High Efficiency, Residential Gas-Fired Adsorption Heat Pump Water Heater Development

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Oak Ridge National Laboratory

Hot Water Forum
Water Heating, Distribution, and Use Efficiency
American Council for an Energy-Efficient Economy (ACEEE)
Session 4 B: Gas Heat Pump Water Heater Research and Development
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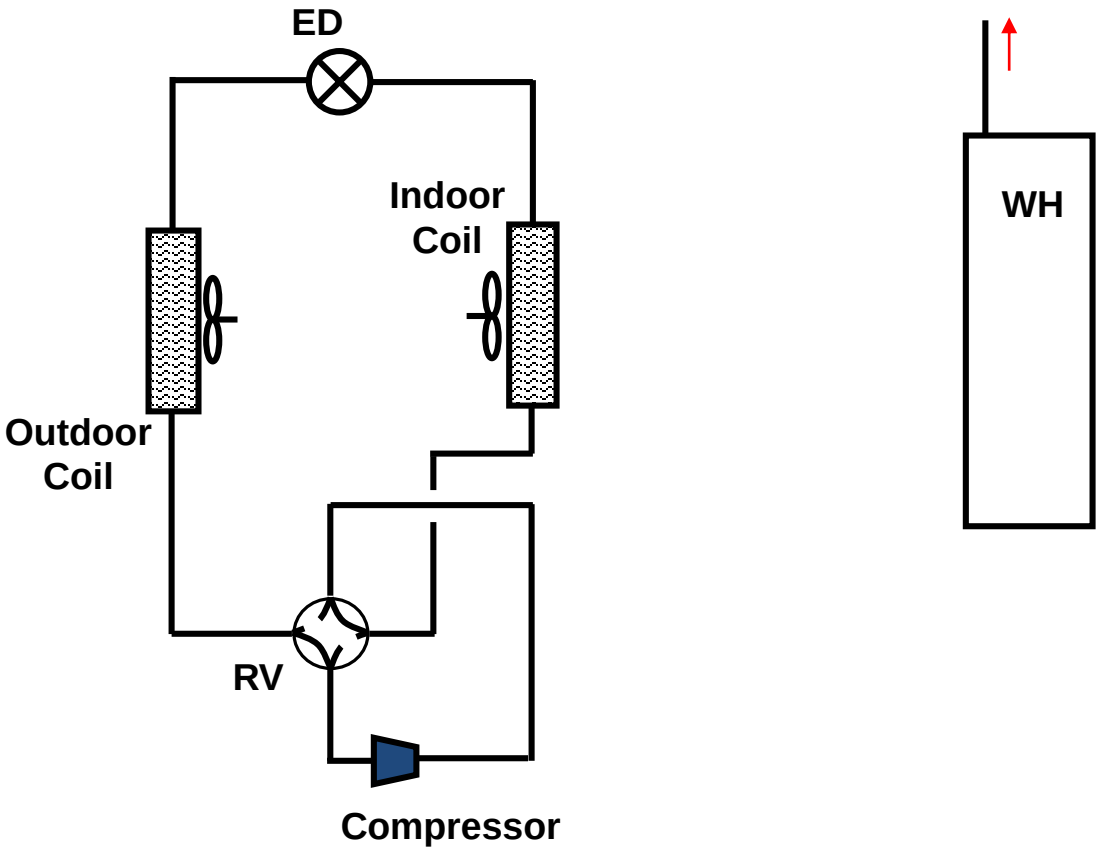
February 22-24, 2015

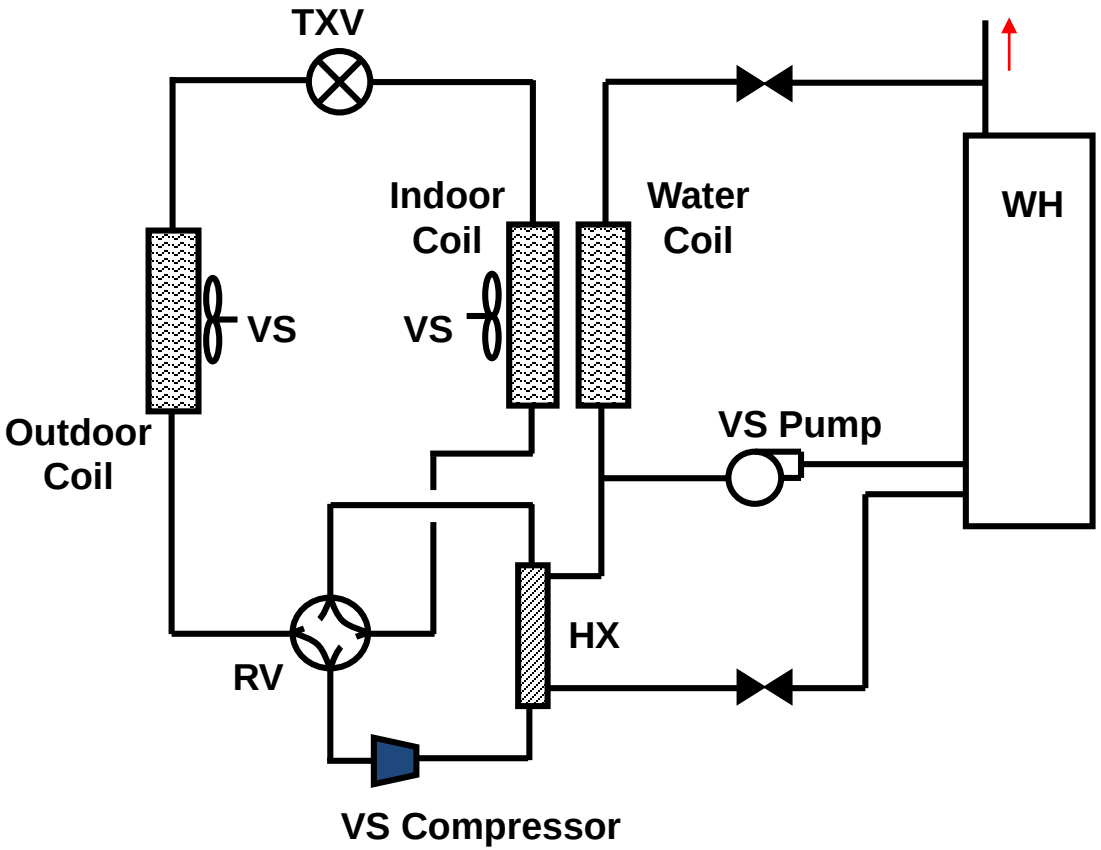
Recent Heat Pump Work at ORNL

- Design and Development of Integrated Heat Pump (IHP) Concept and reduction to practice
- Collaborative R&D with multinational corporations and manufacturers
- Wide range of products brought to the marketplace
- Seeking partnership with industry on new products

Conventional Heat Pump and Water Heater

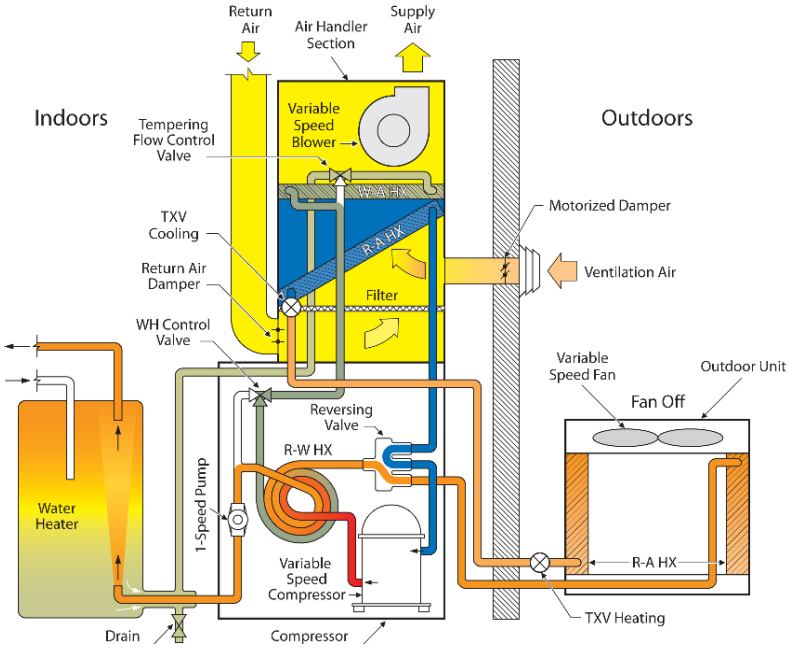


Integrated Heat Pump

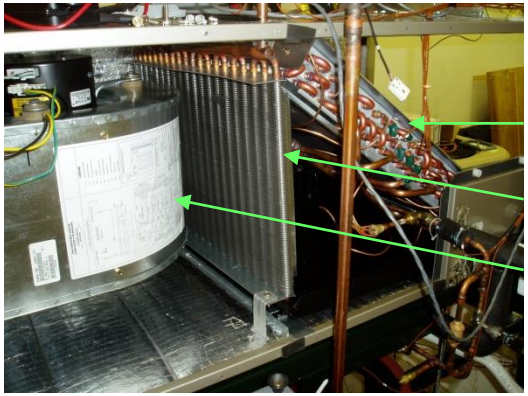


AS-IHP Concept (early ORNL concept)

- **Full integration to heat, cool, ventilate, dehumidify, and heat water as needed**
- **AS-IHP concept, in dehumidification/ventilation/WH mode, shown at right - many modes possible**
  - **H or C/ventilation/WH**
  - **Dedicated water heating**
  - **Dedicated dehumidification and/or humidification**
  - **Ventilation air pre-treatment; H in winter, C & dehumidify in spring/summer/fall**
- **Lab prototype constructed and tested**



Possible AS-IHP packaging approach



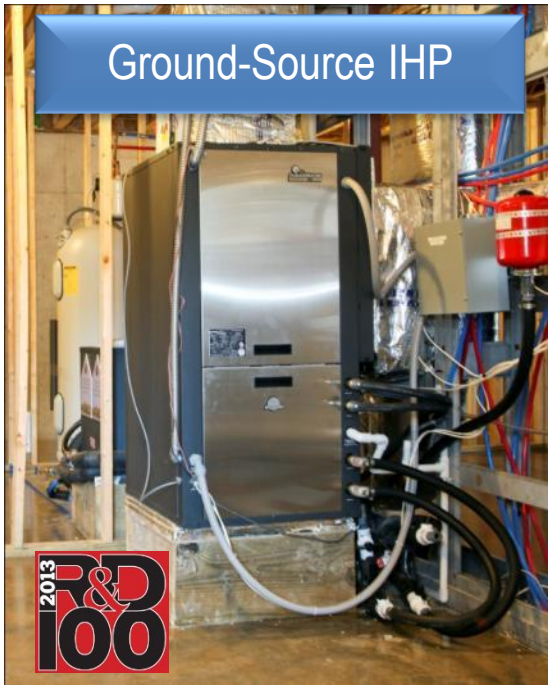
Lab prototype air handler

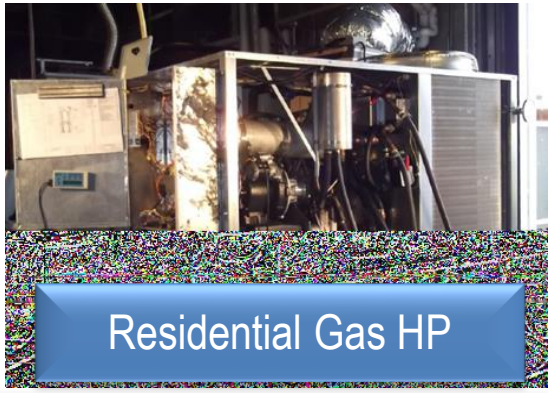
ref/air HX

water/air HX

blower

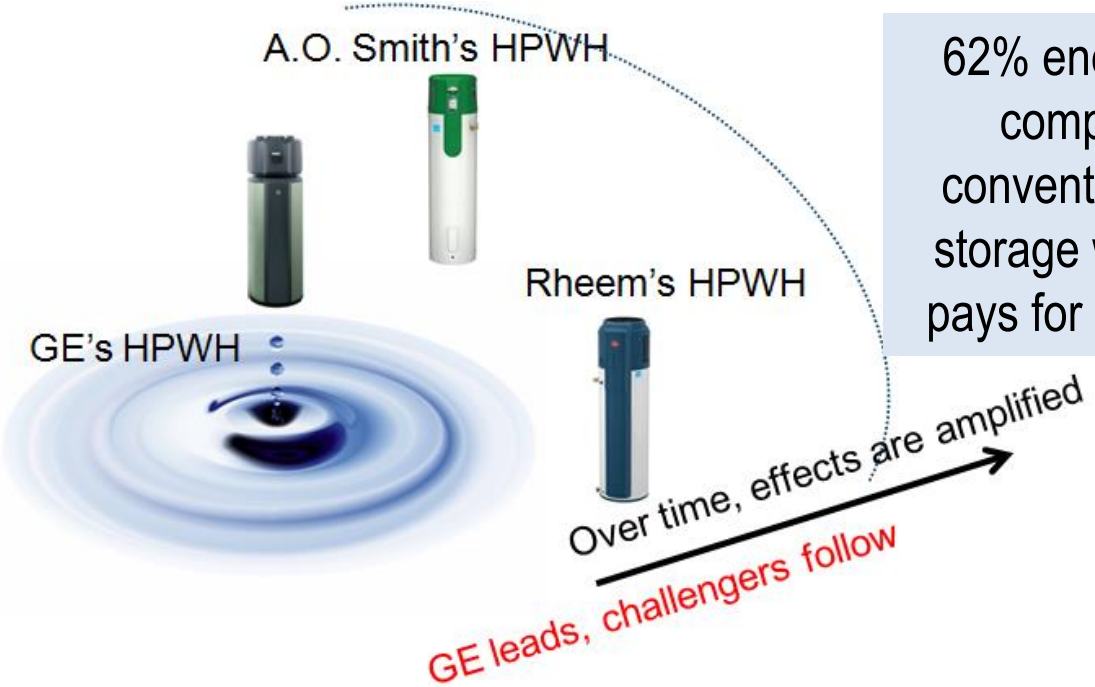
Industry CRADA Collaborations are Delivering Additional Equipment Solutions to the Market



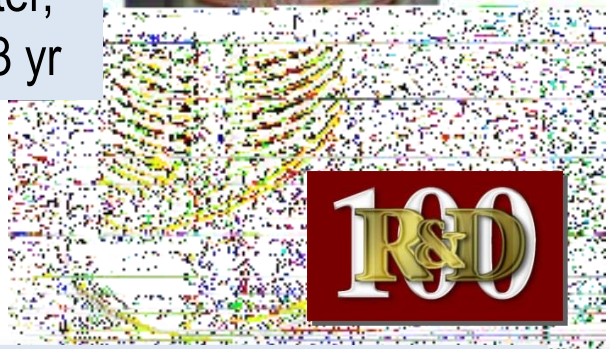


Ripple effects of General Electric-ORNL heat pump water heater CRADA

Began production in Louisville KY
Feb 2012 (created ~1,000 jobs)



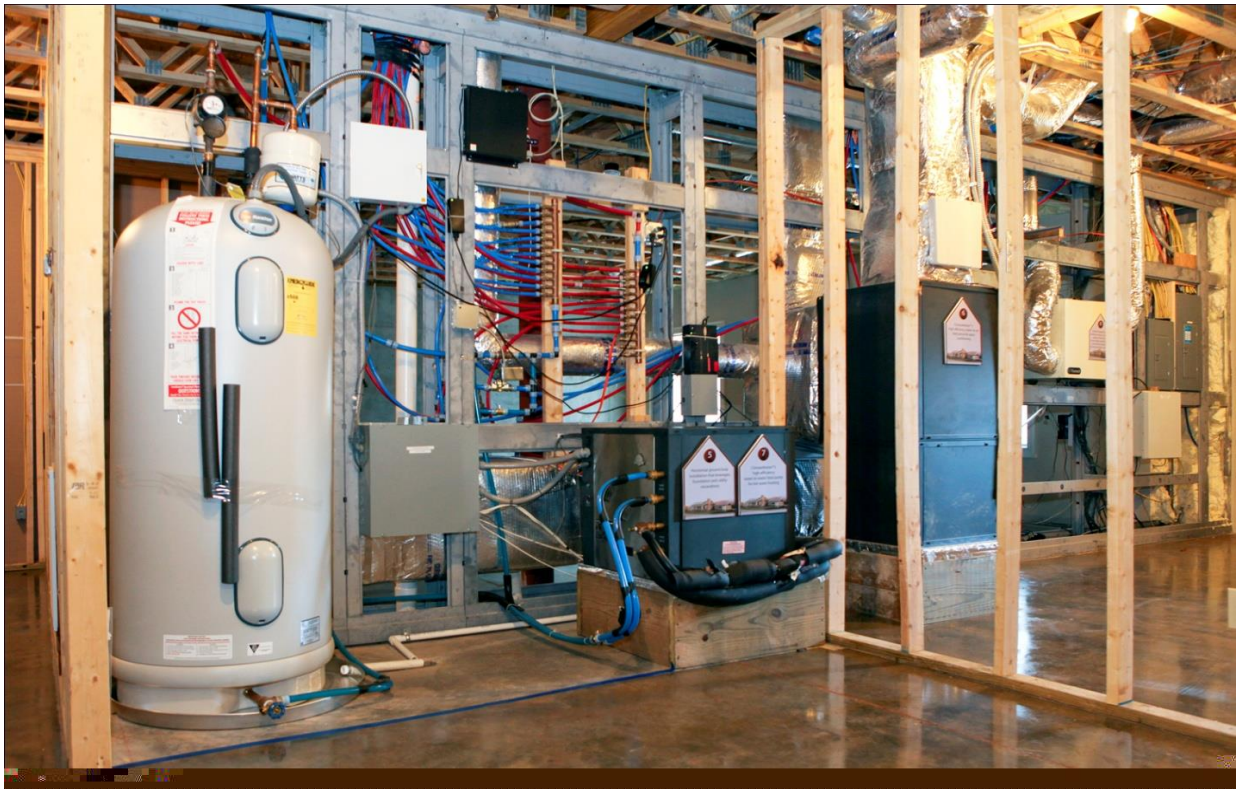
62% energy savings compared to a conventional electric storage water heater, pays for itself in < 3 yr



Heat Pump Water Heater

After CRADA with ORNL, ClimateMaster Launches Trilogy™ 40 Q-Mode™ (1st AHRI Rating > 40 EER)

- Heating, cooling, 100% of water heating (not just a desuperheater)
  - 55-65% energy savings vs. minimum efficiency (SEER 13) equipment
  - 30-35% savings vs. state-of-the-art two-stage GHP with desuperheater



Separate Units [Water Heating; Heating/Cooling]

Single Unit [Water Heating; Heating/Cooling]

The Trilogy 40 Q-Mode Ground Source IHP

- With rated efficiencies as high as 42.1 EER, the Trilogy™ 40 series is the first geothermal heat pump ever certified by the Air Conditioning, Heating, and Refrigeration Institute (AHRI) to exceed 40 EER at ground-loop (GLHP) conditions.

- The Trilogy™ 40 utilizes variable-speed technology to provide an extremely wide range of heating and cooling capacities
- In addition, patent-pending Q-Mode™ technology produces year-round domestic hot water on demand, even when space conditioning is not required.

FLC Award 2014

2013 R&D 100

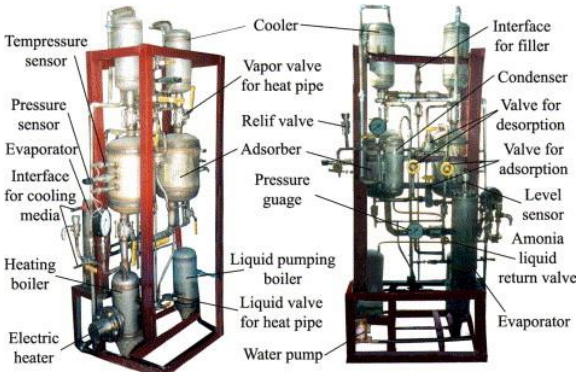
2012 DEALER DESIGN AWARDS the NEWS | GOLD

Pushing the Envelope at ORNL on Adsorption Technology

Old applications

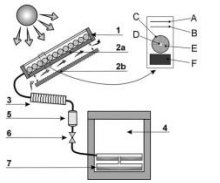
100 kW chiller

ISAAC solar Icemaker
In Kenya



Adsorption ice maker for
Fishing boat

Solar refrigerator



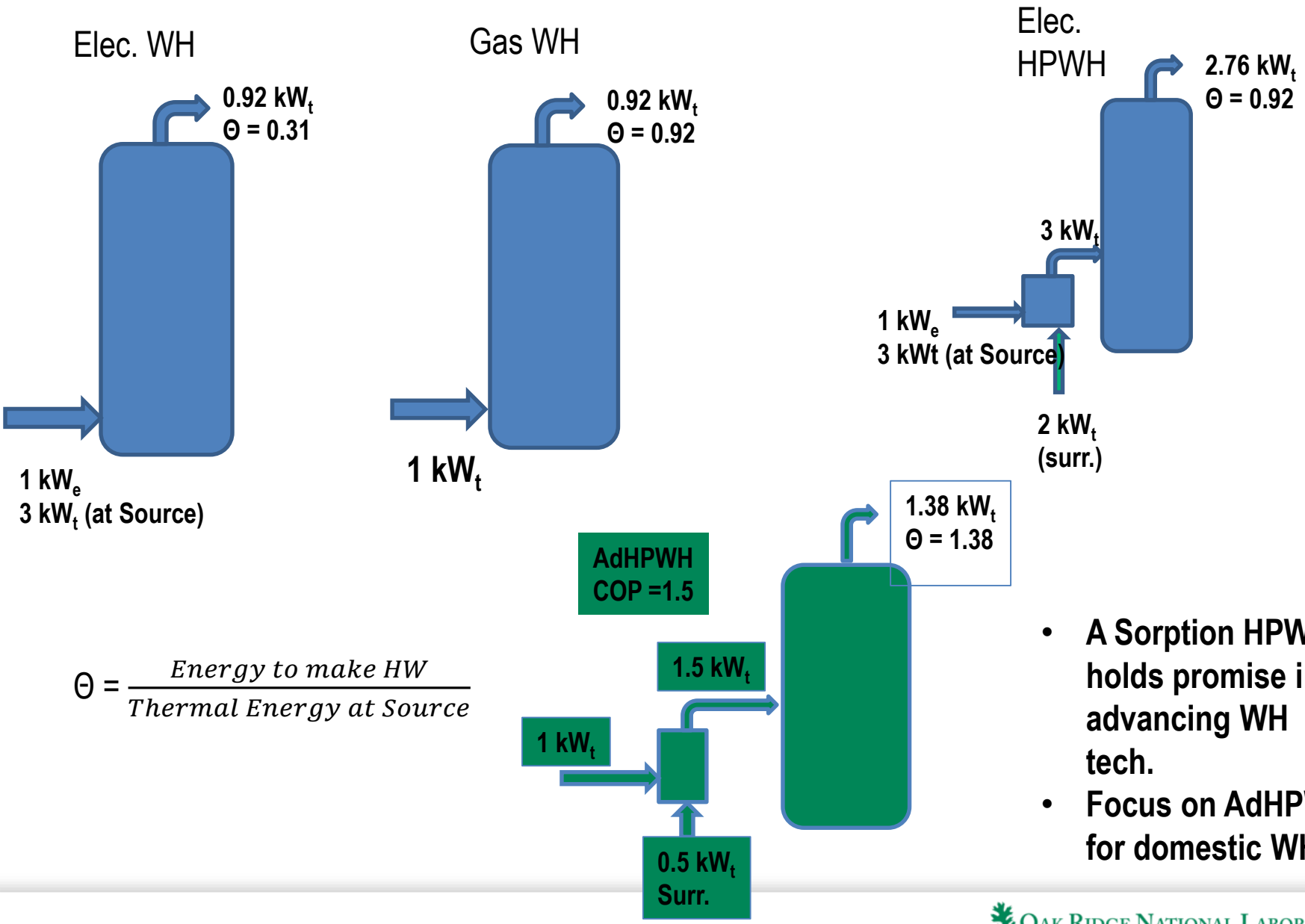
ORNL Pushing the envelope

Gas domestic hot water COP ~ 1.0
Challenge: increase COP to 1.5

Application of Adsorption technology for domestic/commercial hot water production

Adsorbent beds
(generators)

The Case for Sorption HPWH



$$\Theta = \frac{Energy\ to\ make\ HW}{Thermal\ Energy\ at\ Source}$$

- A Sorption HPWH holds promise in advancing WH tech.
- Focus on AdHPWH for domestic WH

Water Heaters Affected by New Standards , Effective April 2015

WATER HEATERS AFFECTED BY NEW STANDARDS		
Product Class	**Energy factor as of January 20, 2004**	**New Energy Factor Requirements**
Gas-fired Water	0.67 – (0.0019 x Rated Storage Volume in gallons).	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.675 – (0.0015 x Rated Storage Volume in gallons). For tanks with a Rated Storage Volume above 55 gallons: EF = 0.8012 – (0.00078 x Rated Storage Volume in gallons).
Oil-fired Water Heater	0.59 – (0.0019 x Rated Storage Volume in gallons).	EF = 0.68 – (0.0019 x Rated Storage Volume in gallons).
Electric Water Heater	0.97 – (0.00132 x Rated Storage Volume in gallons).	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.960 – (0.0003 x Rated Storage Volume in gallons). For tanks with a Rated Storage Volume above 55 gallons: EF = 2.057 – (0.00113 x Rated Storage Volume in gallons).
Tabletop Water Heater	0.93 – (0.00132 x Rated Storage Volume in gallons).	EF = 0.93 – (0.00132 x Rated Storage Volume in gallons).
Instantaneous Gas-fired Water Heater	0.62 – (0.0019 x Rated Storage Volume in gallons).	EF = 0.82 – (0.0019 x Rated Storage Volume in gallons).
Instantaneous Electric Water Heater	0.93 – (0.00132 x Rated Storage Volume in gallons).	EF = 0.93 – (0.00132 x Rated Storage Volume in gallons).
NOTE: The Rated Storage Volume equals the water storage capacity of a water heater, in gallons, as specified by the manufacturer.		

Source: Office of Energy Efficiency and Renewable Energy, Department of Energy. 10 CFR Part 430, [Docket Number: EE–2006–BT-STD–0129] RIN 1904–AA90 Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters.

New, higher energy efficiency standards for residential hot water heaters are due to kick in April 2015, cutting the energy use of all sizes and types of water heaters significantly, and dramatically changing the home hot water landscape. The new regulations will require electric water heaters to use 47% less energy, and gas water heaters to be 30% more efficient.

There are a variety of products that can comply with the 2015 standards
In larger sized units industry facing some headwinds

Ref: CONTRACTOR: The online resource for mechanical contracting
http://contractormag.com/residential-plumbing/new-efficiency-standards-residential-water-heaters-are-horizon

Two distinct projects funded by BTO, U.S. Department of Energy

- Commercial Gas-Fired Absorption Heat Pump Water Heater
  - -Working pair is ammonia-water
  - -Prototype system is essentially complete
  - -Next step is to demonstrate that target goals are achieved with prototype by mid 2015.

- Residential Gas-Fired Adsorption Heat Pump Water Heater (AdHPWH)
  - -Working pair is ammonia-activated carbon (AC)
  - -AdHPWH system, model, components is nearly complete
  - -Next step is to build a 2-3 kW prototype and demonstrate 80% of target goal of EF>1.0 by the standard rating procedure for storage water heaters.

US Market/Environmental Impact

- In 2010, residential water heating accounted for (3.02 x 10^{15} kJ, or 8.4 x 10^{11} kWh) of primary energy use (2011 Building Energy Data Book, Table 2.1.5).

- When fully deployed, the AdWH may provide up to 0.47 x 10^{15} kJ or 1.3 x 10^{11} kWh of primary energy savings, equivalent to 24 million tons of CO_2 emission reductions annually (2011 Building Energy Data Book, Table 1.4.8), eliminating the need for HFC refrigerants with significantly higher ODP and GWP.

- Developed market for AdHPWH is about 15% of residential water heating market

Participation in IEA Annex 43/Research Program

- **The U.S through the Oak Ridge National Laboratory became a participant in Annex 43 – Fuel Driven Sorption Heat Pumps in March 2014**

- **The program of research is the development, demonstration, and promotion of gas-fired heat pumping technology for the commercial and residential markets with COP >1 with working materials having 0 GWP and 0 ODP**

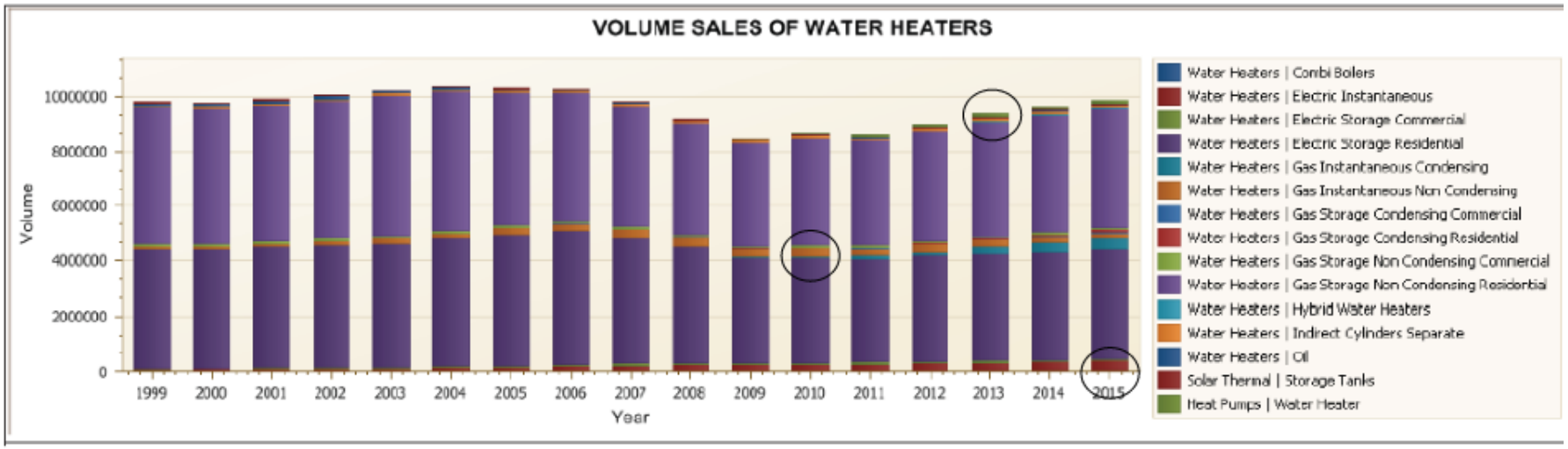
- **Research is conducted under the directive of the U.S Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Buildings Technology Program (BTO)**

Water Heater Shipment Projections

All Water Heater Industry Shipments: U.S

III.3 Historical Trends and Forecasts : Water Heaters

Fig. III.3 US - SUMMARY OF TRENDS IN THE WATER HEATER MARKET : 1999-2010 AND FORECASTS TO 2015



Electric Storage and Gas Storage units dominate sales

Mike Parker; ACEEE Hot Water Forum May 2011
Ref: http://www.aceee.org/files/pdf/conferences/hwf/2011/Plenary%20-%20Mike%20Parker.pdf

Objectives :

- **Residential Gas-fired Adsorption Heat Pump Water Heater**
  - **- To develop an adsorption heat pump water heater (AdHPWH) at an installed cost low enough to enable widespread residential market adoption**
  - **3 to 5 kW capacity**
  - **Provide hot water at 50°-60°C**
  - **Ambient temperature range -10°C to 37°C**
  - **EF>1.0 as determined by the standard rating procedure for storage water heaters.**
- **Industry collaborators to be determined. Currently, In-house R&D at ORNL**

R&D Status

❑ Residential Gas-fired Adsorption Heat Pump Water Heater

- ✓ -Established technical feasibility of AdHPWHs with EF>1.0 using working materials that have 0 GWP and 0 ODP
- ✓ -Identified possible working pairs
- ✓ -Established process constraints and acceptable cost for the manufacturer
- ✓ -Developed a model for parametric analysis
- ✓ -Quantified system size based on cycle times, adsorption capacity, and capacity
- ❖ Currently developing a prototype

What's been done: Large Scale

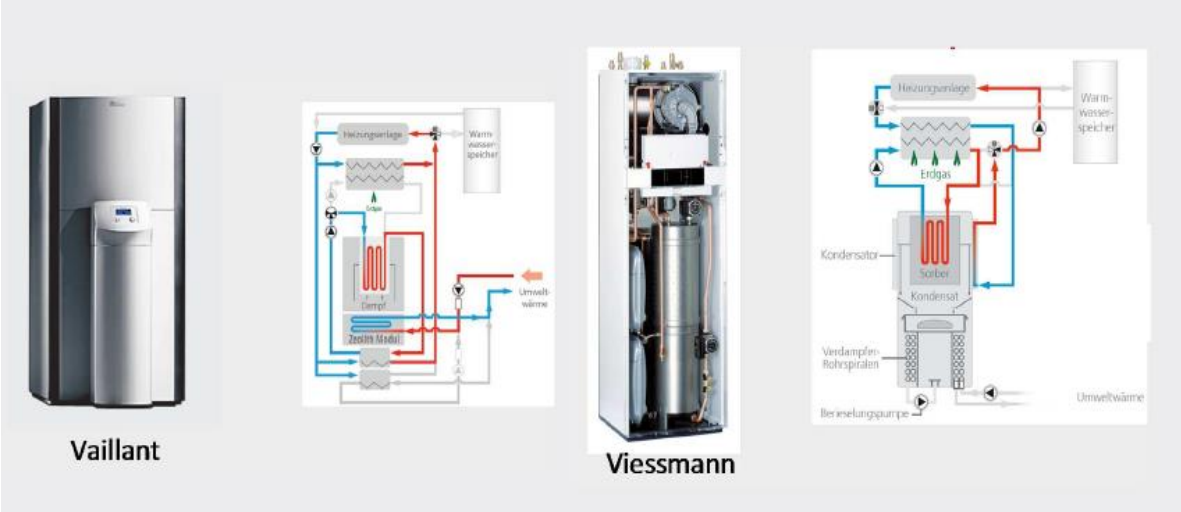
- Mycom Europe markets large capacity (100kW) adsorption chillers (see above)
- Chilled water at 15°C (59°F) with a heat source temperature of 68°C (154.4°F) with 27°C (80.6°F) cooling water inlet temperature
- zeolite-water working pairs.

Hong Kong's 1st zero carbon bldg. houses an ECO-MAX adsorption chiller in a tri-generation system (below, right) providing power, heat and cooling

- Tri-generation packages have capacity ~200kW to 2MW.
- ECO-MAX chillers integrate solar hot water collectors and concentrators to produce the source heat (at least 130°F, or 54.4°C) for the adsorption chiller. In tri-generation systems (above), hot water in the range of 51.7°C (125°F) to 93.3°C (200°F) can be produced

Ref: http://www.ppiway.com/brands-solutions/eco-max/products-services/adsorption-chillers

What's been done: Smaller systems



- Vaillant: 10 kW prototype
- Zeolite-water, gas-fired

Space heating and WH

- 135% eff. relative to condensing furnaces
- 5-25 kW over next several years

- Adsorption Heat Pumps from Vaillant and Viesmann under widespread field tests in Germany (Wessing and Wackertapp 2011)
- Inititive Gaswärmepumpe: by 2011, 51 installations across Germany; gas-fired systems included absorption & adsorption
- Results seem to suggest 120% - 140% WH efficiency improvement relative to condensing furnaces.

Ref: Wessing, W., and Wackertapp, Hans. (2011). Potential of the gas-Heat-Pumps, EFE-ja 1_228_01, Nov 15, 2011.

Choice of Refrigerant

Refrigerant	ODP	GWP
H_2		
Methanol	0.16	2.8
CO_2	0	1
H_2O	0	0
NH_3	0	0

Refrigerant	-10°C<Evap.<+4°C	Evap. >5°C	Cond. 55-65°C	Ads. 55-65°C	Des. >100°C	ΔH kJ·kg^{-1} (25°C)
Water	No	Yes	Yes	Yes	Yes	2443
Ammonia	Yes	Yes	Yes	Yes	Yes	1165

Adsorbents

Best Performance with Two-Bed Configuration at Driving Temperature of 100°C

Samples	Heat Pumping	
	q_H (MJ m^{-3})	COP
KOH-AC (monolithic)	**237**	**1.50**
SRD1352/2 (granular)	**128**	**1.41**
FM10/700 (fibre)	**97**	**1.47**
C-2132 (powder)	**110**	**1.50**
SRD1352/2 (compacted)	**152**	**1.50**

Best Performance with Two-Bed Configuration at Driving Temperature of 200°C

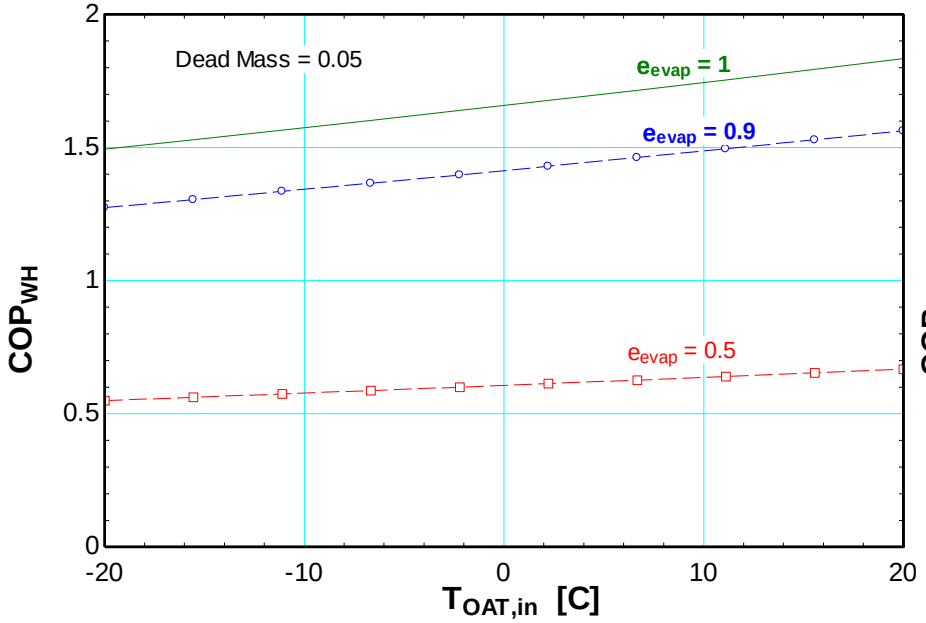
Samples	Heat Pumping	
	q_H (MJ m^{-3})	COP
KOH-AC (monolithic)	**594**	**1.70**
SRD1352/2 (granular)	**287**	**1.70**
FM10/700 (fibre)	**235**	**1.69**
(powder)	**AX-21** **265**	**AX-21** **1.80**
(compacted)	**208C** **132**	**208C** **1.62**

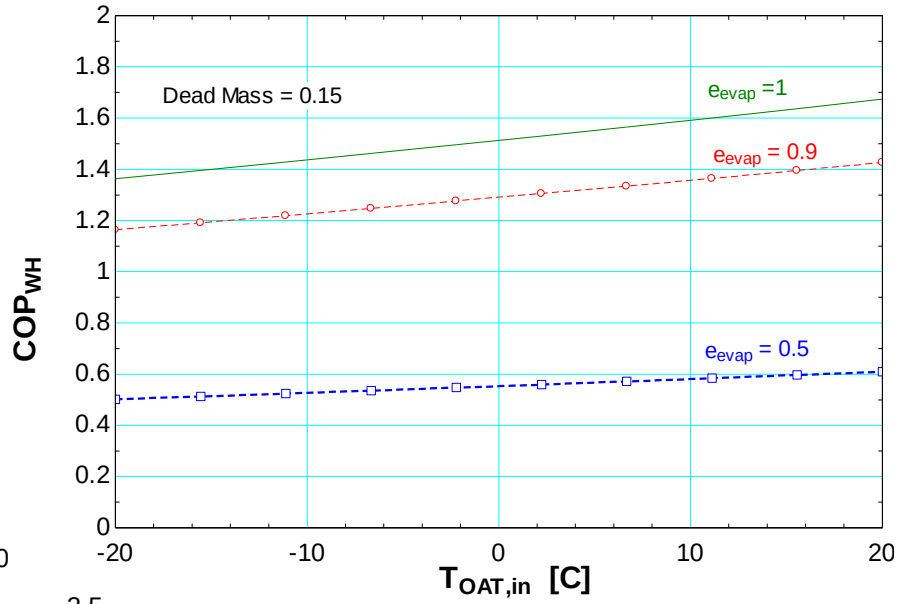
The best performance for heating application with a 2-bed system reported by (Tamainot-Telto, Metcalf et al. 2009) is summarized in above Table.

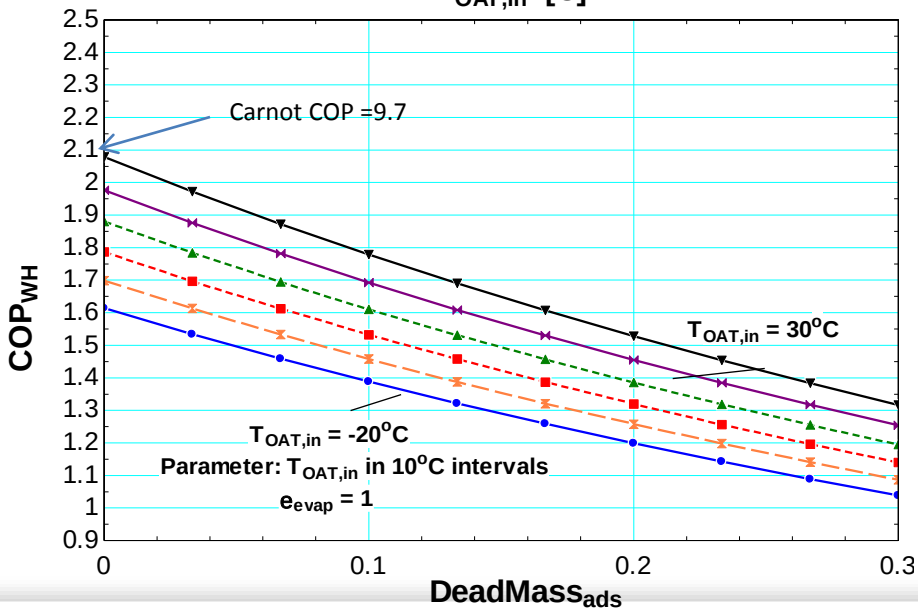
- All 5 types of carbons considered have almost the same COP, but the KOH-AC (monolithic) type yields twice the heat, q_H = 237 MJ·m^{-3} than the other types of carbons.
- Increasing the driving temperature from 100°C to 200°C by a factor of 1.28 (in terms of absolute temperature) essentially doubles the heat delivered, but increases the COP by 25% only.
- **We select a driving temperature of about 200°C as acceptable to produce HW at ~60°C**

Ref: Tamainot-Telto, Z., S. J. Metcalf, et al. (2009). "Carbon-ammonia pairs for adsorption refrigeration applications: ice making, air conditioning and heat pumping." International Journal of Refrigeration 32: 1212-1229.

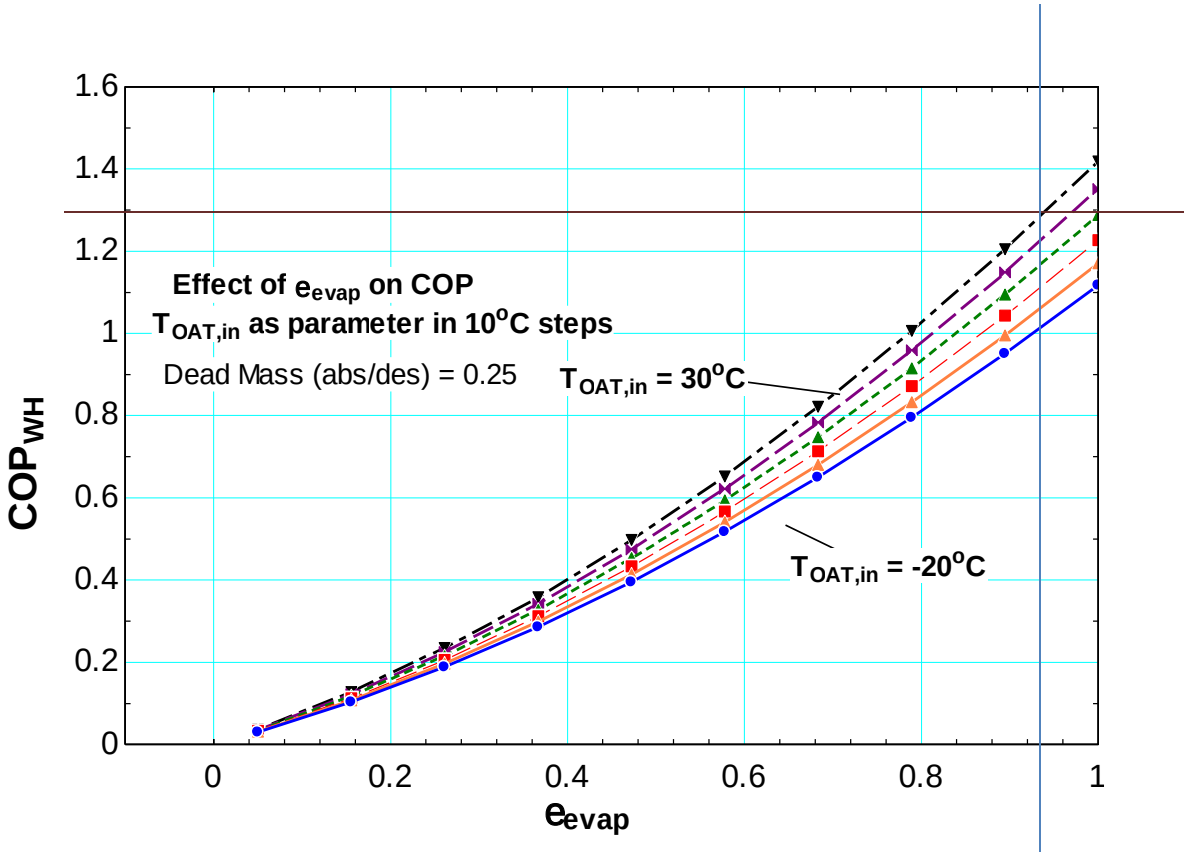
What COPs can we expect?







“Dead Mass” strongly limits COP



U.S Consumer Sentiment

- ❑Consumers are interested ---- but remain skeptical about ----- efficient models
- ❑ENERGY STAR ranking is a significant selling point
- ❑Cost-conscious consumers want efficiency rebates and incentives
- ❑About 26% of consumers are skeptical about claims of utility bill savings
- ❑Consumers willing to pay a modest premium for energy efficiency
- ❑Consumer skepticism is reinforced by inexperienced installers
- ❑Consumers are increasingly relying on on-line information to research products
- ❑The single greatest factor in decision-making is the cost of purchase and installation

Source: NEEA Report # 12-234, January 16, 2012

Thank You !

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