Theory of Semi-Open Sorption Gas-Fired Heat Pump Systems and Early Experimental Results

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ACEEE Hot Water Forum, Portland
February 28, 2017
Session 5B

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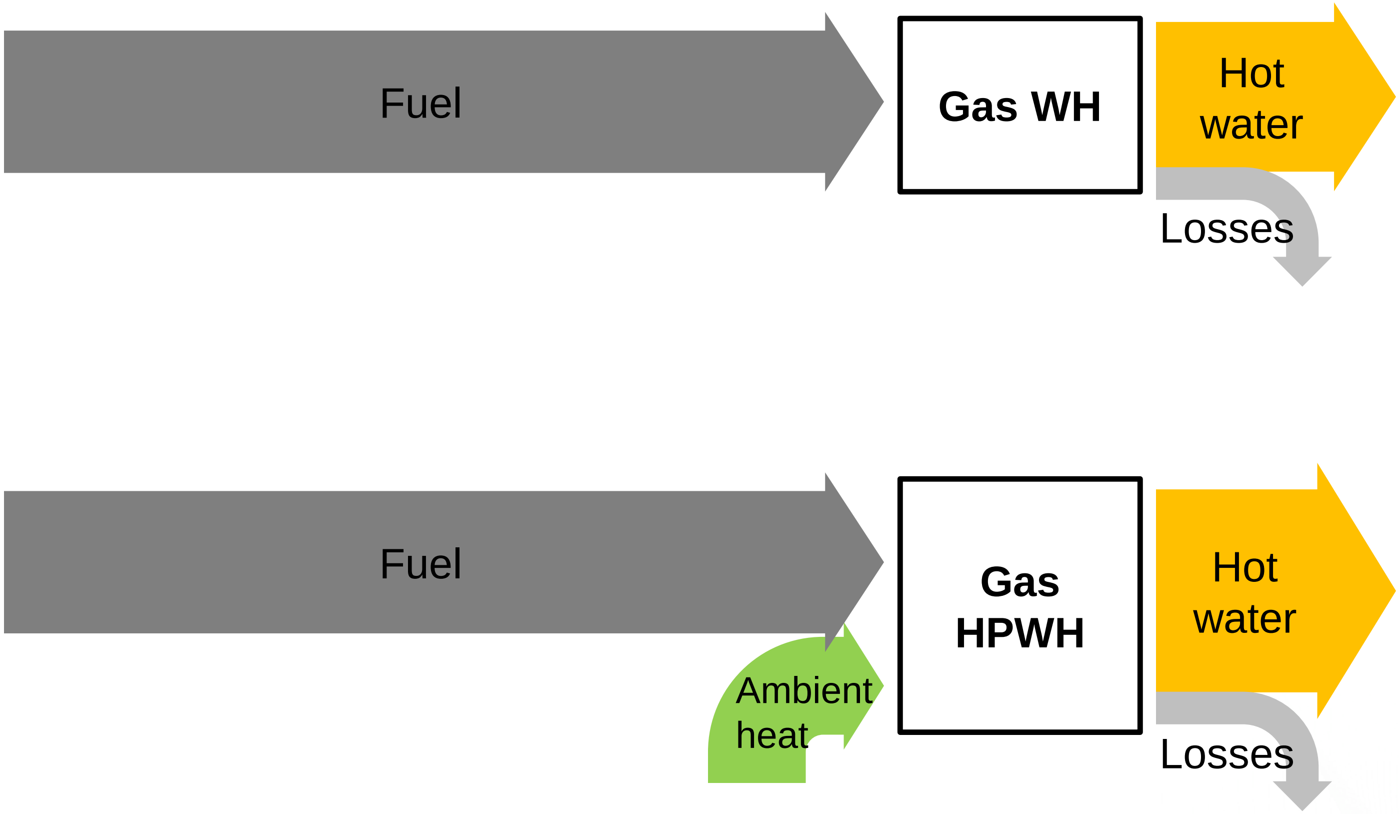
Acknowledgments

- Department of Energy (Contract DE-EE0006718.00)
- DOE Building Technology Office
  - Antonio Bouza
  - Jim Payne
  - Michael Geocaris

Outline

- Motivation
- Introduction to sorption heat pumps
- Theory of *semi-open* sorption
- Experimental results from prototype semi-open system

Water Heater Primary Energy



$PER = EF$

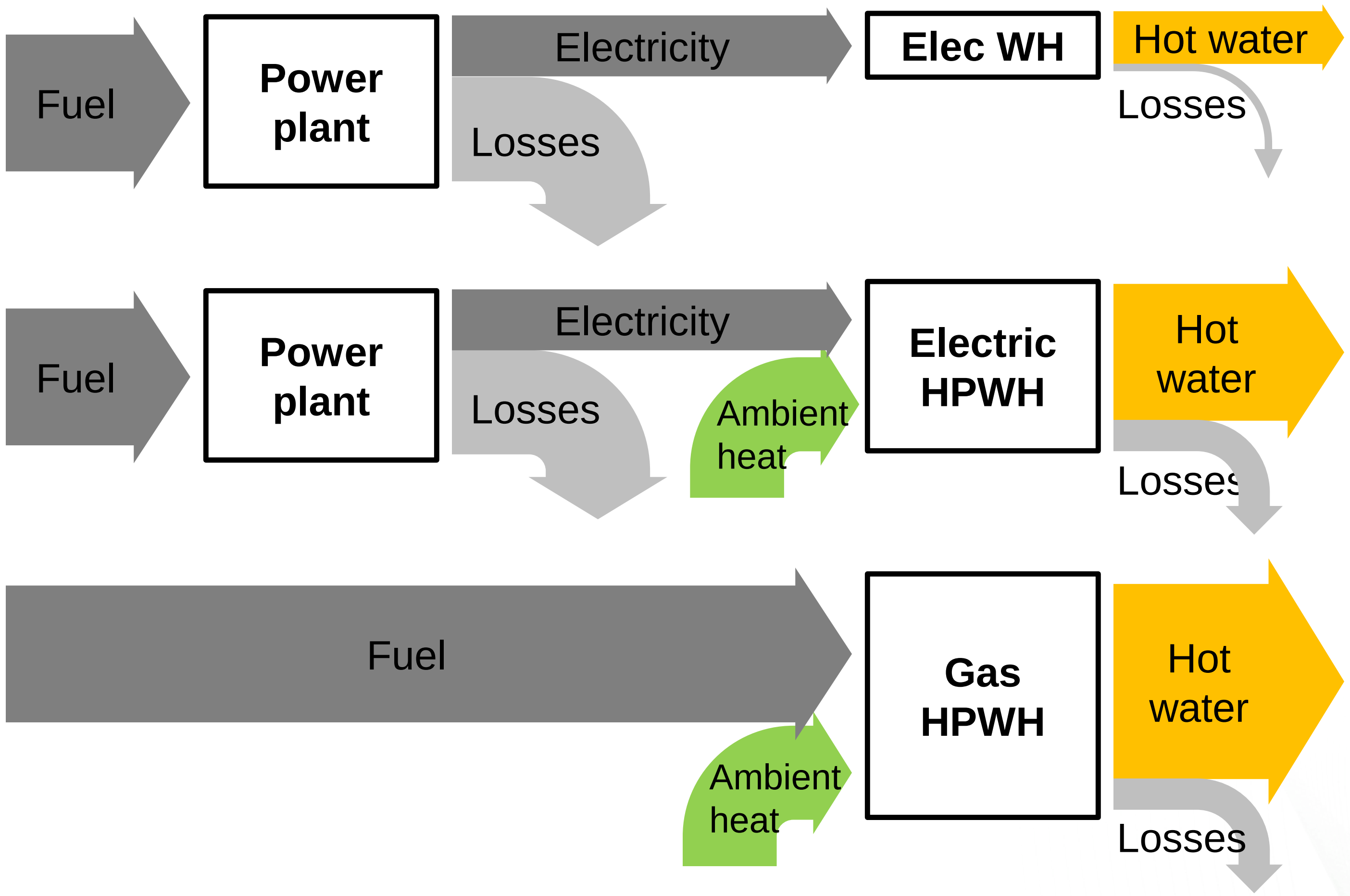
$\boldsymbol{PER \approx 0.65}$

$PER = EF$

$\boldsymbol{PER \approx 1.0 - 1.5}$

- HPWHs have highest potential efficiency
- Cost and novelty are current barriers – R&D needed

Water Heater Primary Energy



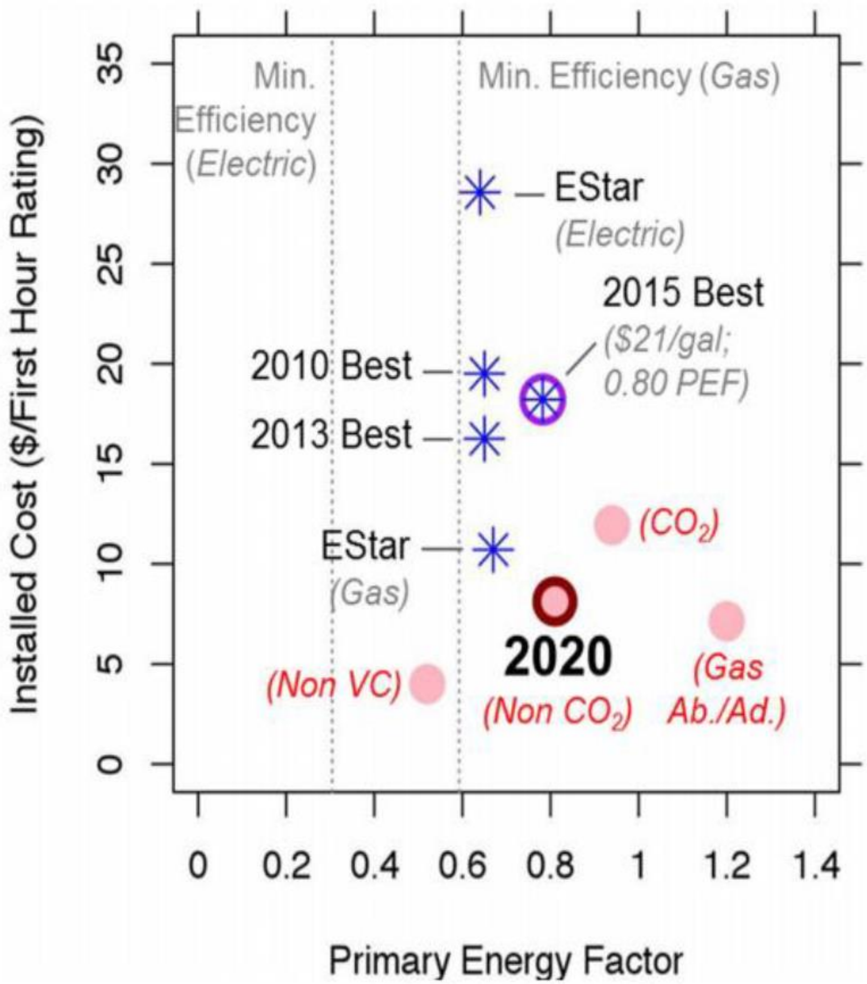
$$PER = \eta_{grid} EF$$
$$PER \approx 0.33 * 0.9$$
$$\boldsymbol{PER \approx 0.30}$$

$$PER = \eta_{grid} EF$$
$$PER \approx 0.33 * 3$$
$$\boldsymbol{PER \approx 1.0}$$

$$PER = EF$$
$$\boldsymbol{PER \approx 1 - 1.5}$$

- Gas-fired HPWHs have highest potential efficiency
- Cost and novelty are current barriers – R&D needed

No Gas-fired HPWH on Market



2020 R&D targets are shown for:

Electric

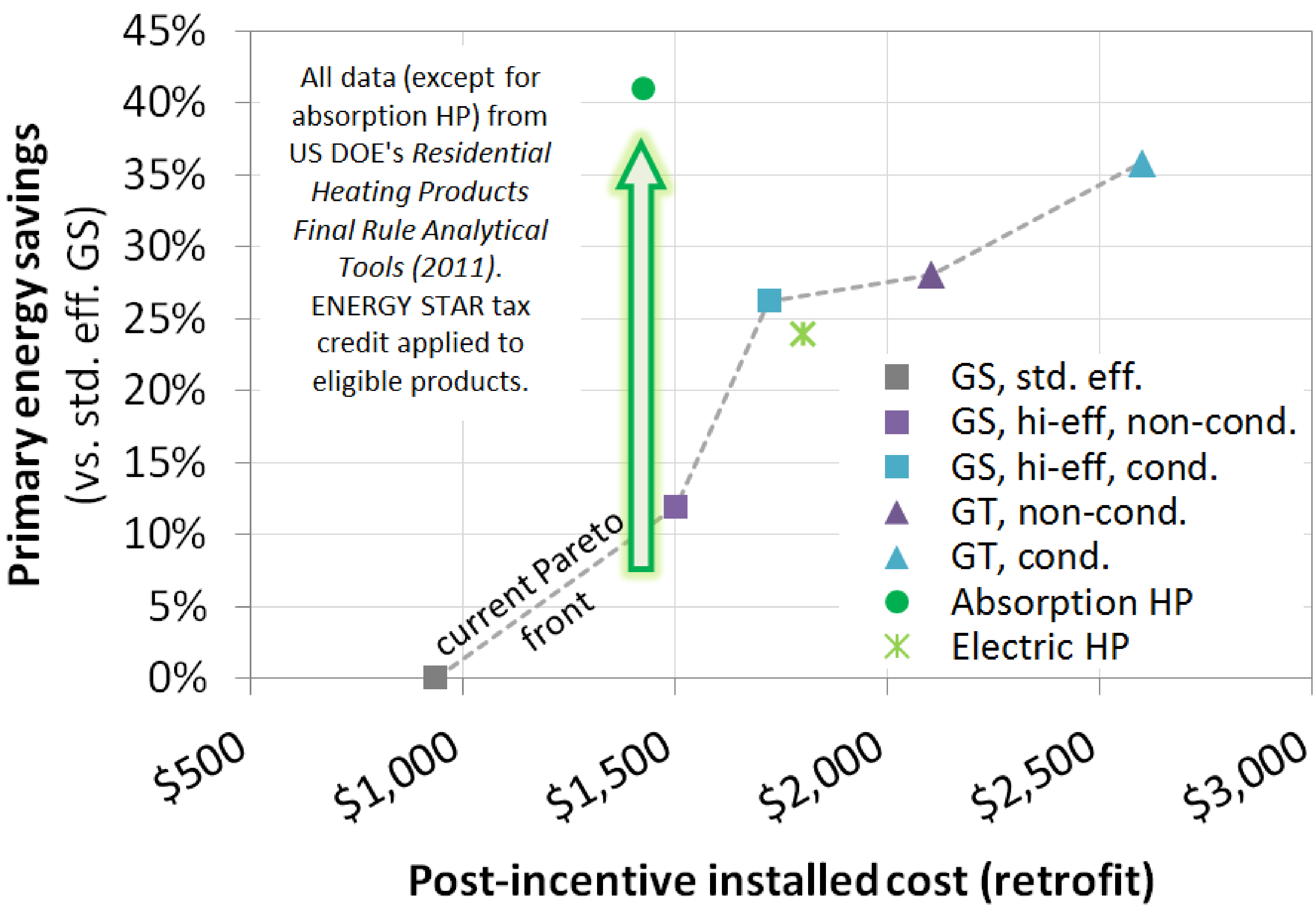
- **Non-CO_2 vapor compression**
- **CO_2 vapor compression**
- **Non vapor compression**

Gas-Fired

- **Absorption/Adsorption**

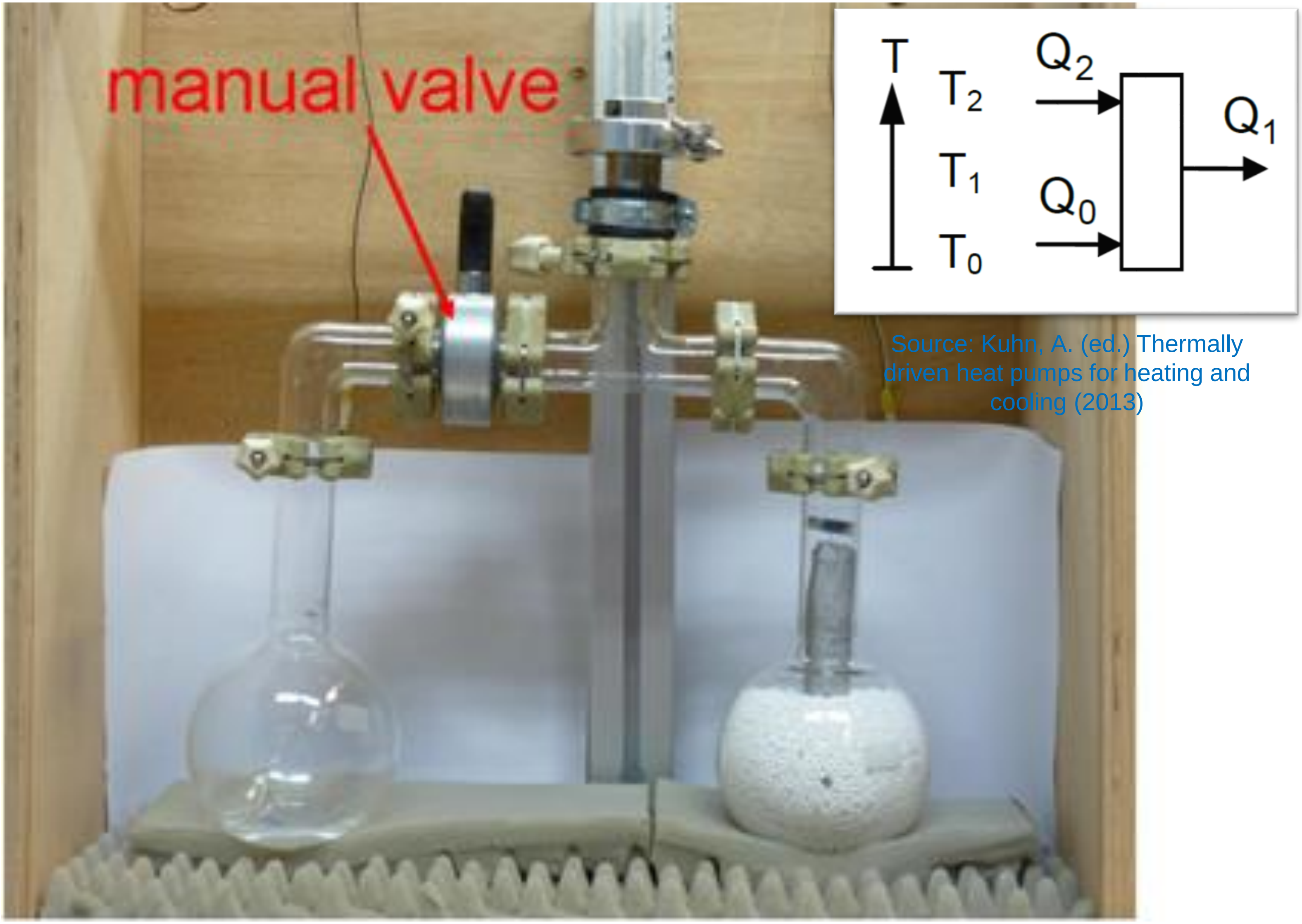
Source: DOE BTO 2016-2020 Multi-Year Program Plan (Feb 2016)

Vision: New Cost Effective Gas Option



Gluesenkamp, DOE BTO Peer Review, 2013

What is a Sorption Heat Pump?



Source: Kuhn, A. (ed.) Thermally driven heat pumps for heating and cooling (2013)

Source: http://www.annex34.org/the-magic-of-thermal-cooling

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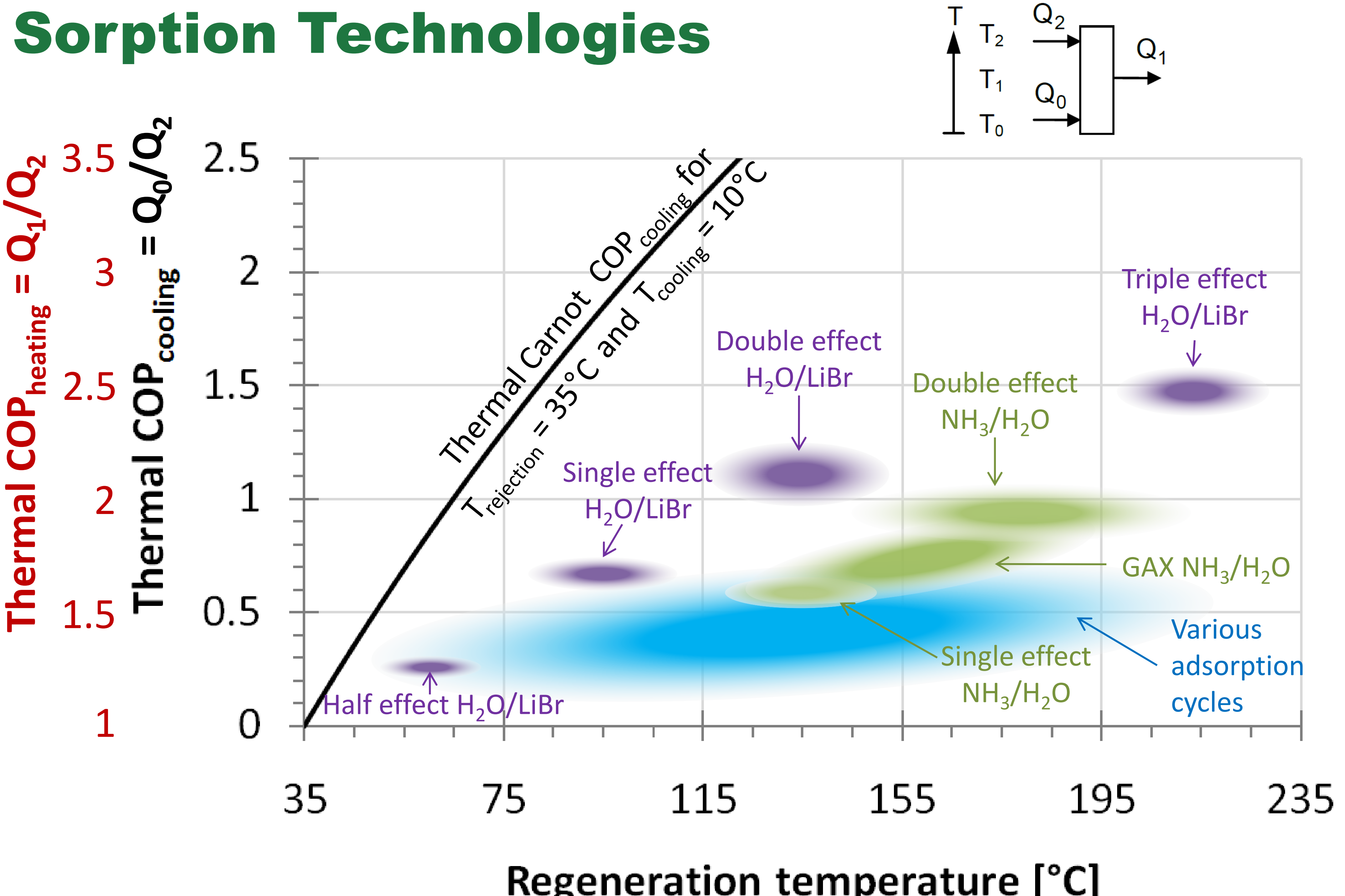
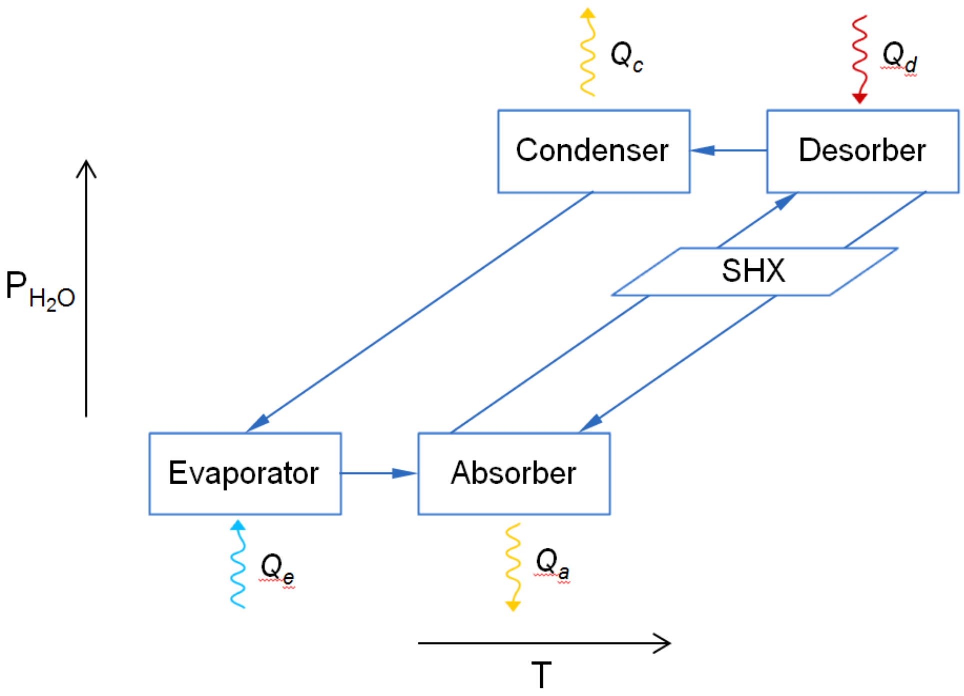
Sorption Technologies



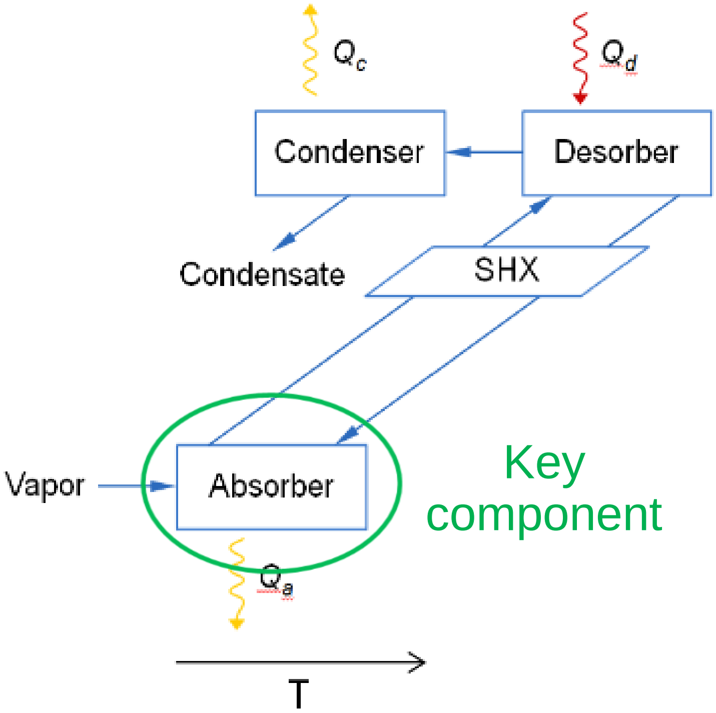
Adapted from: K. Gluesenkamp and R. Radermacher, "Heat Activated Cooling Technologies for Small and Micro CHP Applications," in *Small and Micro CHP Systems*, R. Beith, Ed., ed Cambridge, UK: Woodhead Publishing Ltd., 2013.

Semi-open Sorption Architecture

Traditional closed



Semi-open



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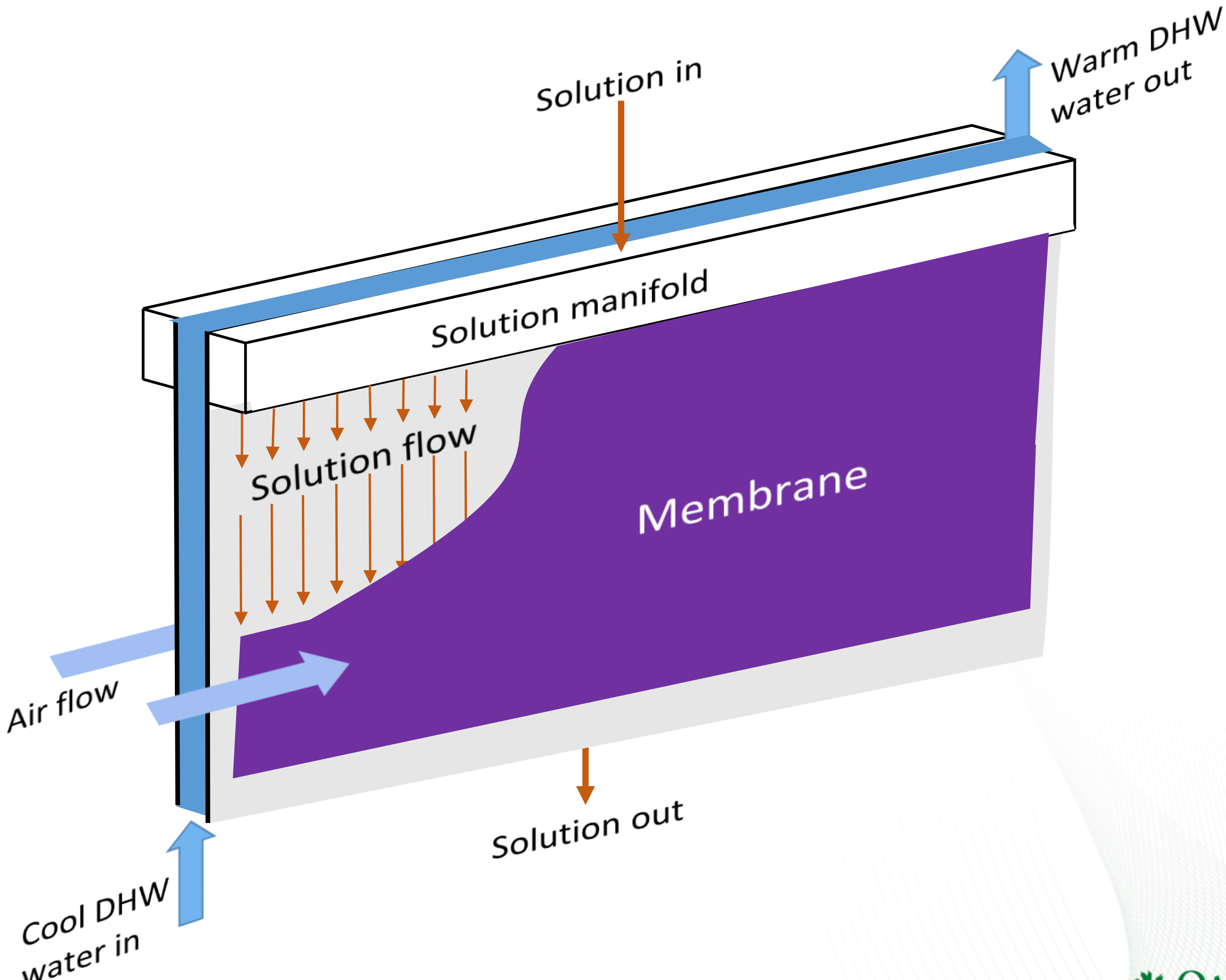
Key Component: Semi-open Absorber



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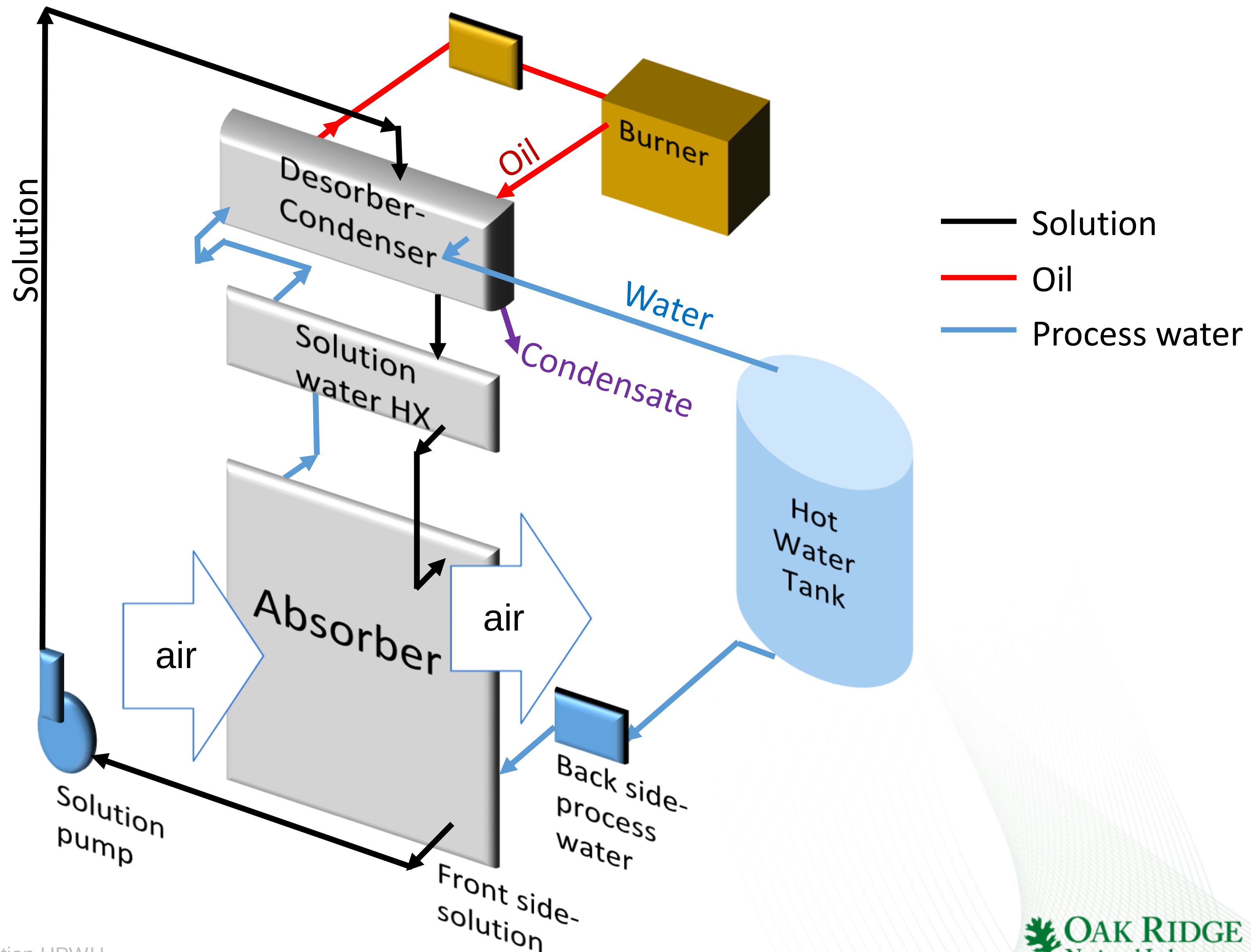
Open Absorption Water Heater



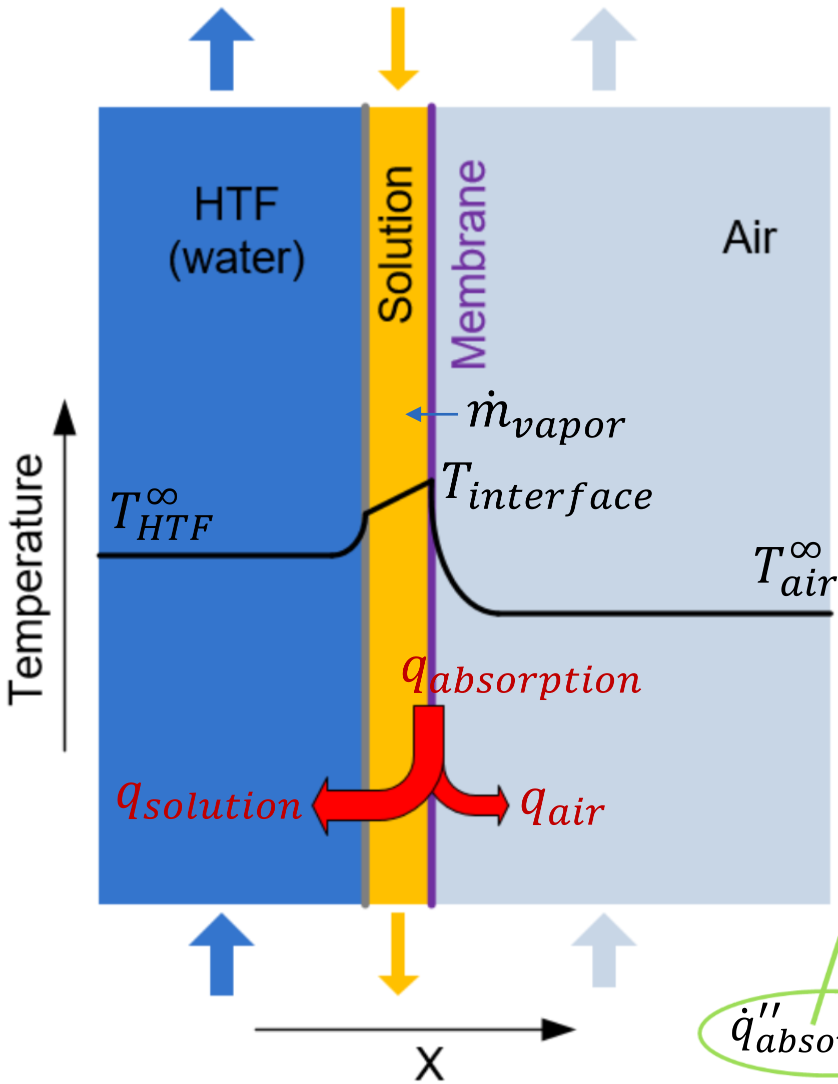
Main Benefit

Significant cost reduction compared with traditional sorption

Component	Traditional closed sorption	Semi-open sorption
Vessel materials	Carbon steel	Polymer
Solution pump	Hermetic, with hydrostatic plus 1–15 kPa variable head	Nonhermetic with constant hydrostatic head
Vacuum requirements	Periodic vacuum pumping	None
Vessel pressure rating	Must withstand full vacuum (34 ft)	Only hydrostatic pressure differentials (~2 ft)
Evaporator	Required	Not required

K. Gluesenkamp, D. Chugh, O. Abdelaziz, and S. Moghaddam, "Efficiency Analysis of Semi-Open Sorption Heat Pump Systems," Renewable Energy, 2016.

Theoretical Efficiency Established



$$COP_{htg} = 1 + \frac{(\alpha - 1)L_{abs} + L_{cond}}{L_{abs} + C_{p,liq}(1 - \varepsilon_{SHX})\Delta T_{D-A}(FR)}$$

$$\alpha \equiv \frac{\dot{q}''_{solution}}{\dot{q}''_{absorption}} = \frac{1}{1 + \dot{q}''_{air} / \dot{q}''_{solution}}$$

$$\alpha = \frac{1}{1 + \frac{UA_{air}\left(T_{interface} - T_{air}^{\infty}\right)}{UA_{soln}\left(T_{interface} - T_{HTF}^{\infty}\right)}}$$

$$T_{interface} = \frac{\dot{q}''_{absorption} + U_{soln}T_{HTF}^{\infty} + U_{air}T_{air}^{\infty}}{U_{soln} + U_{air}}$$

Only three measured values

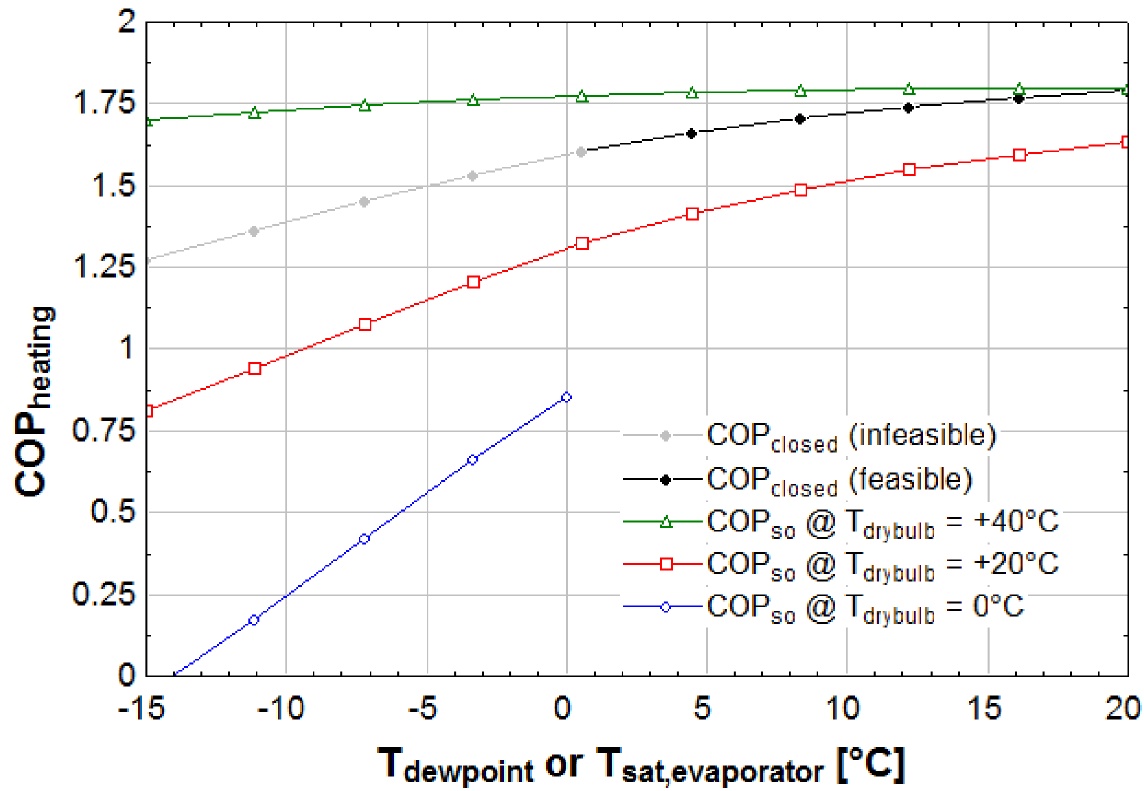
$$\dot{q}''_{absorption} = h_m L_{abs}\left(P_{w,air} - P_{w,soln}\{T_{interface}, X_{soln}\}\right)$$

Gluesenkamp, K., Chugh, D., Abdelaziz, O., and Moghaddam, S., "Efficiency Analysis of Semi-Open Sorption Heat Pump Systems," *Renewable Energy* (in press).

Efficiency Expected by Theory

Parameter	Measured value in prototype
h_m	4.9×10^{-2} $g^1 m^{-2} s^{-1} kPa^{-1}$
U_{air}	2.67 ± 0.15 $W^1 m^{-2} K^{-1}$
U_{soln}	28.6 ± 1.7 $W^1 m^{-2} K^{-1}$

Efficiency can be lower or higher than conventional closed absorption cycle, depending on ambient temperature

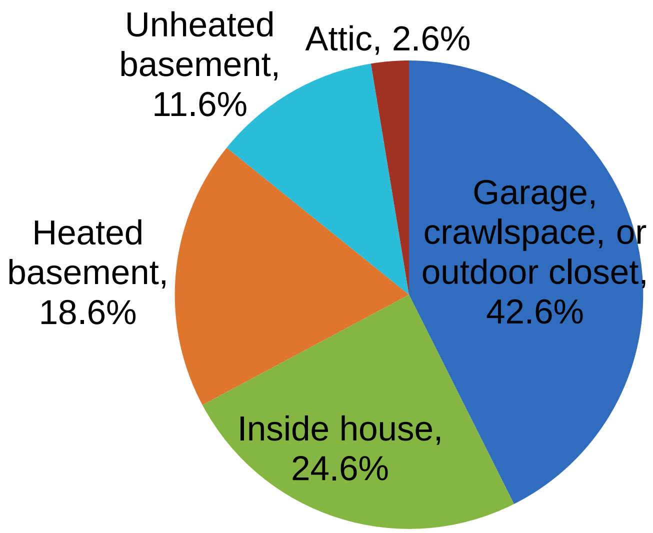


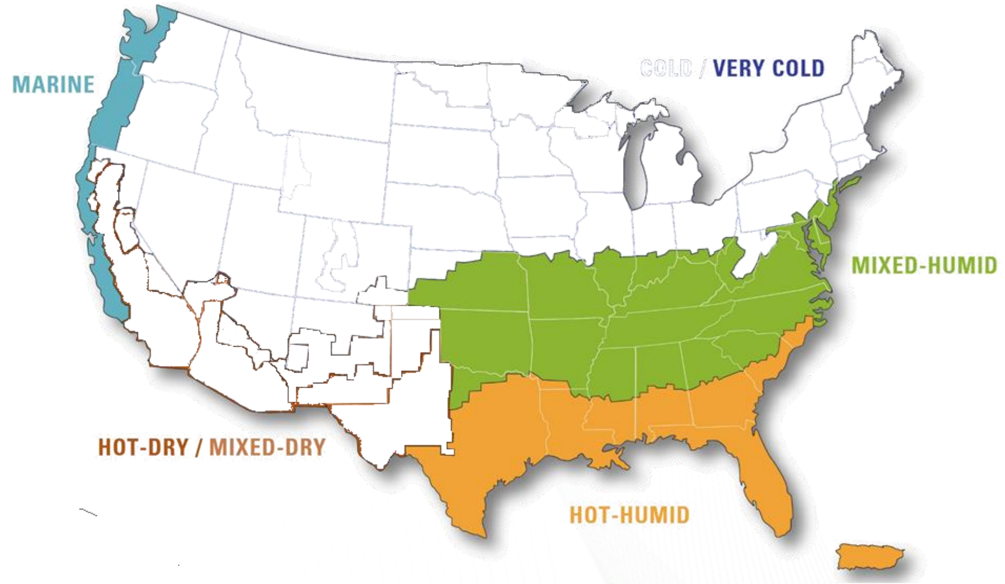
Contours of heating COP for closed and semi-open cycles at various ambient conditions.

Gluesenkamp, K., Chugh, D., Abdelaziz, O., and Moghaddam, S., "Efficiency Analysis of Semi-Open Sorption Heat Pump Systems," *Renewable Energy* (in press).

Favorable Climates for Semi-open System

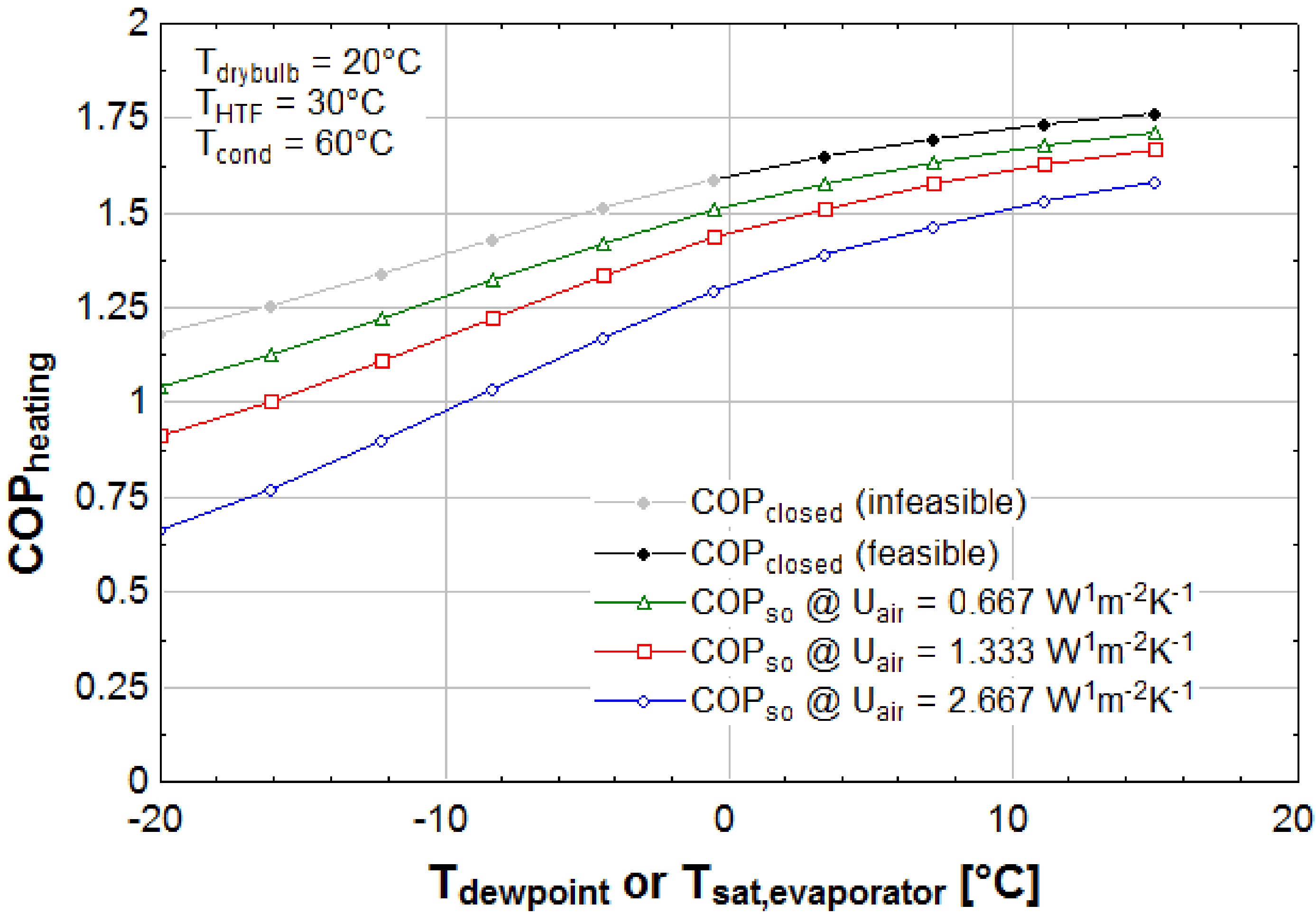
- Favorable for residential application in 3 climate zones, encompassing 54% of US homes





Research Opportunities

Performance improved by **lower** air side heat transfer…



Lower U_{air} values improve performance at fixed permeability (h_m =0.049 $g^1m^{-2}s^{-1}kPa^{-1}$)

Gluesenkamp, K., Chugh, D., Abdelaziz, O., and `Moghaddam, S., *Renewable Energy* (in press).

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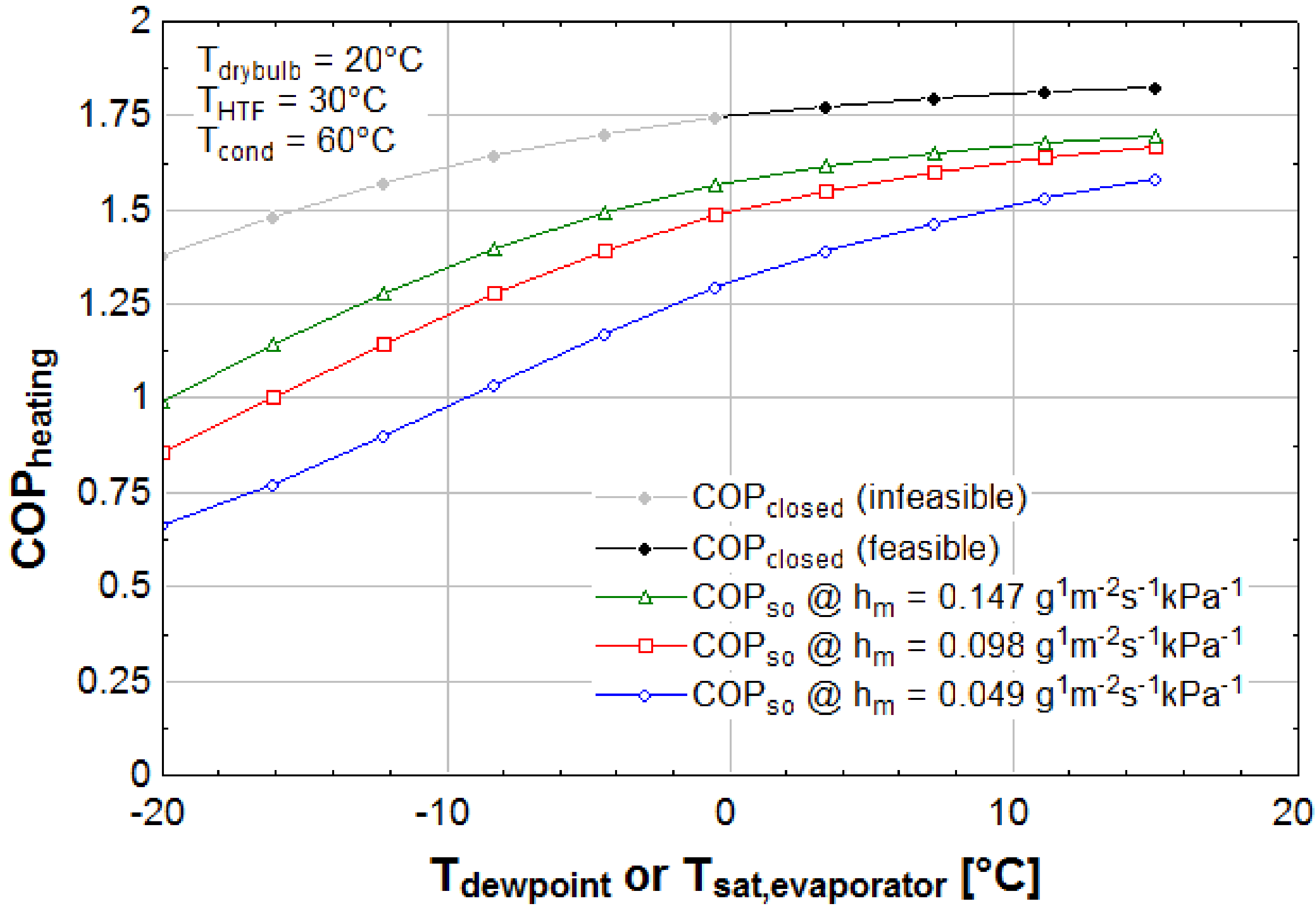
Research Opportunities

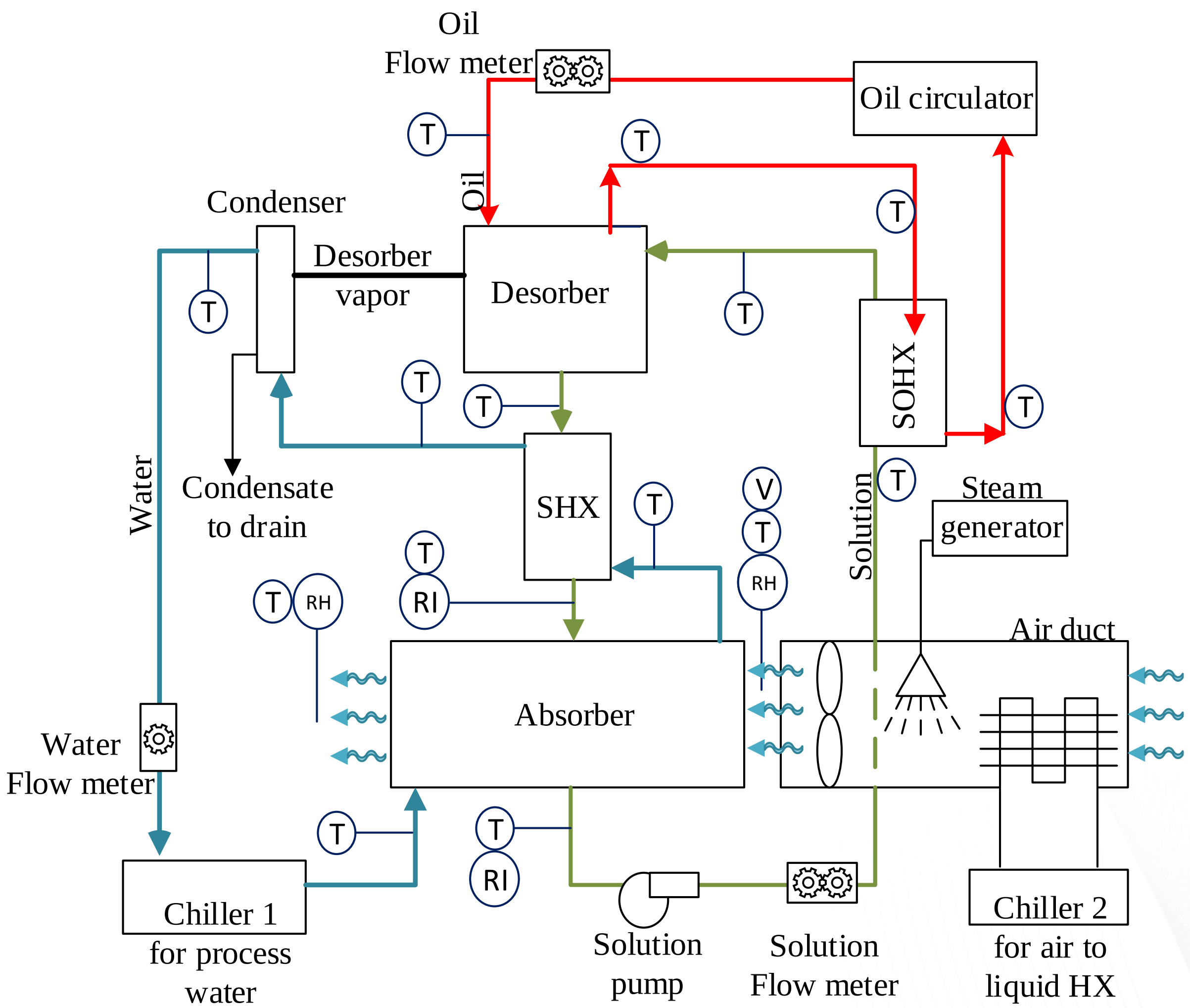
… and **higher** moisture mass transfer.



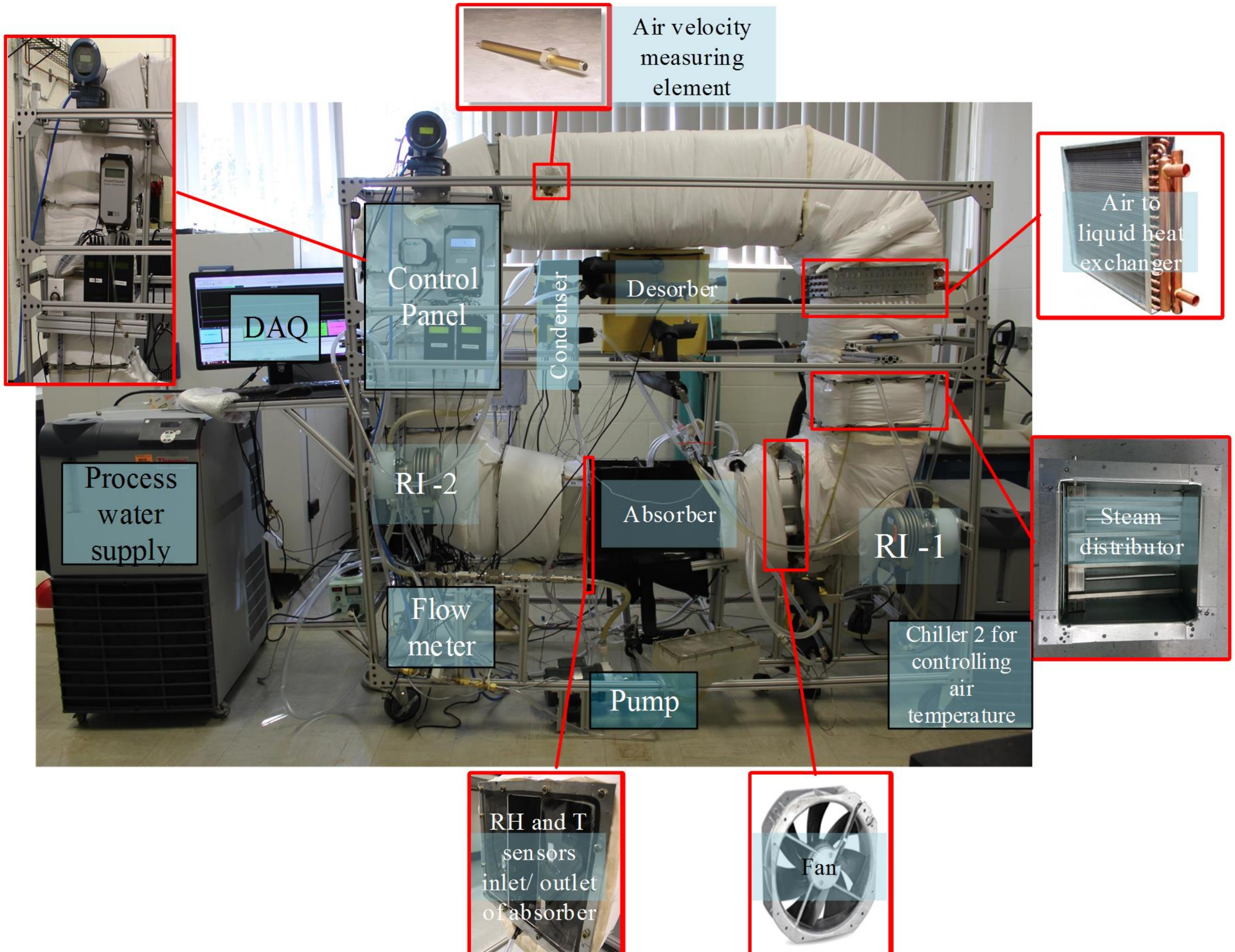
Higher membrane permeability at fixed $U_{air} = 2.667\ W^1m^{-2}K^{-1}$ leads to better performance

Gluesenkamp, K., Chugh, D., Abdelaziz, O., and `Moghaddam, S., *Renewable Energy* (in press).

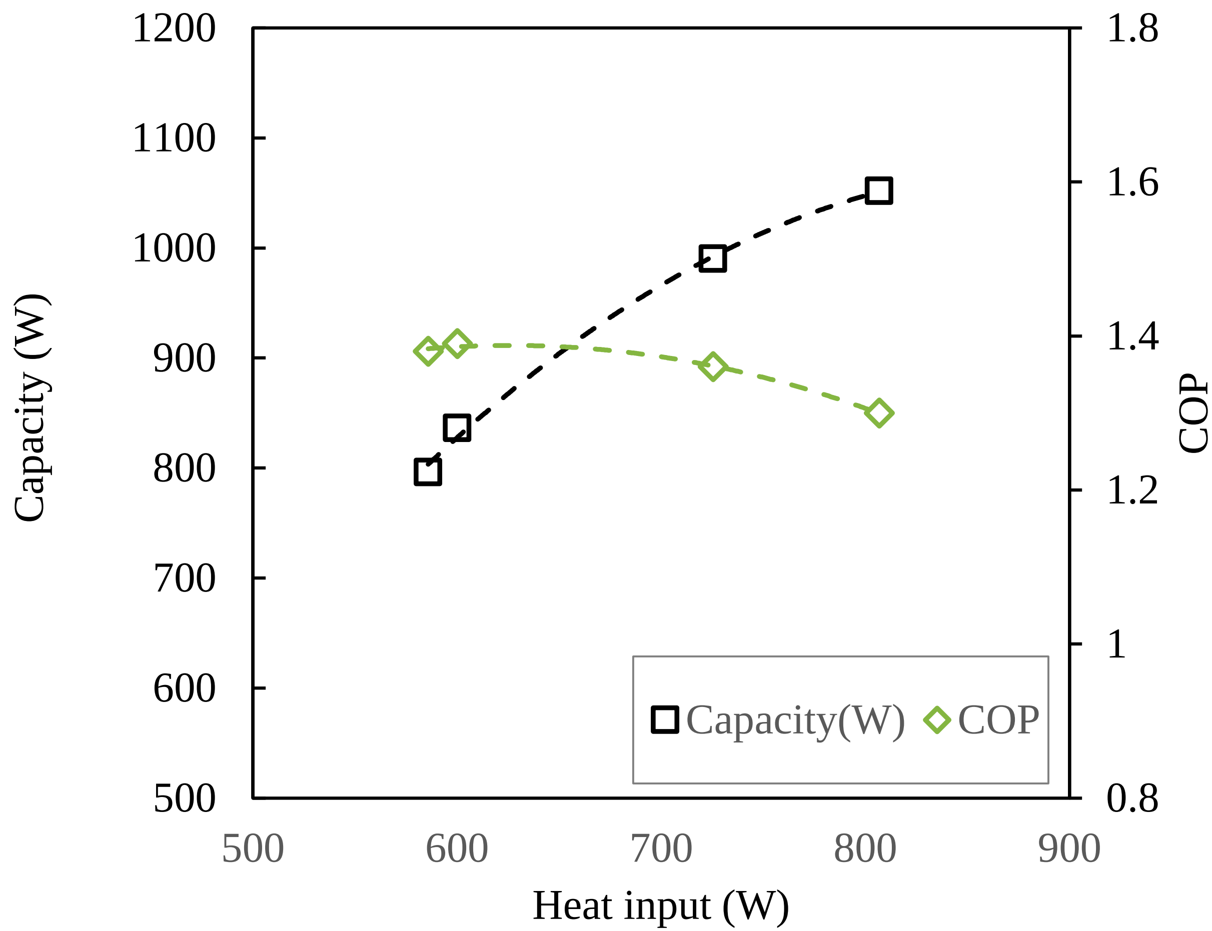
Experimental System Diagram



Prototype Evaluation



Prototype Evaluation



Water inlet temperature of 17°C, ambient conditions are 30°C and 70%RH.

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Discussion

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