unit Description | weight (grams | volume (cc |
|---|---|---|
| rotary | 590 | 180 |
| reciprocal | 4313 | 2130 |
| ECC Gen 5a | 17520 | 2418 |
| ECC Gen 5b | 5760 | 2418 |
| ECC Gen 7a | 17568 | 2959 |
| ECC Gen 7b | 5776 | 2959 |
| ECC Gen 7c | 4728 | 2423 |

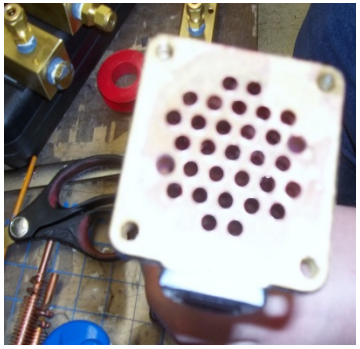




# Progress and Accomplishments: Heat Exchangers

1. Stopped buying Hydrogen storage units and set up in house MH Heat Exchanger production capability

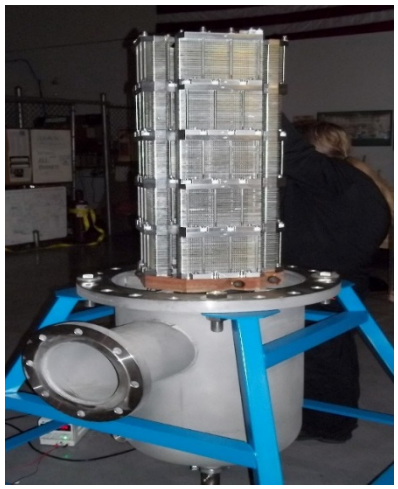
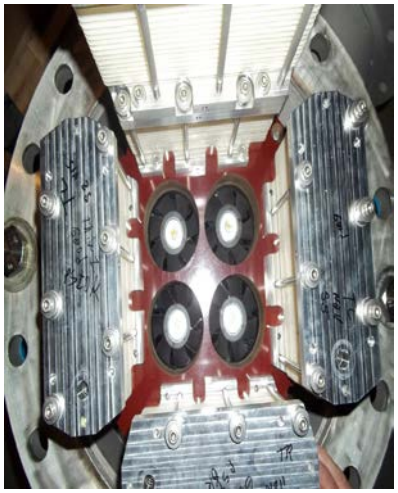
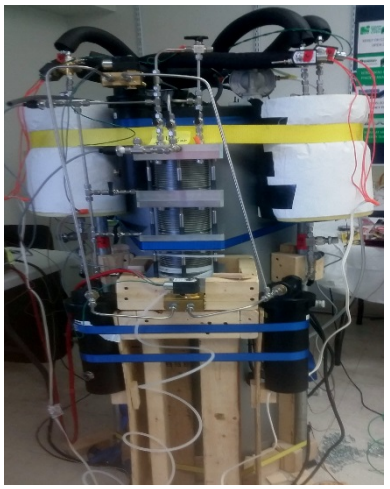
2. Set up Partnership with Delaware State University, that is a DOE center of excellence for Metal Hydride (and fuel cell) technology (>$5 Mn in DOE investment at Del State)

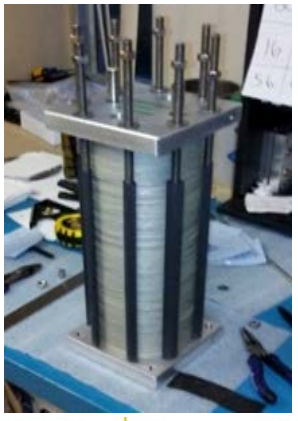


DSU Delaware State University

# Progress and Accomplishments: Deliveries

- Delivered 150 W (Water Compressor) to GE (SBIR II), and prototype Water Compressor for 7 Ton Chiller
- Assembled 7 generations of .4 L, and 4 L (150 Watt) Hydrogen compressors
- Built 50 Gallon (Hydrogen / MHHX) HHWH System & Testing (SBIR II)



# Progress and Accomplishments

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

- **New systems, 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**)

**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, Xergy, Inc.
  - Bamdad Bahar, President Xergy, Inc.
- Haier / General Electric Appliances
  - Dave Beers, Manager, Heat Engines R&D

**Communications**: Currently have 30+ 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

- System integration is a critical issue – much to be done
- Perform Endurance testing, validate long-term performance with Partners
- Consider integration projects with others in this space

Also, separately, engaging current capabilities to assist other DOE programs with membrane development

- New Anionic Composite Membranes & MEA's

Partnered in 3 ARPA Awards: RPI/GT, UD, WU

- New Cationic Composite Membranes & MEA's – UD

- Opportunities to leverage capabilities to develop business in other areas:
  - (Custom) Composite Membrane Production – ARPA-E
  - Micro-Climate Control Systems – Appliance Applications
  - Gas Sensors – Commercial Applications
  - ILD Systems – Commercial Applications
  - Advanced Metal Hydride Systems – re-establish U.S. Capability & R&D

# Spin Off Technologies …