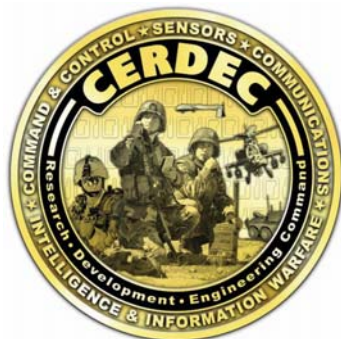


Power Generation and Alternative Energy Branch

US Army RDECOM CERDEC CP&ID Power Division
Aberdeen Proving Ground, MD



PGAE - CR - 12 - 10

Microscale Waste Heat Driven Cooling System

Michael Garrabrant, et al, Stone Mountain Technologies Inc

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Microscale Waste Heat Driven Cooling System

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May 2, 2012



Sustainable Products for a Sustainable Future

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US Army - CERDEC
**Smaller Lighter Co-Generation & Absorption Environmental
Control Technologies**

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Patricia Davis, Contracting Officer
William Campbell, Contracting Officers Representative

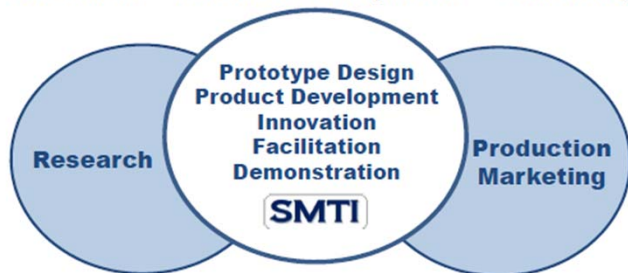


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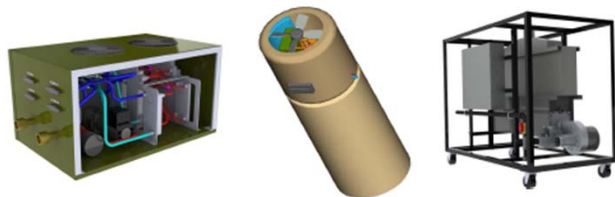


Stone Mountain
Technologies, Inc.

Research • Product Development • Consulting



- ❖ Waste Heat Driven Chillers
Engines, Turbines & Fuel Cells
- ❖ Residential Solar Cooling
- ❖ Gas Heat Pump Water Heaters
- ❖ Heat Pump Crop Dryers
- ❖ High Performance Process Heating
- ❖ Modulating Combustion

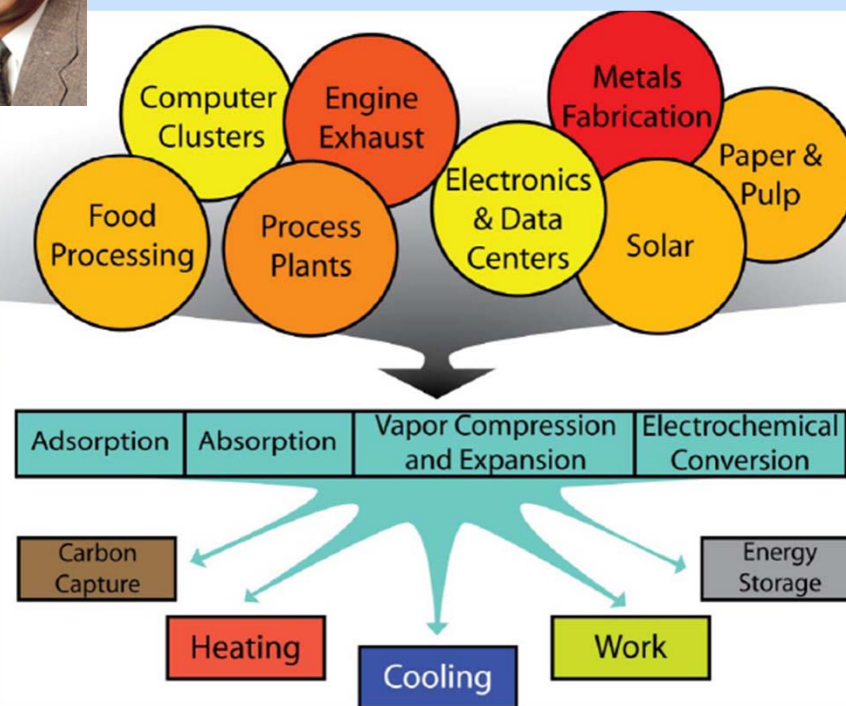


"Sustainable Products for a Sustainable Future"

SMTI



Dr. Srinivas Garimella
Georgia Tech
Sustainable Thermal Systems Lab



Sustainable Thermal Energy Utilization through an understanding of the fundamentals of single-phase and phase-change heat and mass transfer in single- and multi-component fluids for the development of innovative micro- and macro-scale components and systems

Sustainable Products for a Sustainable Future

Microscale Waste Heat Driven Cooling System Objective

Medium Sets

- 5kW, 10kW, 15kW, 30kW, and 60kW, Skid Mounted, Diesel Fueled Tactical Quiet Generator, 60Hz and 400Hz
- AMMPS – Advanced Medium Mobile Power Sources



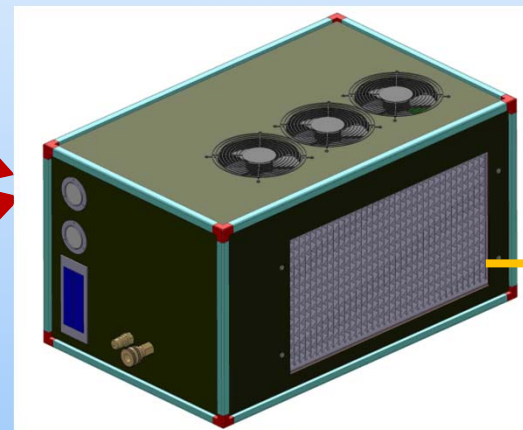
Power Unit/Power Plant (PU/PP)

- Trailer Mounted Tactical Quiet Generators in the 3kW, 5kW, 10kW, 15kW, 30kW, 60kW, 100kW, and 200kW Power Ratings.
- 20 Different Models That Use 4 Different But Standardized TACOM Trailer Models



Waste Heat

Microscale Heat Pump



Reject Heat to Ambient

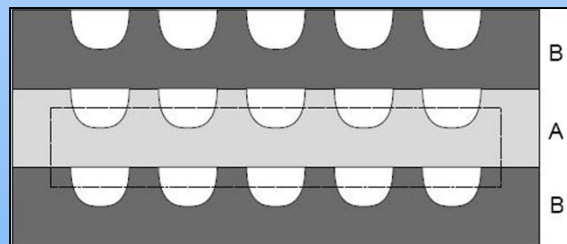
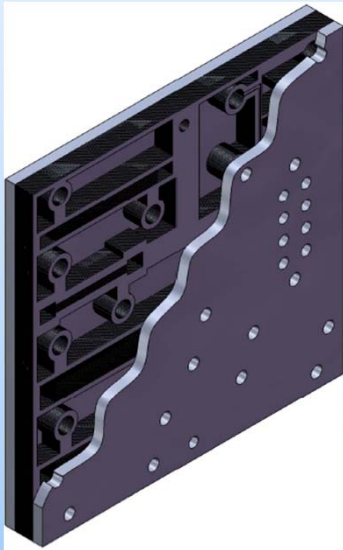
Direct Air-Cooled

Develop a diesel engine waste heat driven ammonia-water absorption environmental control unit (ECU) using micro-scale heat exchanger technology.

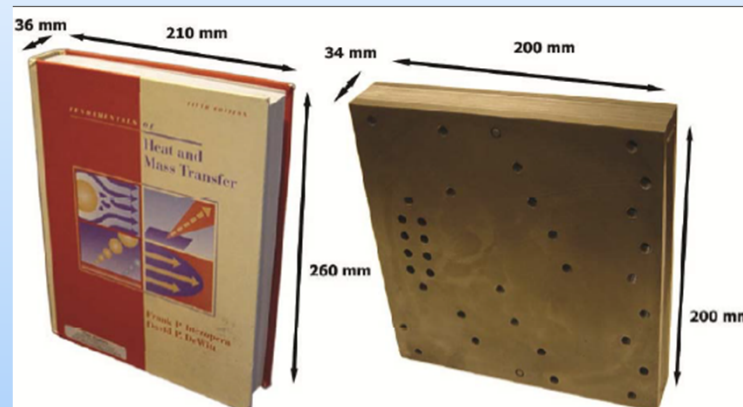
1 – 20 kW Cooling

Microscale Waste Heat Driven Cooling System

History & Rationale



$D_h = 0.5 \text{ mm}$



- ❖ Can it be scaled to larger capacities?
- ❖ Can it be manufactured using low cost processes?
- ❖ Is counter-flow heat and mass transfer possible in microscale geometries?

Microscale Waste Heat Driven Cooling System

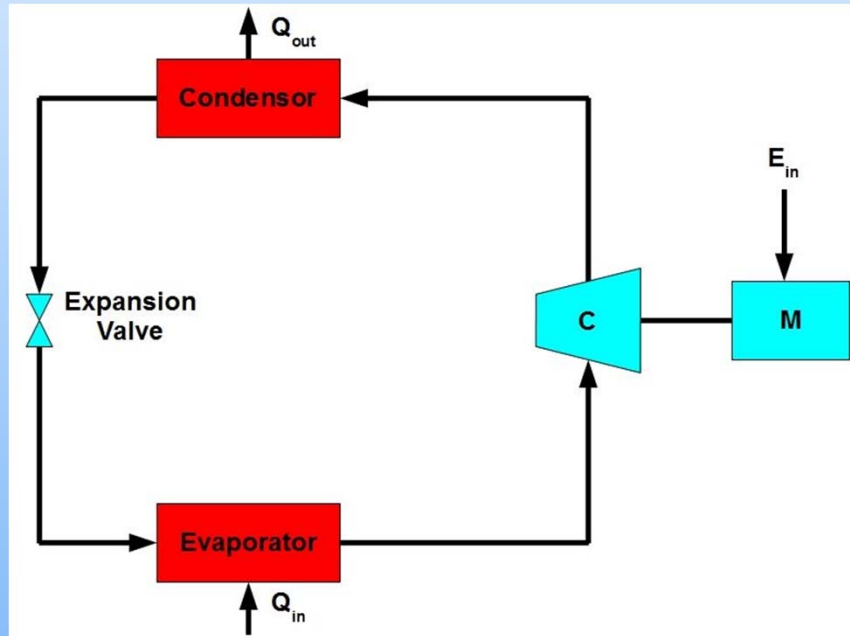
Major Project Tasks

- ❖ **Optimize Absorption Cycle For Application**
- ❖ **Microscale Heat Exchanger Design for Absorption Systems**
- ❖ **Low-Cost Microscale Heat Exchanger Manufacturing Method**
- ❖ **Compact Solution Pump Development**
- ❖ **Breadboard Testing**
- ❖ **2kW Packaged Prototype Demonstration Unit**

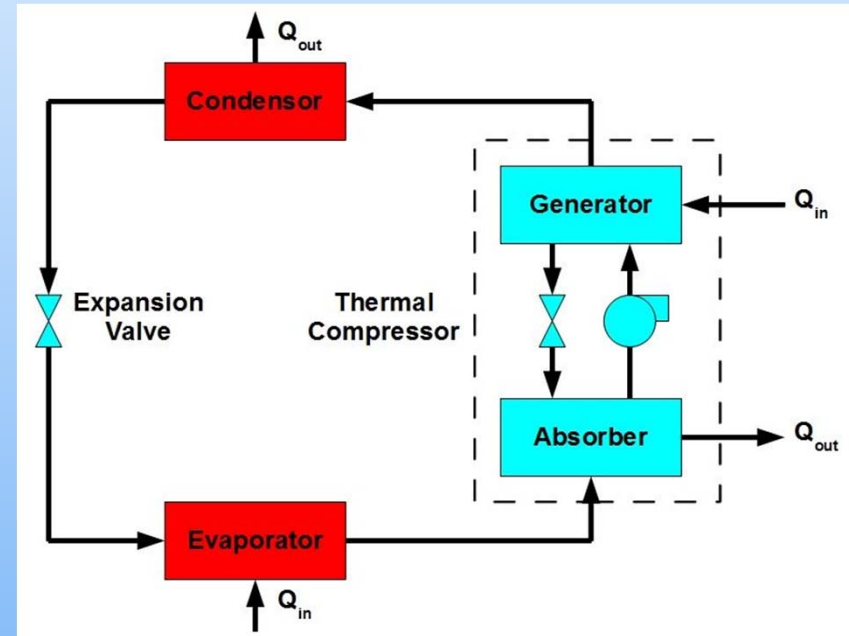
Microscale Waste Heat Driven Cooling System

Cycle Optimization

Vapor Compression Cycle

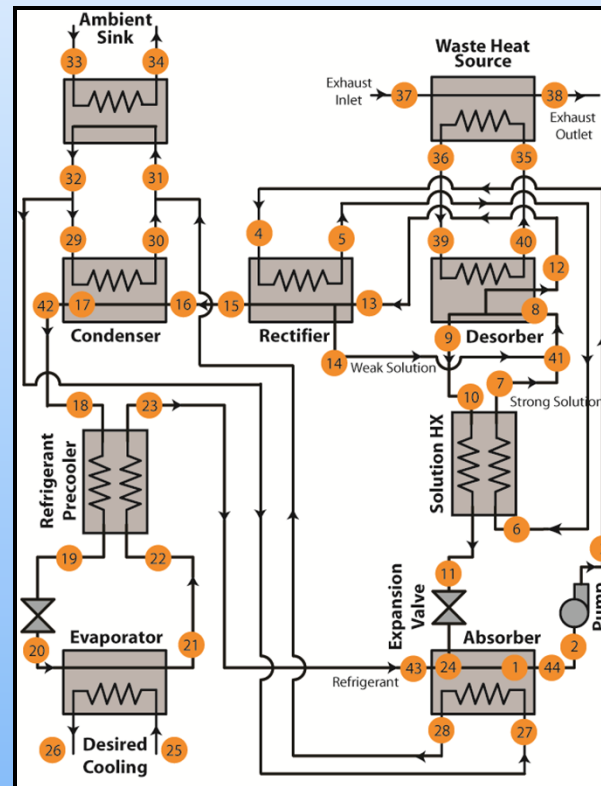
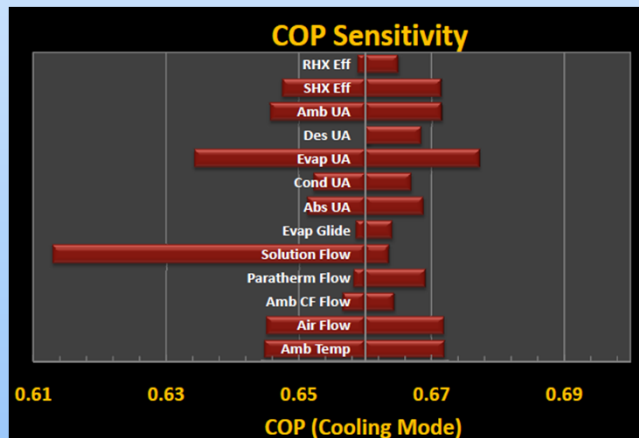


Absorption Cycle



Microscale Waste Heat Driven Cooling System

Cycle Optimization

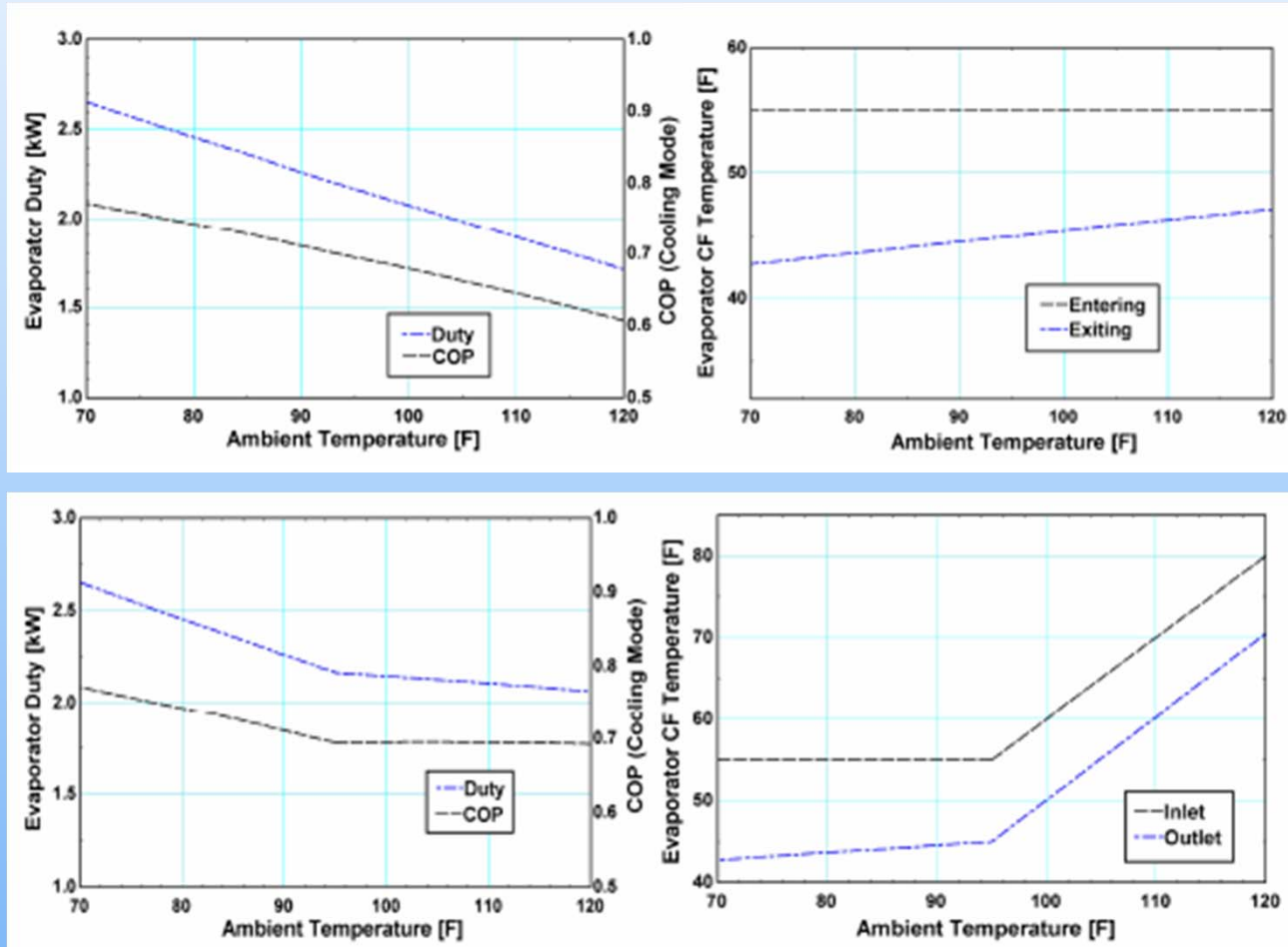


Component	UA (kW/K)	Duty (kW)
Rectifier	0.014	0.45
Solution HX	0.100	1.49
Desorber	0.079	3.11
Condenser	0.350	2.02
Precooler	0.039	0.21
Evaporator	0.502	2.09
Absorber	0.300	3.19
Ambient HX	2.400	5.21
Exhaust HX	0.032	3.11
COP	0.67	

**95°F Ambient
45/55°F Chilled Water**

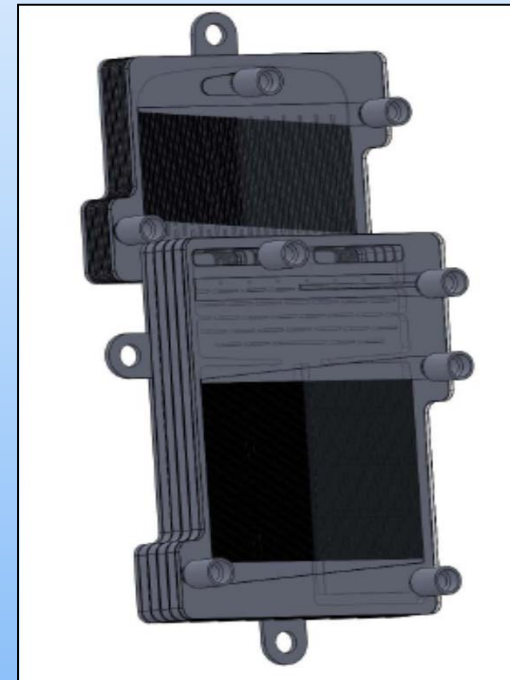
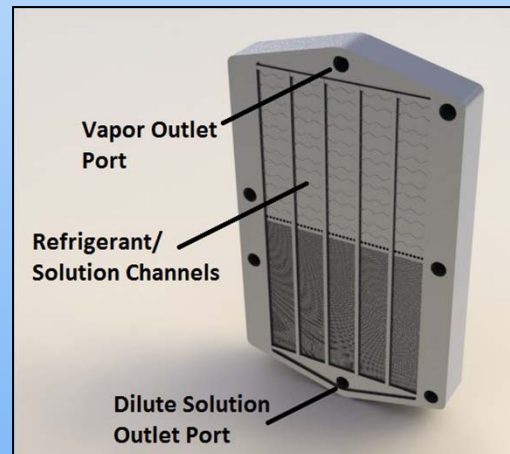
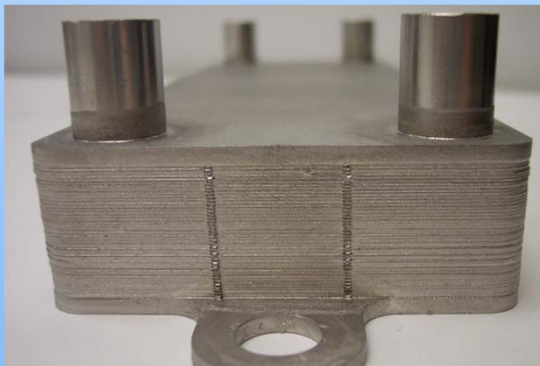
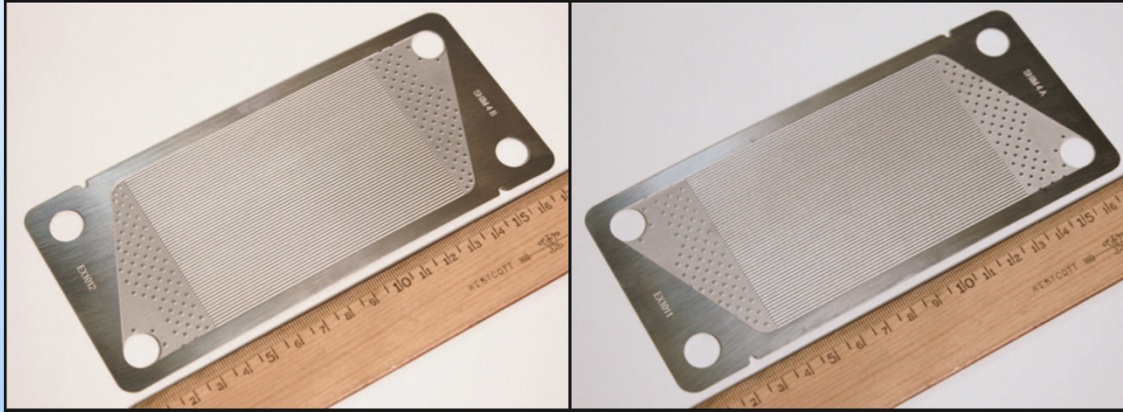
Optimized Waste Heat Driven Absorption Cooling Cycle

Microscale Waste Heat Driven Cooling System Cycle Optimization



Microscale Waste Heat Driven Cooling System

Microscale Heat Exchanger Design



Microscale Waste Heat Driven Cooling System

Microscale Heat Exchanger Manufacturing Development

❖ **Microscale Shim Production**

- ❖ Chemical “Photo” Etching Used for Proof-of-Concept & Shims for this project
- ❖ Proven process can achieve dimensions and tolerances
- ❖ Dedicated production line can hit target production costs

❖ **Heat Exchanger Bonding**

❖ **Diffusion Bonding Used for Proof-of-Concept**

- ❖ Slow, expensive, one-at-a-time process

❖ **Nickel Brazing Lower Cost Method**

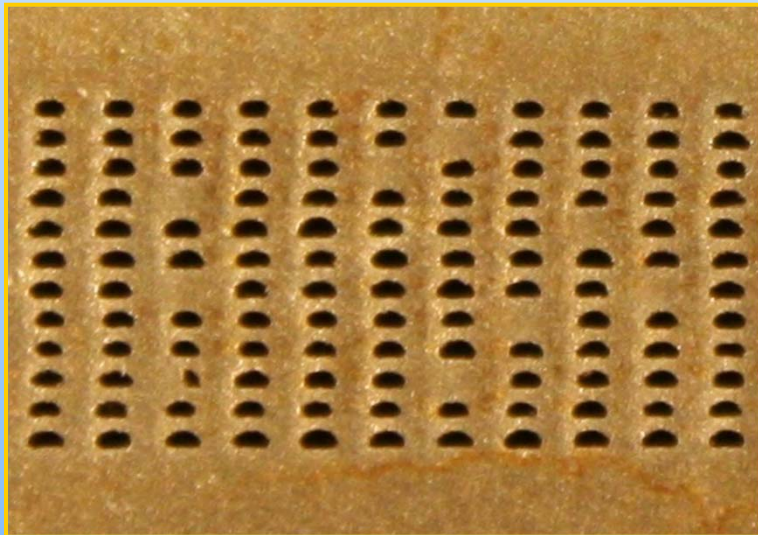
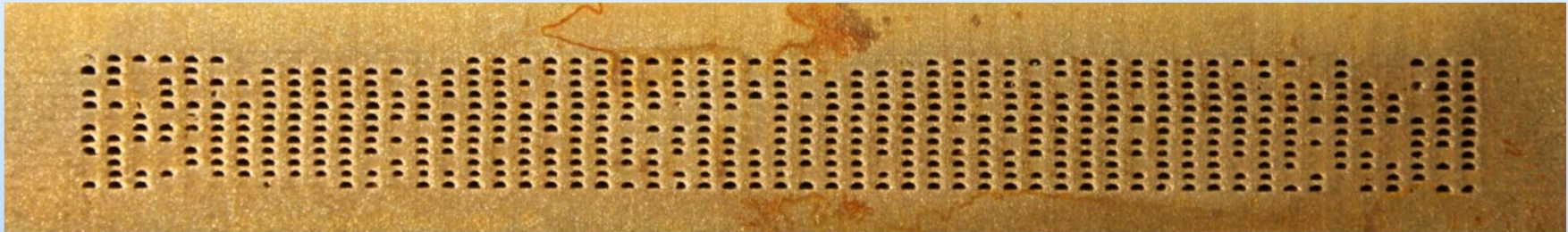
- ❖ Can braze 50 – 200 in single furnace run (vs 1 – 2 using Diffusion Bonding)
- ❖ Potential Use of Continuous Belt-Type Furnace

❖ **Nickel Brazing Technical Issues**

- ❖ Micro channel size reduction and/or blockage
- ❖ Amount of Alloy: Pressure Tightness vs. Channel Blockage
- ❖ Alloy Application: Spray, Plating, Foil
- ❖ Furnace Temperature and Heat/Cool Rates

Microscale Waste Heat Driven Cooling System

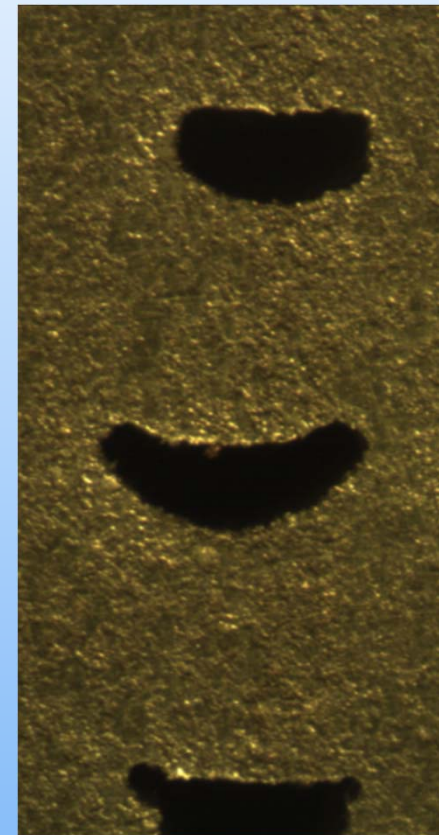
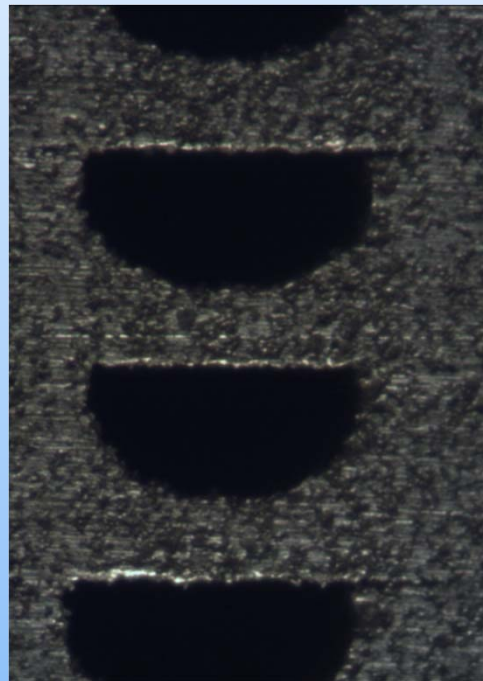
Microscale Heat Exchanger Manufacturing Development



Microscale Waste Heat Driven Cooling System

Microscale Heat Exchanger Manufacturing Development

- ❖ Brazing at 100% Success
- ❖ Minimal Full Channel Blockage
- ❖ Hydraulic Diameter Reduction
 - ❖ 5 – 20%
- ❖ Limiting HX Performance
 - ❖ Distribution Channel-Channel



Microscale Waste Heat Driven Cooling System

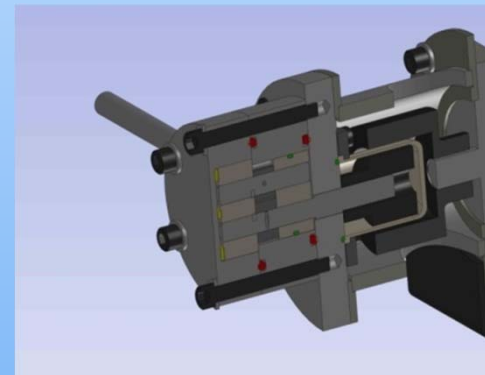
Solution Pump Development

Unique Design Requirements

- ❖ Low Flow Rate/ High Head (300+ psig)
- ❖ Solution Near Saturation Point
- ❖ Ability to Pump Partial Vapor
 - ❖ Compact and Low Cost
- ❖ Hermetically Sealed
- ❖ Long Service Life
- ❖ No Normal Lubricants

Historically Used Technology

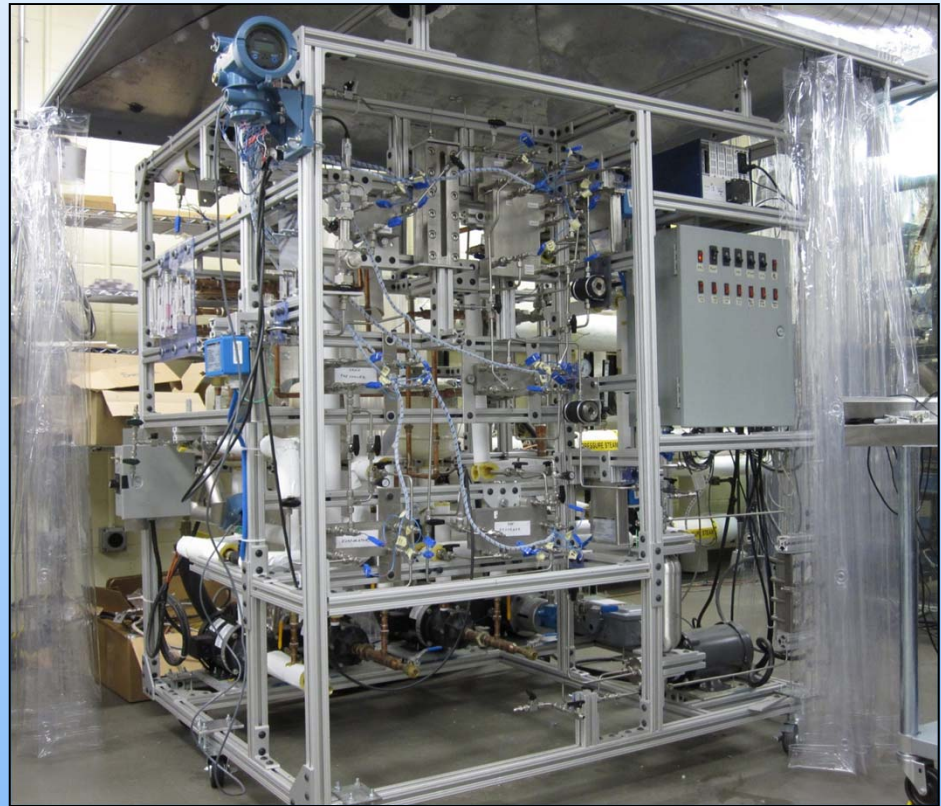
- ❖ Hydraulically driven diaphragm
 - ❖ piston or vane oil pump
- ❖ Complex, expensive, large, heavy



Microscale Waste Heat Driven Cooling System

Breadboard Testing – Georgia Tech Sustainable Thermal Systems Laboratory

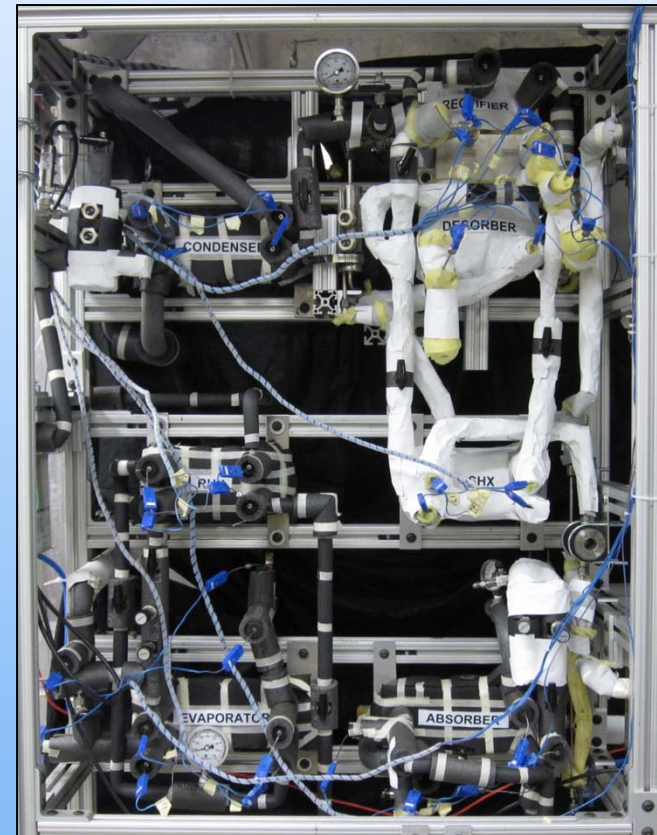
- ❖ Independent control of each hydronic loop
 - ❖ Condenser
 - ❖ Evaporator
 - ❖ Absorber
- ❖ Heat Transfer Fluid - Desorber
 - ❖ Steam heating
- ❖ Mass Flow, Thermocouple and Pressure Transducers at each state point



Microscale Waste Heat Driven Cooling System

Breadboard Testing – Georgia Tech Sustainable Thermal Systems Laboratory

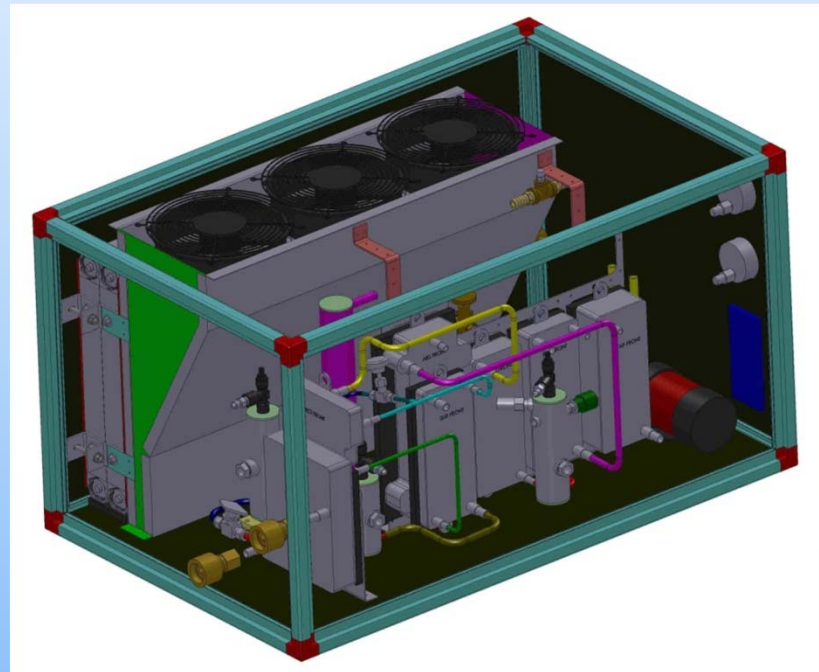
- ❖ Two Desorber-Rectifier Designs
 - ❖ Two Absorber Revisions
 - ❖ 1.9 kW steady state cooling
 - ❖ 0.60 – 0.64 COP, baseline conditions
-
- | | |
|-----------------------------|--------|
| ❖ Desorber-Rectifier Rev 1: | 100% |
| ❖ Desorber-Rectifier Rev 2: | 95% |
| ❖ Condenser: | 100% |
| ❖ RHX & SHX: | 80-90% |
| ❖ Evaporator: | 80% |
| ❖ Absorber A: | 50% |
| ❖ Absorber B: | 65% |



Microscale Waste Heat Driven Cooling System

Packaged Prototype

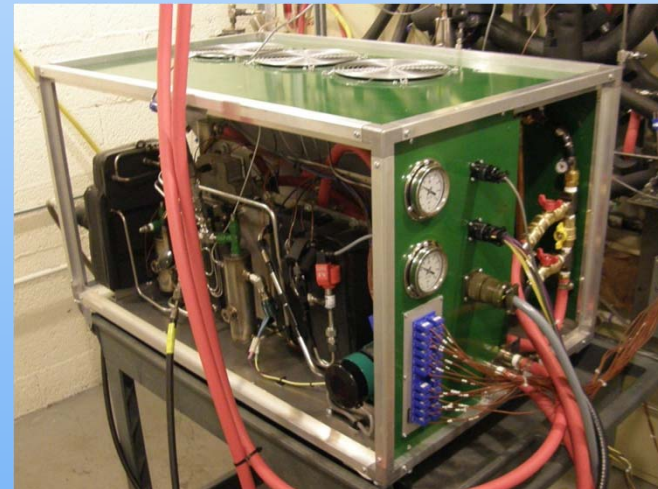
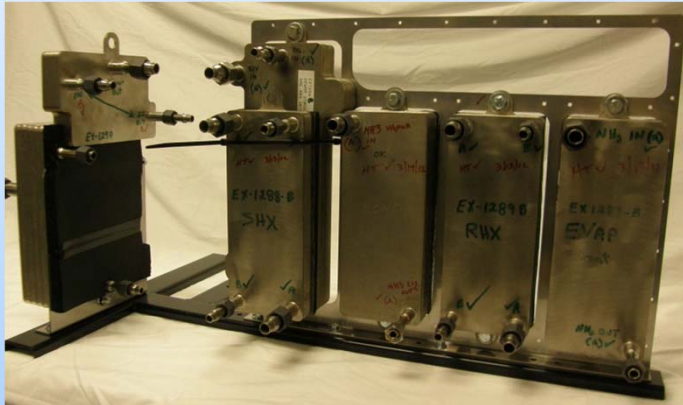
- ❖ **Designed/Sized 2nd Gen HX's**
 - ❖ Based on Lessons Learned
- ❖ **“Off-the-Shelf” Ambient Coil**
 - ❖ Variable Speed Fans
- ❖ **Packaged Unit Layout**
- ❖ **PLC Control System**
 - ❖ Development of Control Algorithm
- ❖ **Electronic Expansion Valve**
 - ❖ Optimum Performance vs Ambient



Approximate Size: 20 x 20 x 36" (ambient coil constrained)

Microscale Waste Heat Driven Cooling System

Packaged Prototype



Microscale Waste Heat Driven Cooling System

Packaged Prototype



Air-Cooled Ammonia-Water Absorption

Commercialization Opportunities

❖ Military/Commercial/Industrial CCHP

- ❖ Gas-Engine and Micro-Turbine Exhaust Driven Refrigeration
 - ❖ Food Processing & Restaurants
- ❖ SOFC Waste Heat Driven Space Cooling and Refrigeration

❖ Residential and Light Commercial Solar Driven

- ❖ Space Cooling or Refrigeration
- ❖ Domestic Hot Water

❖ Residential and Commercial Domestic Hot Water Heating

- ❖ Gas-Fired COP > 1.5

❖ Micro CCHP

- ❖ Residential Sized Gas Engine and Fuel Cell



Thank You!



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