Building Energy Technologies

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Building Energy Technologies

- HVAC
  - ➢ Heat-activated heat pumps
    - Expander/compressor cycle
    - Absorption cycle HP
    - Adsorption cycle HP
  - ➢ Advanced heat transfer
    - Boiling heat transfer
    - Air-side heat transfer
  - ➢ Advanced system concepts
    - ❑ CCHP: co-gen power and cooling
    - ❑ Compact distributed systems
    - ❑ Desiccant cooling
    - ❑ Concentrated solar cooling
    - o Energy recovery ventilator
- Envelope
  - ➢ Wavelength-selective coatings
- Appliances
  - ➢ Heat pump dryer
  - o Heat pump water heater
- Energy
  - ➢ PV – solution deposition
  - o Fuel cell technologies
  - o Energy storage - batteries

➢ Established technology and/or capability
❑ Has been proposed
o Potential application of microtechnology

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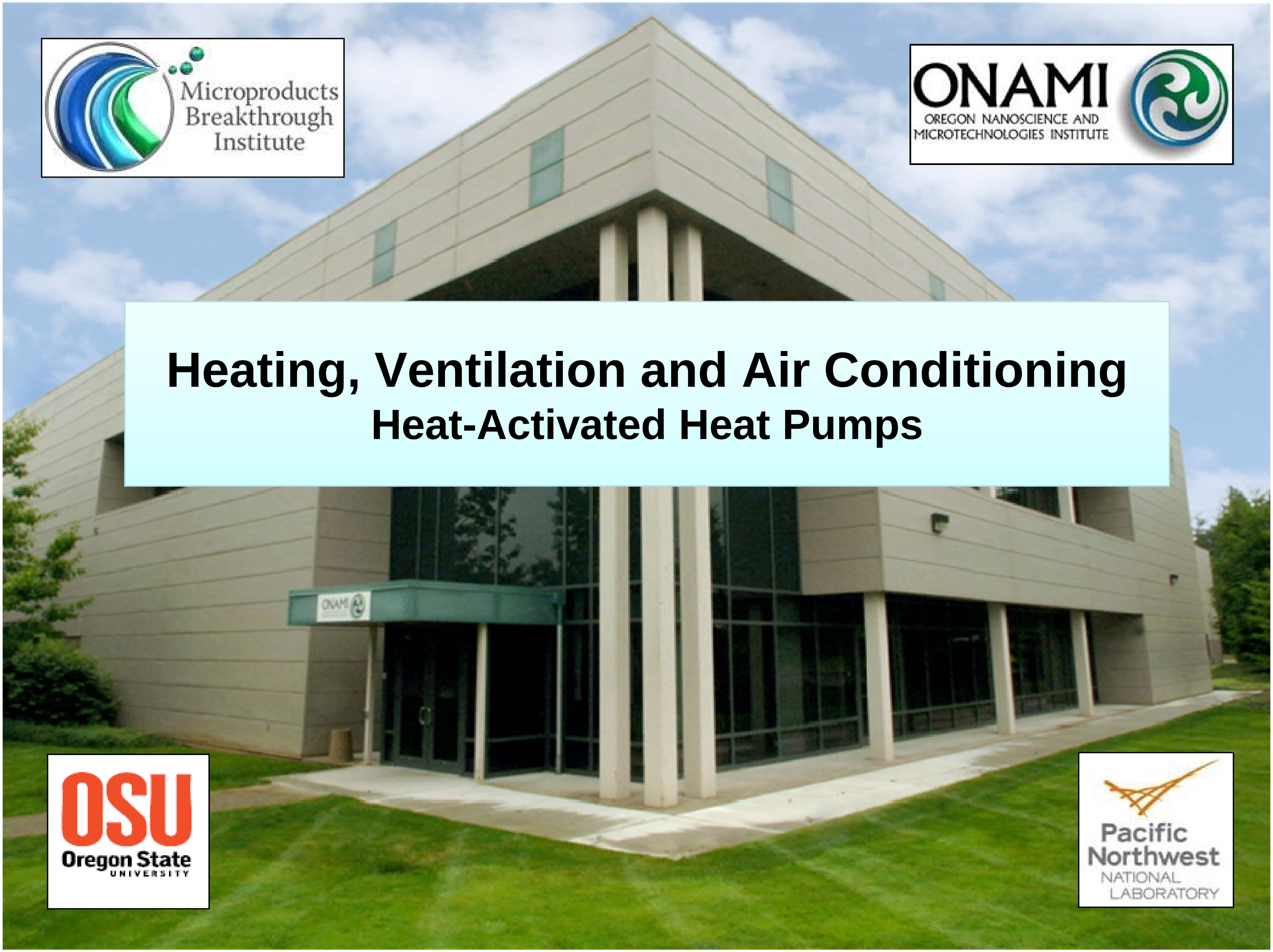
Heating, Ventilation and Air Conditioning
Heat-Activated Heat Pumps



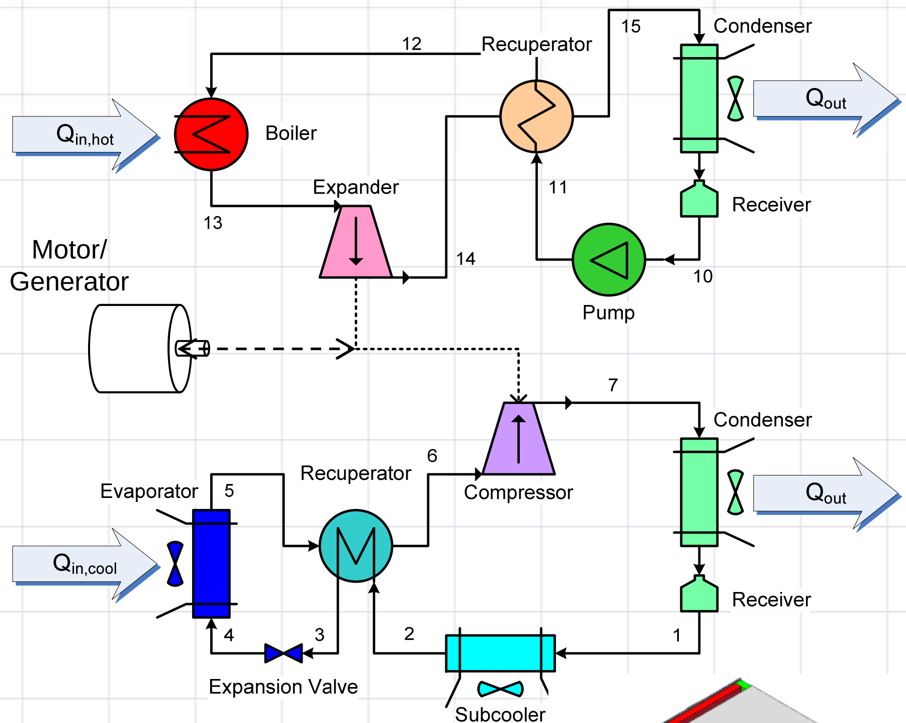
Heating, Ventillation, and Air Conditioning (HVAC)

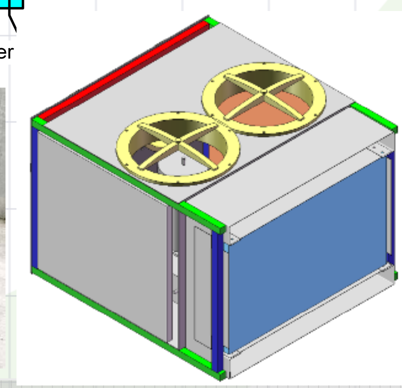
Heat-Activated Heat Pumps

- Use heat to provide cooling, heating, and power
  - Burn a fuel, such as H_2, natural gas, propane, or military fuel
  - Waste heat source—engine exhaust, fuel cell reject heat, etc…
  - Solar thermal—need >100°C, preferably >170°C
- Three systems under development
  - Expander/Compressor cycle—coupled ORC and vapor compression
    - Can provide power, cooling, and/or heating
    - 1.5 ton demonstration system currently in testing (U.S. Army)
  - Absorption heat pump—ammonia-water cycle
    - Can provide cooling and/or heating
    - 1.5 ton demonstration system scheduled for Summer, 2010 (U.S. Army)
  - Adsorption heat pump—ammonia carbon
    - Can provide cooling and/or heating
    - Rapid cycle thermal swing modeling showing COP_{cool}>1.1 and COP_{heat} > 2.4

HVAC: Heat-Activated Heat Pump
Expander/Compressor Cycle

- **Concept**
  - Coupled organic Rankine cycle (ORC) and vapor compression.
  - Mechanical linkage of expander, compressor, and motor/generator allows for any combination of cooling, heating, or power.
  - Co-fired with heat and electric power for highly flexible load-following system.
- **Progress & Status**
  - System models project COP>1.1 at military conditions of 50°C ambient.
  - Developed high performance scroll expander technology (see below).
  - Incorporated advanced microchannel heat exchangers to improve performance.
  - Developed 5.3 kW (~1.5 tons) cooling system, currently in testing.
- **Point of Contact**
- Prof. Rich Peterson, richard.Peterson@oregonstate.edu





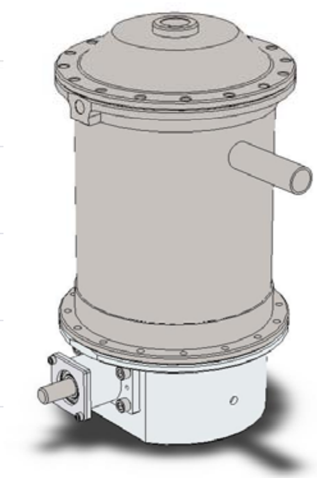
HVAC: Expander/Compressor Cycle

Technology Development – Scroll Expanders

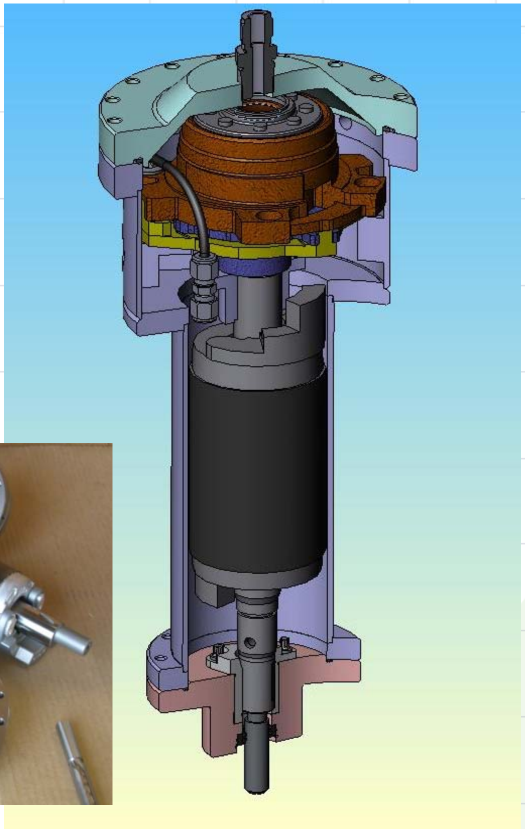
- Based on commercial, high volume production scroll technology.
- Measured near 100% volumetric efficiency in preliminary testing (no blow-by of working fluid).
- Measured isentropic efficiency and power output in test rig show efficiencies approaching 80%.

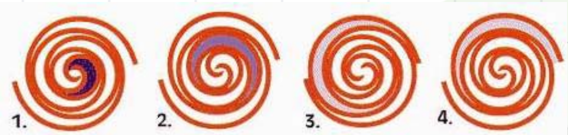
- Packaging and housing
  - Provides output shaft to measure power and to connect to compressor unit.
  - Fully sealed to allow pressurized working fluid.

Latest Design



Earlier Test Design





HVAC: Heat-Activated Heat Pump

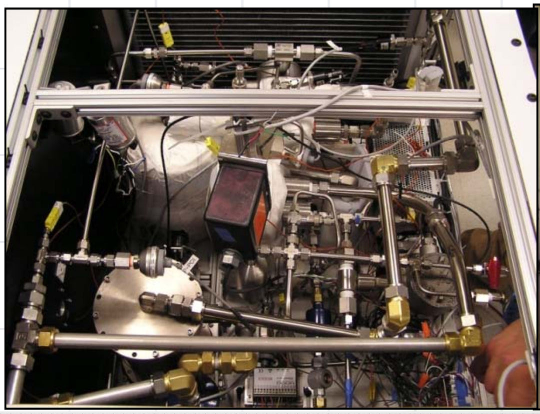
Expander-Compressor Cycle Heat Pump

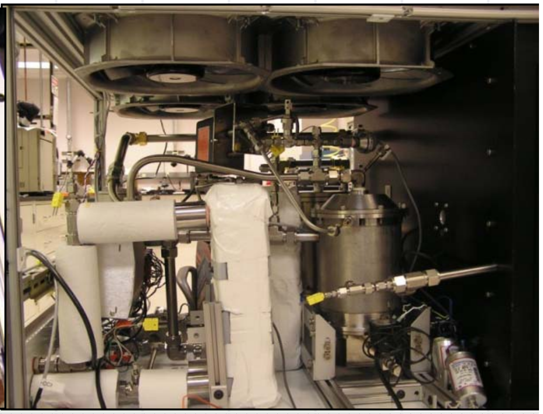
- Competition
  - Commercial electric heat pumps
  - Absorption (solution) cycle heat pumps
  - No commercial heat pumps in U.S. for residential and smaller heat-activated cooling
- Advantages
  - High-efficiency, compact equipment
  - Flexible co-generation of power and cooling/heating
  - Utilize growing supply of natural gas reserves
- Next steps
  - Test system at designed out door temperature of 120 ^{o}F
  - Replace current oil heater loop with heat recovered from the exhaust of a diesel engine
- Intellectual Property
  - Patent application in final stages of

  review by the U.S. patent office.
  Most claims accepted.

Assembled 5.3-kW E/C system viewed from cool air discharge side

Dimensions are 34”x32”x24”

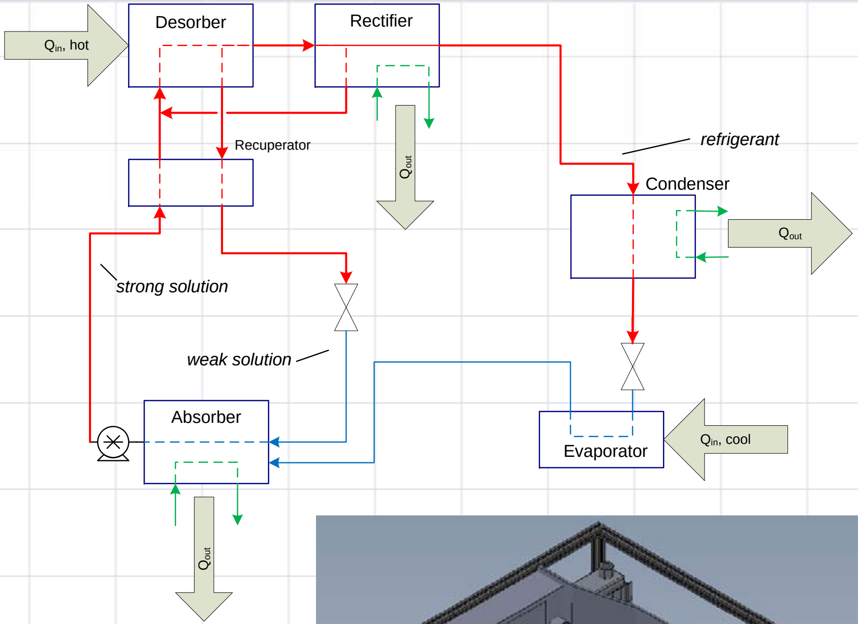


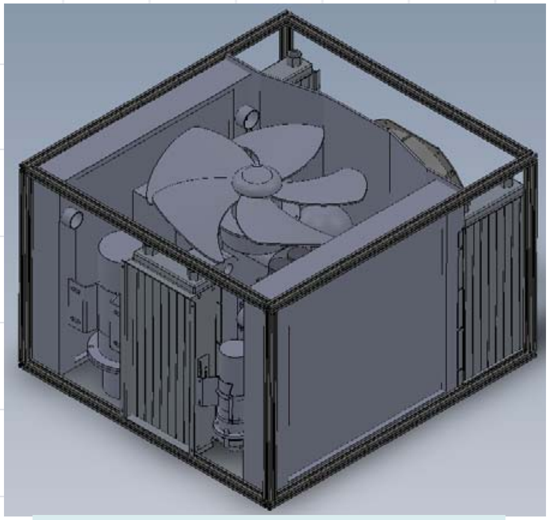


HVAC: Heat-Activated Heat Pump

Absorption Cycle Heat Pump

- **Concept**
  - Natural gas or solar heat pump for air conditioning, space heating, and water heating.
  - High energy efficiency obtained through extensive heat integration and heat recuperation—COP >0.6 projected at military conditions (50°C ambient).
  - Compact system is achieved through microchannel absorber, desorber, and heat exchanger technologies.
- **Progress & Status**
  - 300W-scale breadboard used as test bead for new concepts and subscale prototype demonstration.
  - COP > 0.6 projected at military conditions of 50°C ambient temperature.
  - 5.3 kW system designed and being assembled for Summer 2010 demonstration.
  - Substantial investment being made in low-cost manufacturing.
- **Point of Contact**
  - Dale King, dale.king@pnl.gov





5kW-scale military system

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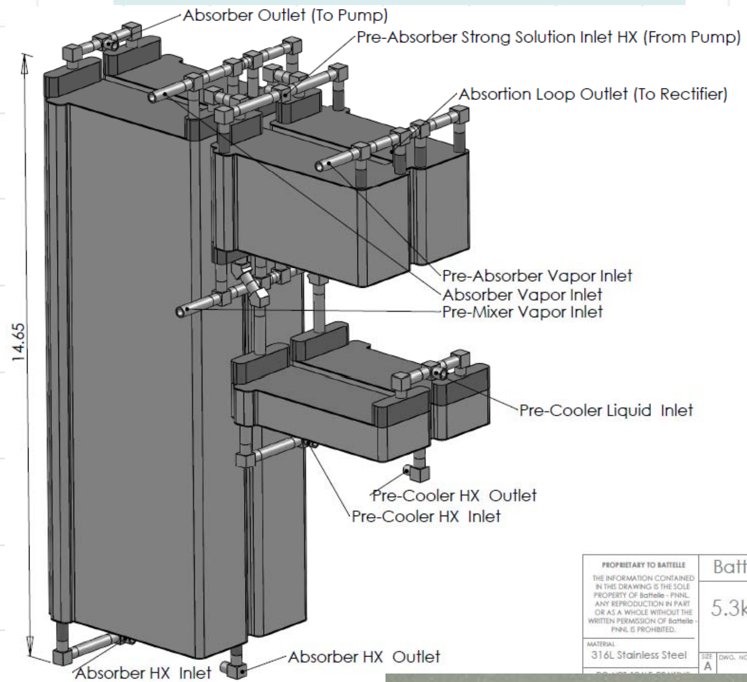
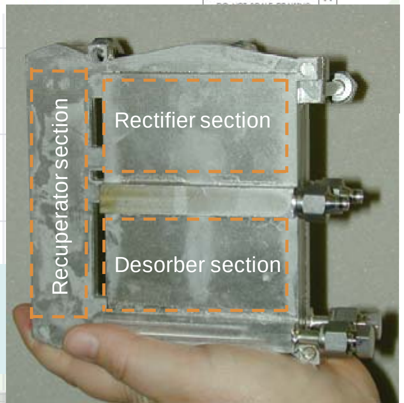
HVAC: Heat-Activated Heat Pump

Absorption Cycle Heat Pump

- Competition
  - Commercial electric heat pumps
  - No commercial heat pumps in U.S. for residential and smaller heat-activated cooling
- Advantages
  - High-efficiency, compact equipment
  - Scalable from <1 ton up to commercial building
  - Utilize growing supply of natural gas reserves
  - Reduce electricity demand growth by offloading cooling during peak demand.
- Next steps
  - Demonstrate 5.3 kW military system
- Intellectual Property
  - TeGrotenhuis, W.E., et al., U.S. Patent 6,666,909, December 2003.
  - TeGrotenhuis, W.E., et al., U.S. Patent 6,869,462, March 2005.
  - TeGrotenhuis, W.E., et al., U.S. Patent 6,875,247, April 2005.
  - TeGrotenhuis, W.E., et al., U.S. Patent 7,272,941, September 2007.
  - TeGrotenhuis, W.E., et al., U.S. Patent 7,344,576, March 2008.
  - Advance wick patent application pending.
  - Integrated desorber patent application pending.

5 kW scale absorber subsystem





500W-scale integrated desorber

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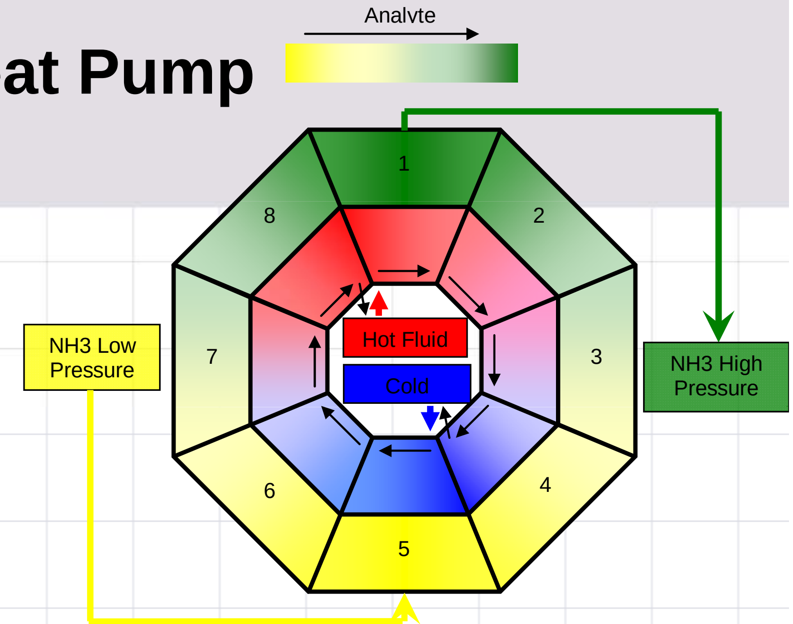
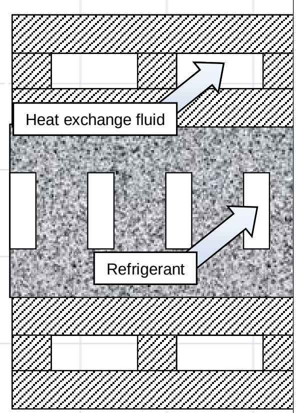
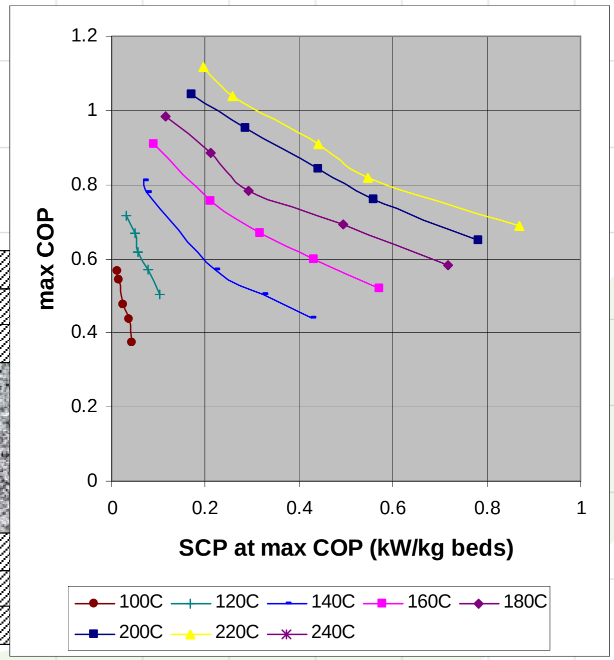
HVAC: Heat-Activated Heat Pump

Adsorption Cycle Heat Pump



- **Concept**
  - Natural gas or solar heat pump for air conditioning, space heating, and water heating.
  - High energy efficiency obtained through effective heat recuperation using a patented multi-bed system.
  - Compact system is achieved through:
    - integrated microchannel heat exchange for rapid thermal cycling, and
    - monolithic carbon sorbent having high capacity and high thermal conductivity.
- **Progress & Status**
  - Detailed models predicting compressor performance at specified conditions.
  - COP > 1 projected for residential cooling at standard conditions with >180ºC heat.
  - COP > 2.4 projected for residential space heating with >180ºC heat.
  - Progress made in aluminum joining for interleaved microchannel sorbent beds
- **Point of Contact**
  - Ward TeGrotenhuis, ward.tegrotenhuis@pnl.gov



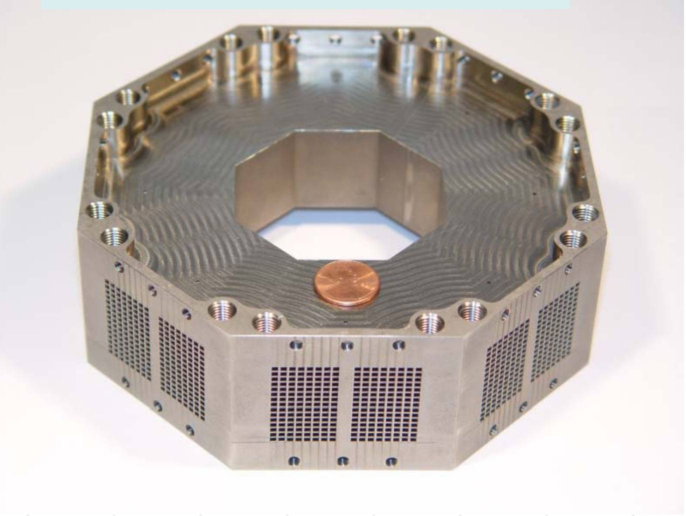


HVAC: Heat-Activated Heat Pump

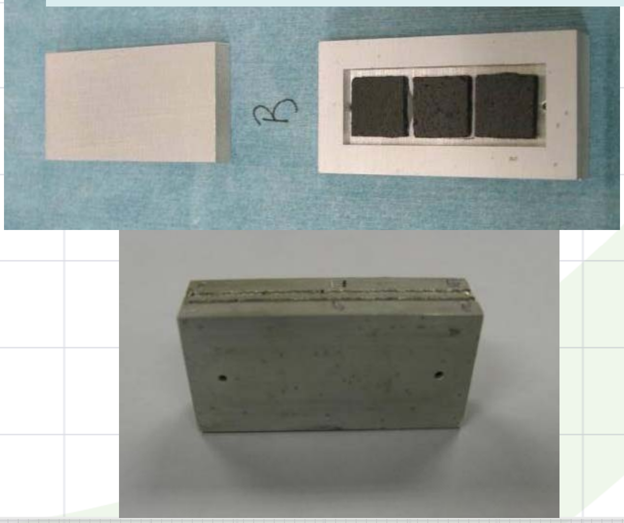
Adsorption Cycle Heat Pump

- Competition
  - Commercial electric heat pumps
  - Absorption (solution) cycle heat pumps
  - No commercial heat pumps in U.S. for residential and smaller heat-activated cooling
- Advantages
  - High-efficiency, compact equipment
  - Scalable from <1 ton up to commercial building
  - Utilize growing supply of natural gas reserves
  - Low corrosivity enabling aluminum construction
  - No solution pump
- Next steps
  - Bed fabrication and system demonstration
  - Multi-port valve development
- Partners
  - ATMI (carbon monolith sorbents)
- Intellectual Property
  - Wegeng, R.S., et al., U.S. Patent No. 6,974,496, December 2005.
  - Wegeng, R.S., et al., U.S. Patent 6,746,515, June 2004.
  - Wegeng, R.S., et al., US Patent 6,630,012, October 2003.

NASA Mars CO2 compressor



Welded aluminum test assembly



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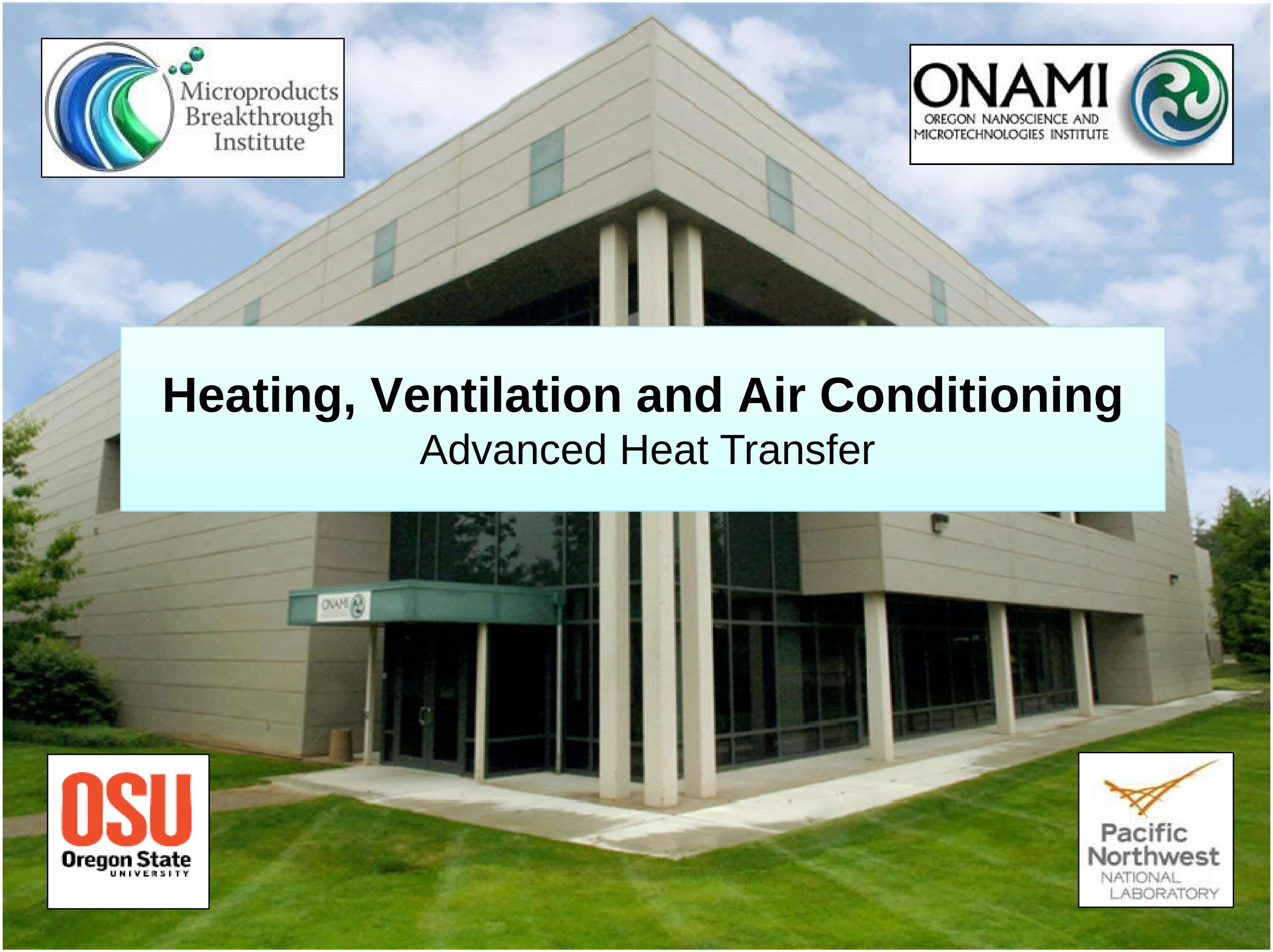

Heating, Ventilation and Air Conditioning

Advanced Heat Transfer

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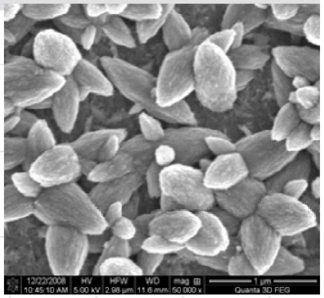
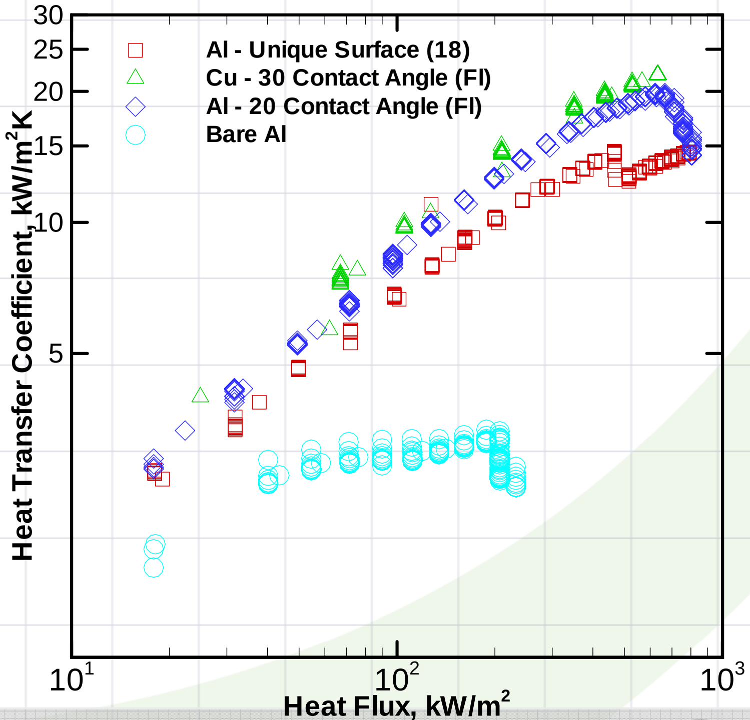
HVAC: Advanced Heat Transfer

Nano-Scale Coatings for Enhanced Boiling



- Concept
  - Nano-textured surfaces can enhance boiling heat transfer coefficient by about an order of magnitude.
  - Surface created by cost-effective micro-assisted nano-deposition (MAND™) process.
- Progress & Status
  - Proof-of-principle testing demonstrating higher heat transfer coefficient and higher critical heat flux.
- Advantages
  - Enhance HVAC coefficient of performance
  - Lighter, more compact evaporators
- Next Step
  - Demonstrate prototype scale device
- Intellectual Property
  - U.S. Pat. App. 12/709,266, Filed 2/2010 (OSU/PNNL)
  - U.S. Pat. App. (MAND™) (OSU)
- Point of Contact
  - Terry Hendricks, terry.hendricks@pnl.gov



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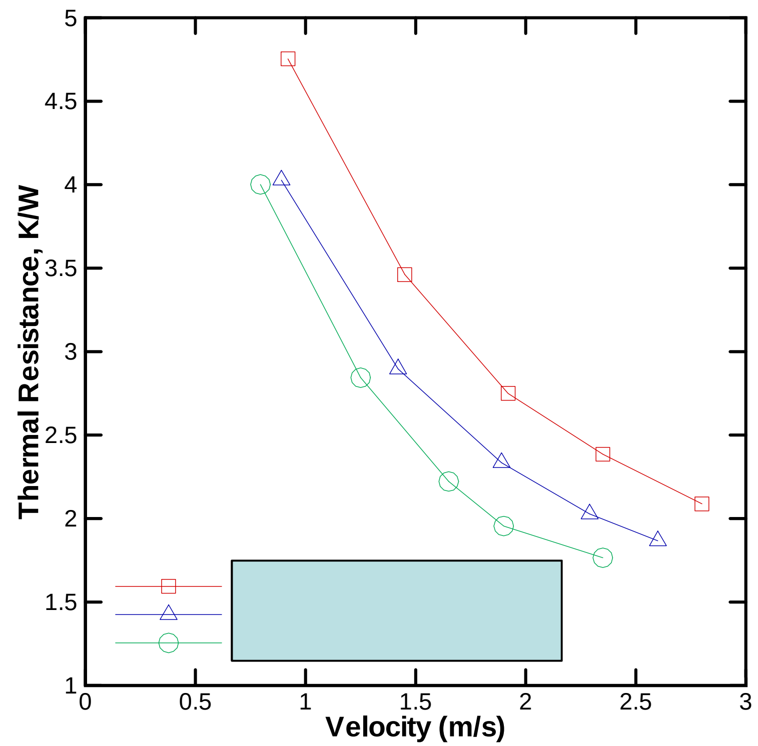
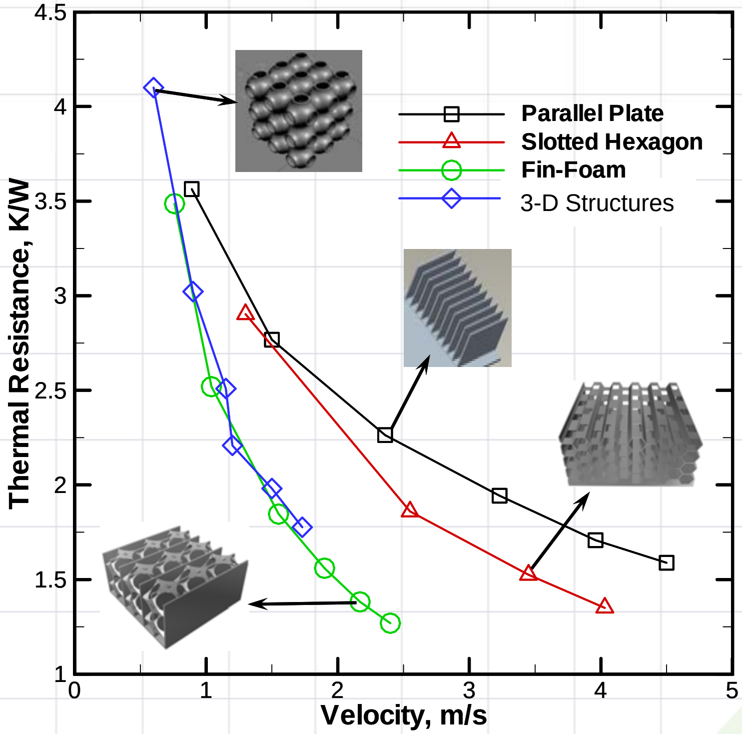
HVAC: Advanced Heat Transfer
Air-side Heat Transfer

- Concept
  - Dramatically reduce gas heat transfer resistance
- Progress and Status
  - Demonstrated 44% reduction in gas heat transfer resistance at comparable pressure drop relative to straight fins.
  - Series resistance model indicates substantial further improvement possible.
- Advantages
  - Enhanced HVAC coefficient of performance
  - Lighter, more compact, higher performing evaporators and condensers
- Next Steps
  - Demonstrate prototype scale device
  - Second generation testing
- Intellectual Property
  - Invention disclosure filed
- Point of Contact
  - Ward TeGrotenhuis, ward.tegrotenhuis@pnl.gov



HVAC: Advanced Heat Transfer
Air-side Heat Transfer with 3-D Periodic Structures

- Concept
  - Use unique 3-D periodic microstructures to reduce gas heat transfer resistance by 45% compared to standard fin-plate structures.
  - Cost-effective manufacturing approaches identified.
- Progress and Status
  - Concept stage with in-house expertise
- Advantages
  - Enhanced HVAC coefficient of performance
  - Lighter, more compact, higher performing evaporators and condensers
- Next Steps
  - Proof-of-concept manufacturing
  - Demonstrate prototype-scale device
  - Develop intellectual property
- Point of Contact
  - Terry Hendricks, terry.hendricks@pnl.gov



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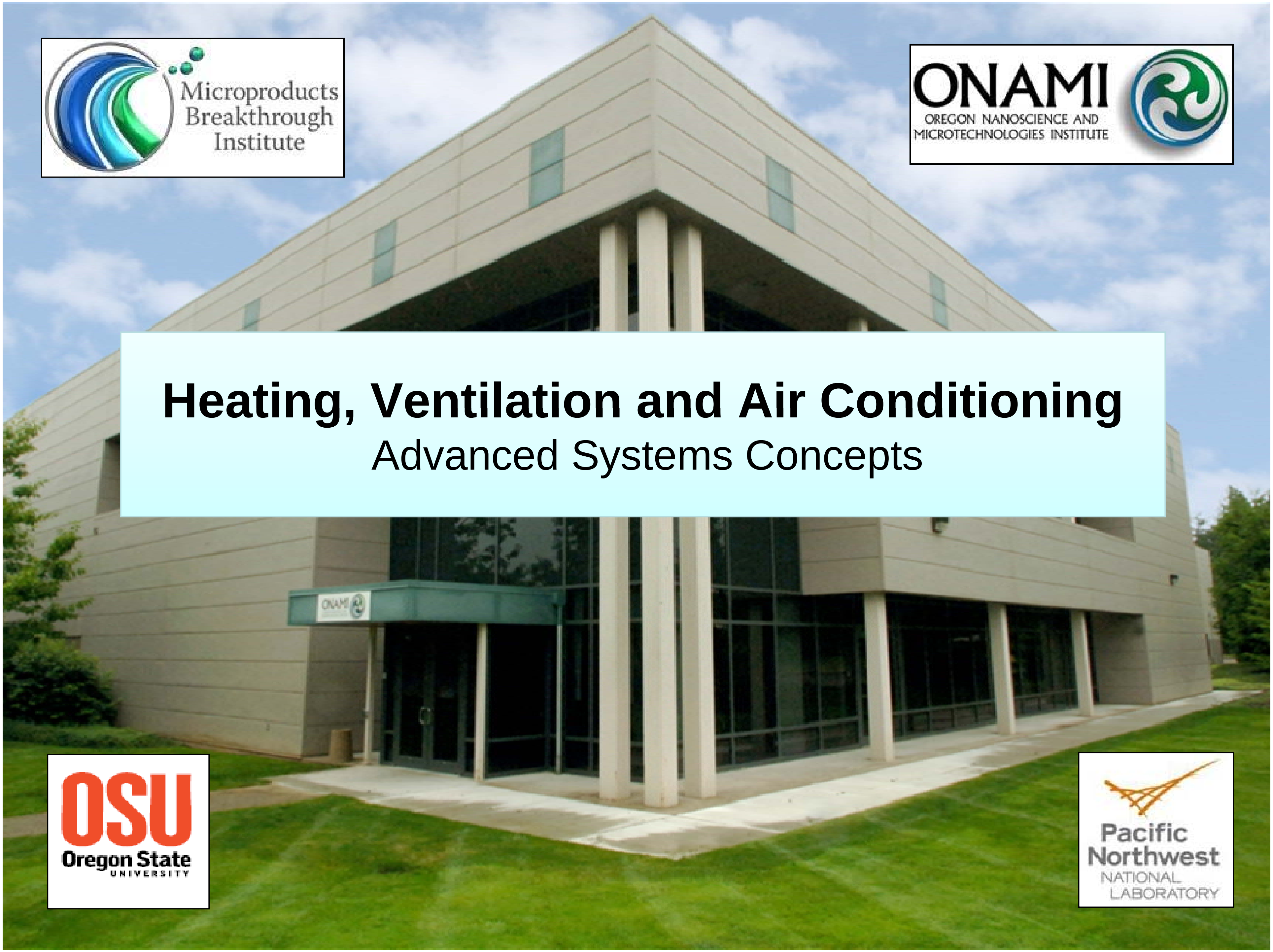
Heating, Ventilation and Air Conditioning

Advanced Systems Concepts



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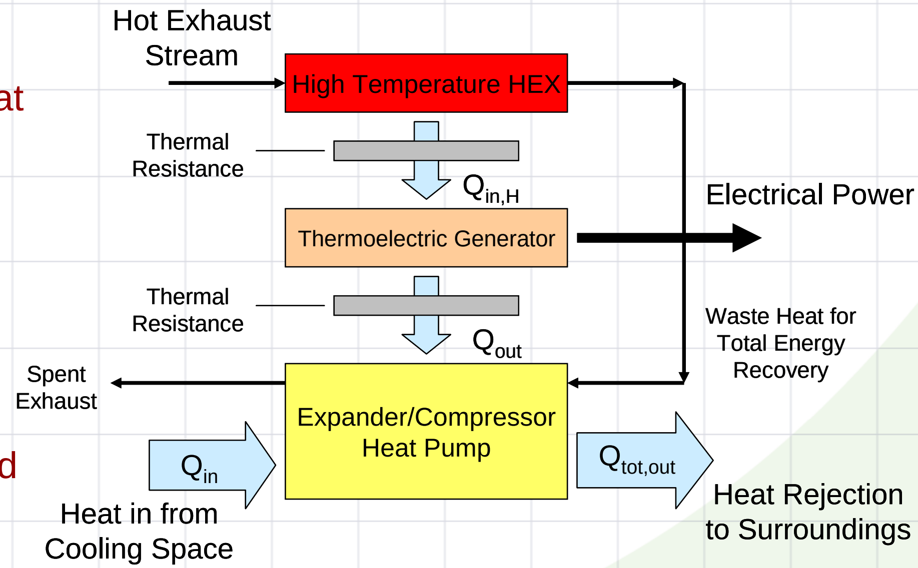
Advanced System Concepts

CCHP: Co-Functional Power / Cooling Systems

- Concept
  - Produce combined power and cooling utilizing waste heat or by combusting fuel.
  - Integrate a thermoeletric generator (TEG) power module as a topping cycle with a heat-activated cooling technology as a bottoming cycling.
  - Heat coming from the TEG combined with hot exhaust gas is used to run the cooling system—effectively achieves 100% energy conversion efficiency in the TEG. Potentially saves 20 to 30% in fuel usage in forward deployed applications.
- Progress and Status
  - Being developed for battlefield applications, stationary and mobile, with various heat waste heat sources including diesel generator exhaust.
  - Currently developing co-functional integration of 3 power & cooling technologies:
    - Advanced thermoelectric (TE) power system
    - Organic Rankine cycle (ORC) cooling system
    - Microchannel heat exchangers
  - Currently testing a demonstration system designed for ~100 W power generation & 5.3 kW cooling capacity



- Point of Contact
  - Terry Hendricks, terry.hendricks@pnl.gov

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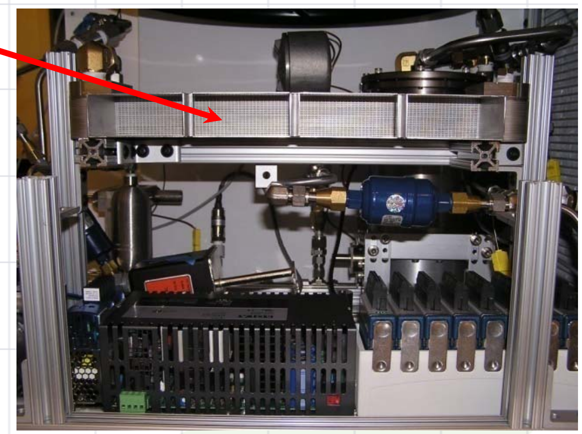
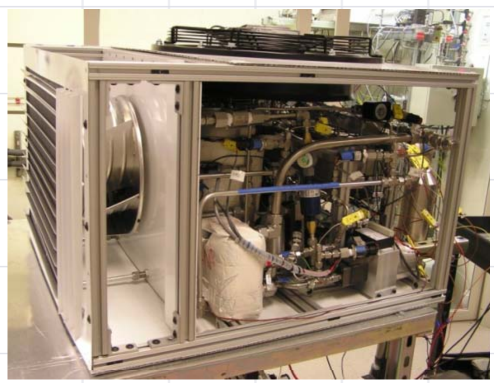
Military Co-Functional Power / Cooling Systems

- TEG Power System Uses MicroChannel Heat Exchangers
  - Stainless Steel Air HX On Hot-Side
  - Aluminum R245fa HX on Cold-Side
  - 16-22 TE Modules
- ORC Boiler Uses MicroChannel Heat Exchangers
- High-Temperature Bi_2Te_3 Modules
  - First-Ever 320°C Bi_2Te_3 Modules
- System Size
  - Microtechnology Enables Smaller System
  - Dimensions: 30” X 30” X 19”
  - Weight: ~100 kgs
- Next Steps
  - System Testing

TEG Power System

ORC Boiler





Co-Functional System

Other ‘Drawing Board’ Concepts

- Distributed Heat-activated Heat Pumps
  - Distributed HVAC replaces a single large central HVAC unit with zonal or distributed HVAC units.
  - Advantages: reduces ducting and associated with central system cycling losses, enables zonal heating and cooling, lower building capital cost (no ducts will reduce a story height by 1 m)
- Integrated Heat-activated Heat Pump and Desiccant Dehumidification
  - Utilize waste heat from a heat-activated heat pump to regenerate the desiccant of a dehumidification system—heat pump topping cycle and desiccant bottoming cycle.
  - Advantages: No need to cool air to desired dew point allows higher evaporator temperature, higher heat pump Carnot efficiency, and increased energy efficiency.
- Concentrated Solar HVAC
  - Leverage MBI heat actuated HVAC technologies and partner to obtain affordable single-axis solar trough collectors leveraging low-cost technology currently marketed for solar heating.
  - Advantages: Increasing solar heat temperature increases HVAC efficiency and reduces HVAC and solar collector size and cost.