Outlook on Future Heat Pumping Technologies Challenges and Opportunities

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What I have in the back of my mind…

- Compressor is heavie
  and most dense
  component
- Heat Exchangers
  determine the ov
  volume of the he
  pump

= Empty space

Broad Brushstrokes !

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Some Drivers for Change

Anthropogenic Climate Change

It is the biggest driver of all.

But there is more:

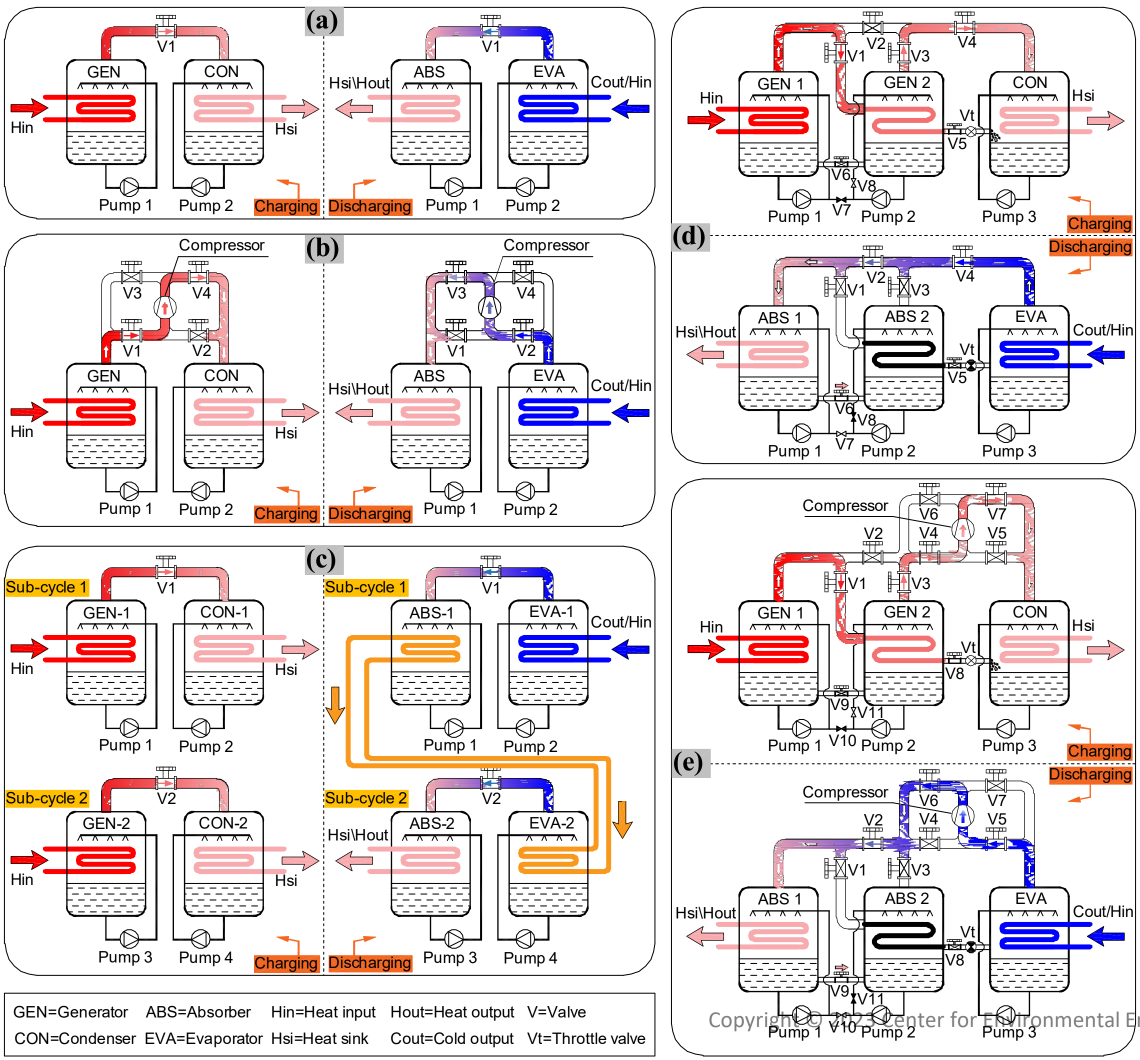
IEA: 1.6 Billion Air-conditioners Worldwide Today

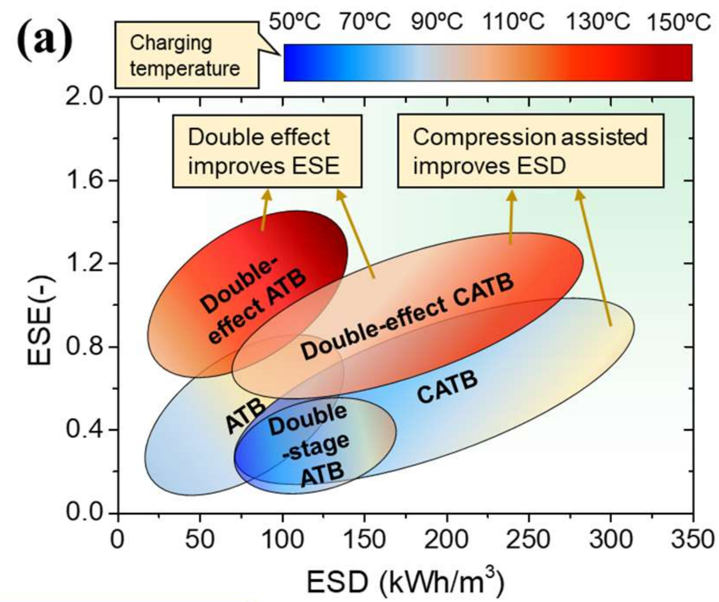
2050: 5.6 Billion Air-conditioners Worldwide + Refrigeration Systems and Heating-only HPs

Where will the resources come from?

IEA Annex 53 Project Sampling

Comparisons of various ATB cycles





- Single-effect
- Comp.-assisted
- Double-stage
- Double-effect
- Comp.-assisted double-effect

Dr. Wei WU
City University
Hong Kong
IEA HPC 2023

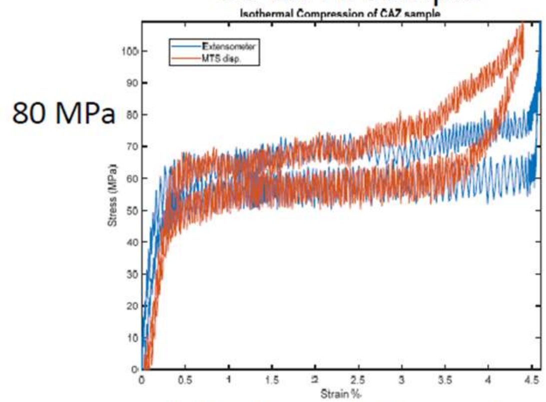
Thermoelastic (Elastocaloric) Cooling

Elastocaloric materials beyond NiTi: Cu-based alloys with much smaller critical stress

Cu-Mn-Al tubes

w/ S. Kise (Furukawa)

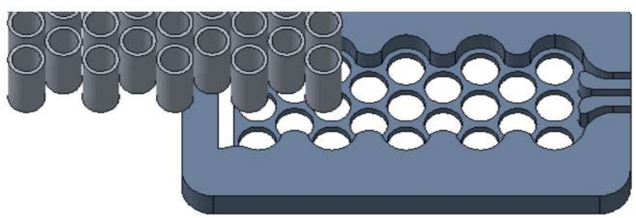
Cu-Zn-Al sample

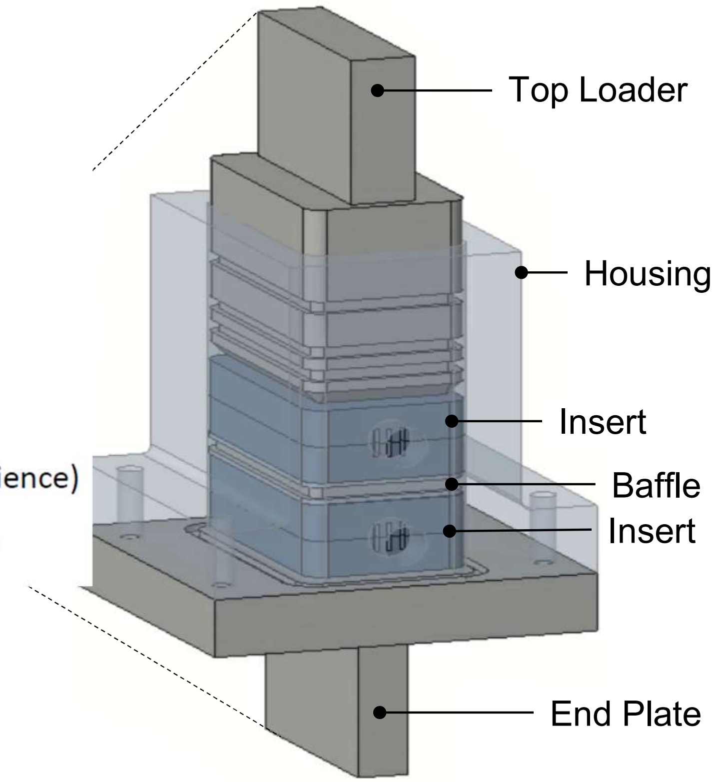


w/ K. Fujimoto (Tokyo Univ. of Science)

Regenerator being constructed and tested

ΔT ~ 5K; ~60,000 cycles to date





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Membrane Dehumidifer

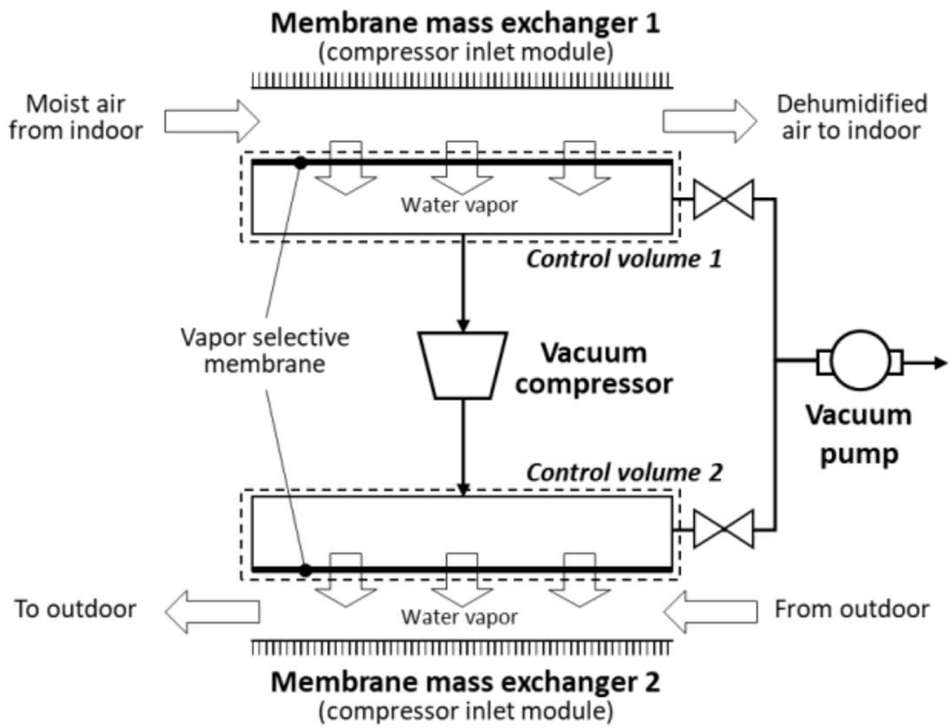
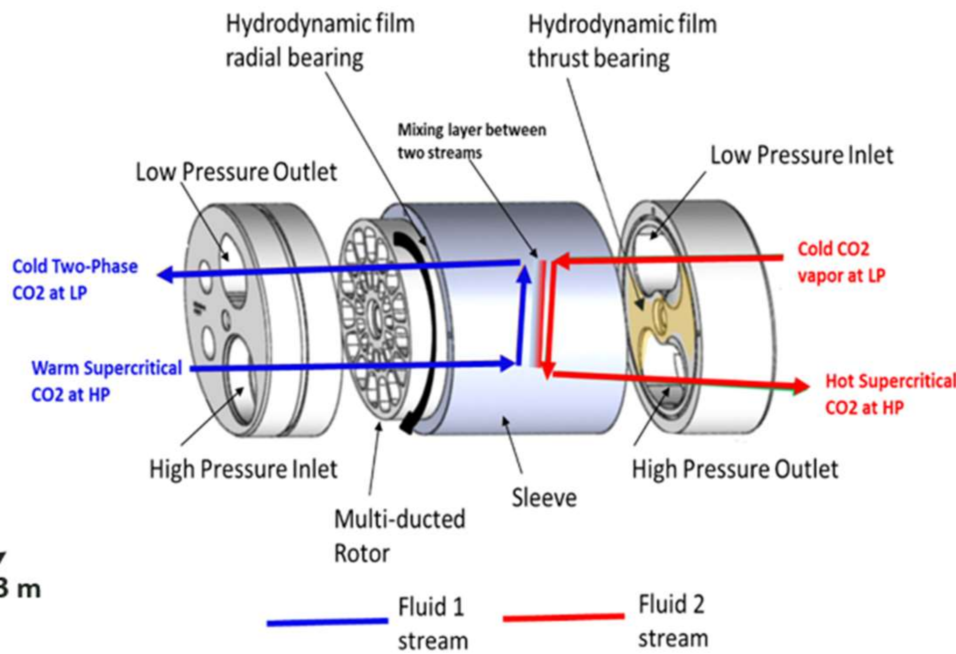


Fig. 6. Revised MVD with a vacuum pump for dry air discharge.

D Ku, S Bae, S Kim, M Jung, S Jeong, G Seo, M Kim (2023) Cyclic operation of a membrane-based vacuum dehumidification system by finite selectivity of the membrane, Journal of Mechanical Science and Technology

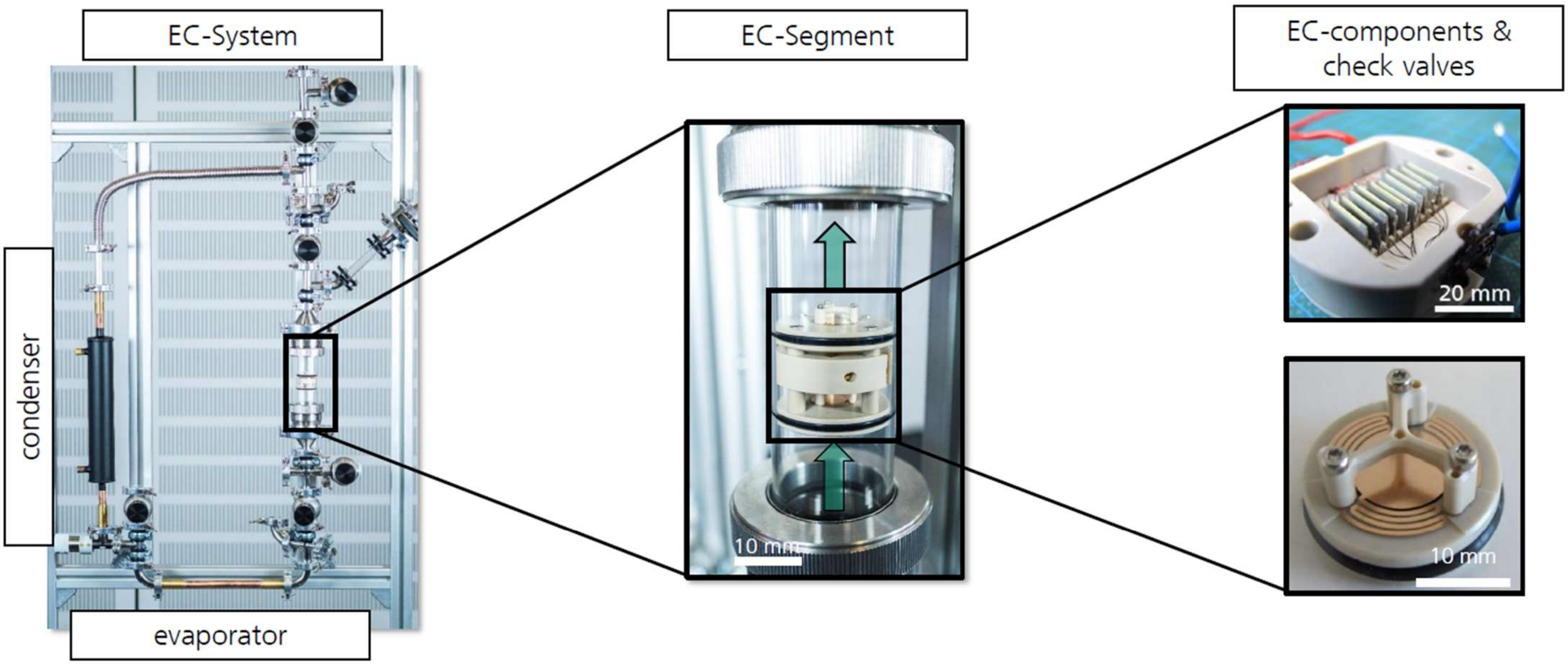
Trans-Critical Rotary Pressure Exchanger (PX G1300)

***Animation

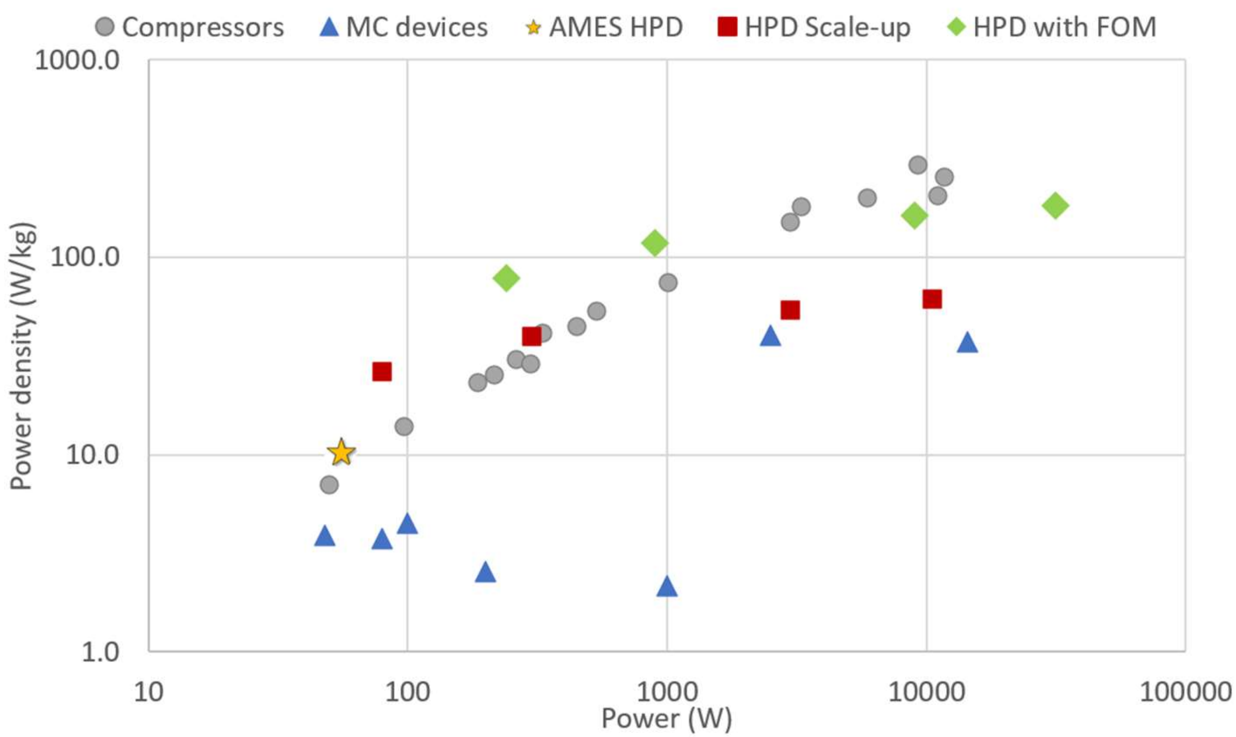


Electrocaloric System
Setup

- **Combination of Heat Pipe and Thermal Diode Concepts**
- **Applicable to mageto-, elasto- and electro-caloric Devices**



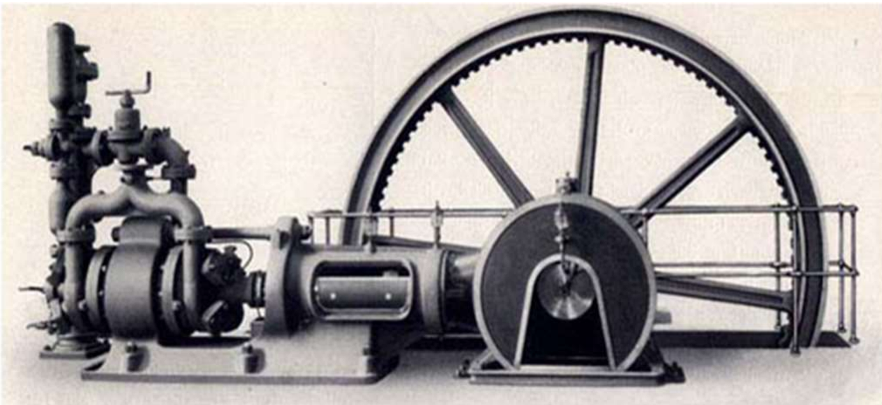
Status of Magnetocaloric Technology at AMES

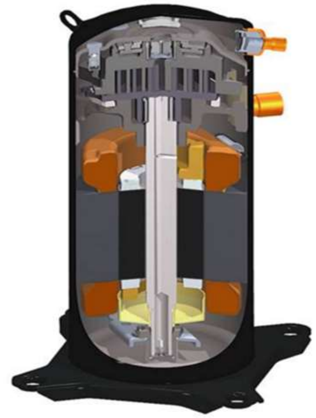


- New device developed at AMES exceeds MC devices in the same range [1-7] and meets or exceeds power density of off-the-shelf compressors [8-10]
- Models using outlined scaling strategies show that HPD MC devices match compressors up to ~500 W using gadolinium packed particle beds
- Assuming the use of first order MCMs, such as LaFeSi-family, models indicate competitiveness up to ~3 kW

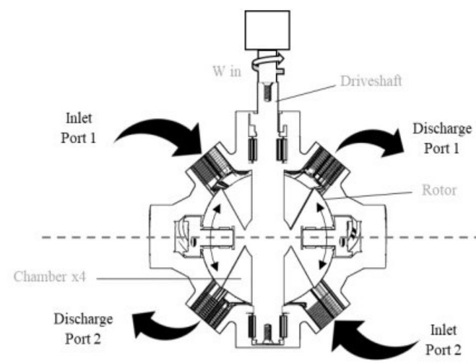
Future of Compressors

Historical Compressor Development





Roticulating Compressor



https://iopscience.iop.org/article/10.1088/1757-899X/604/1/012070

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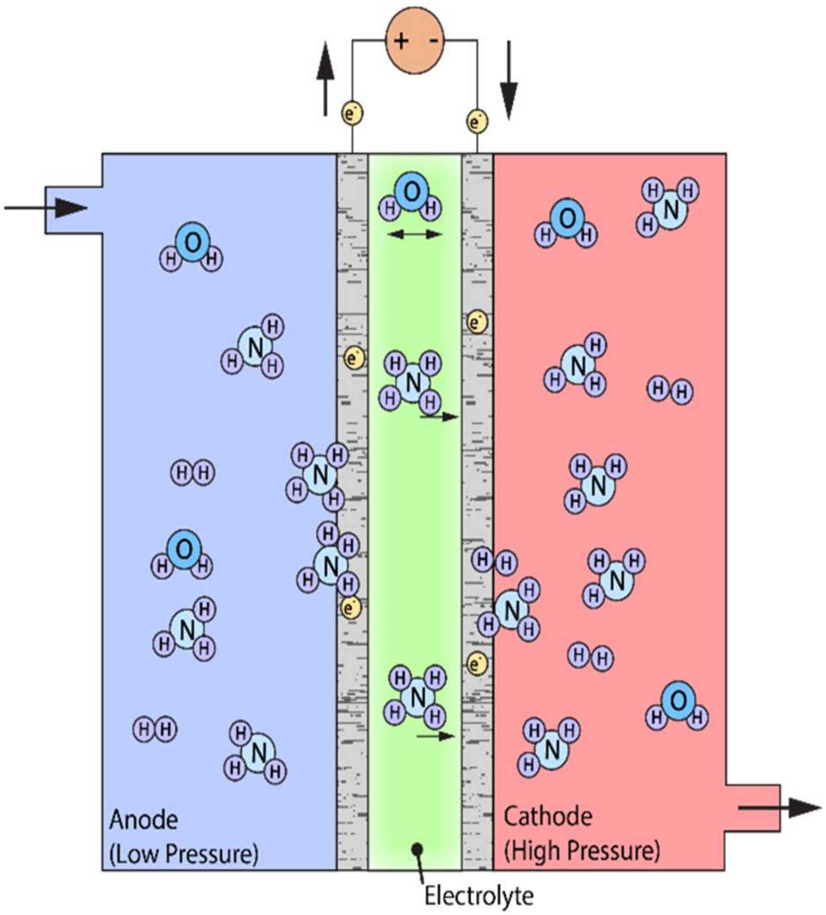
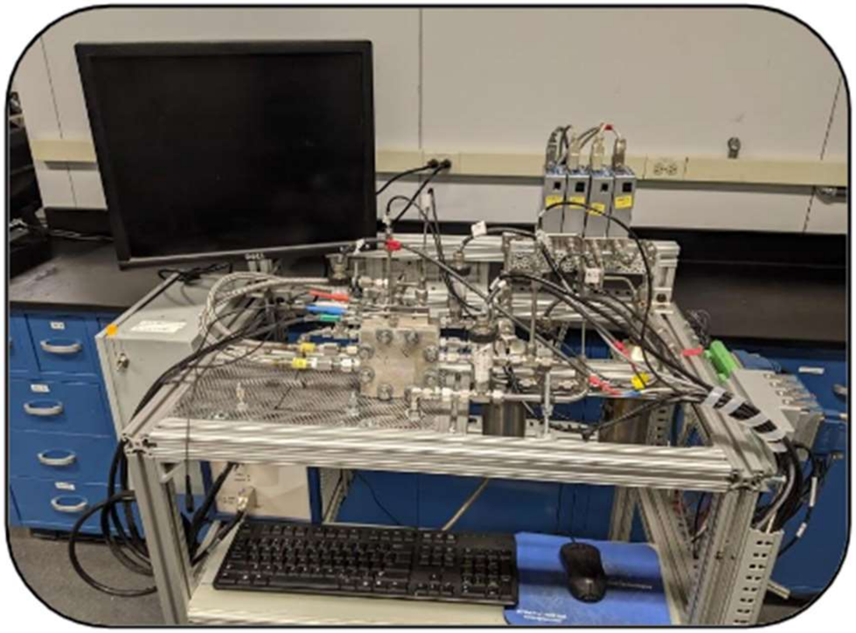
Electrochemical Compression of NH_3, CO_2



EC Dehumidifier Test Facility

Test Facility.



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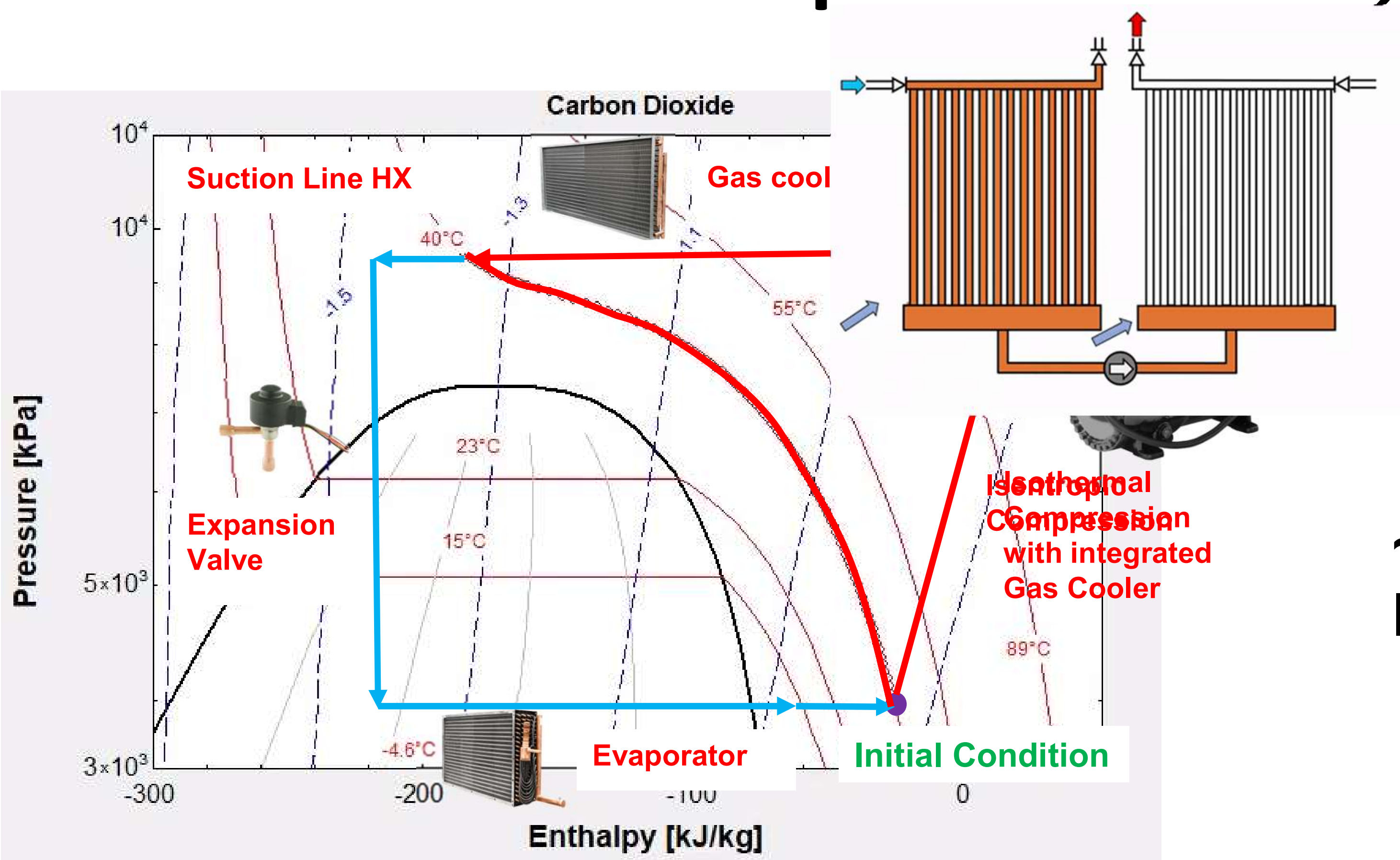
Isothermal Compression of CO_2



~ 30% COP Improvement

The Future of Compressors

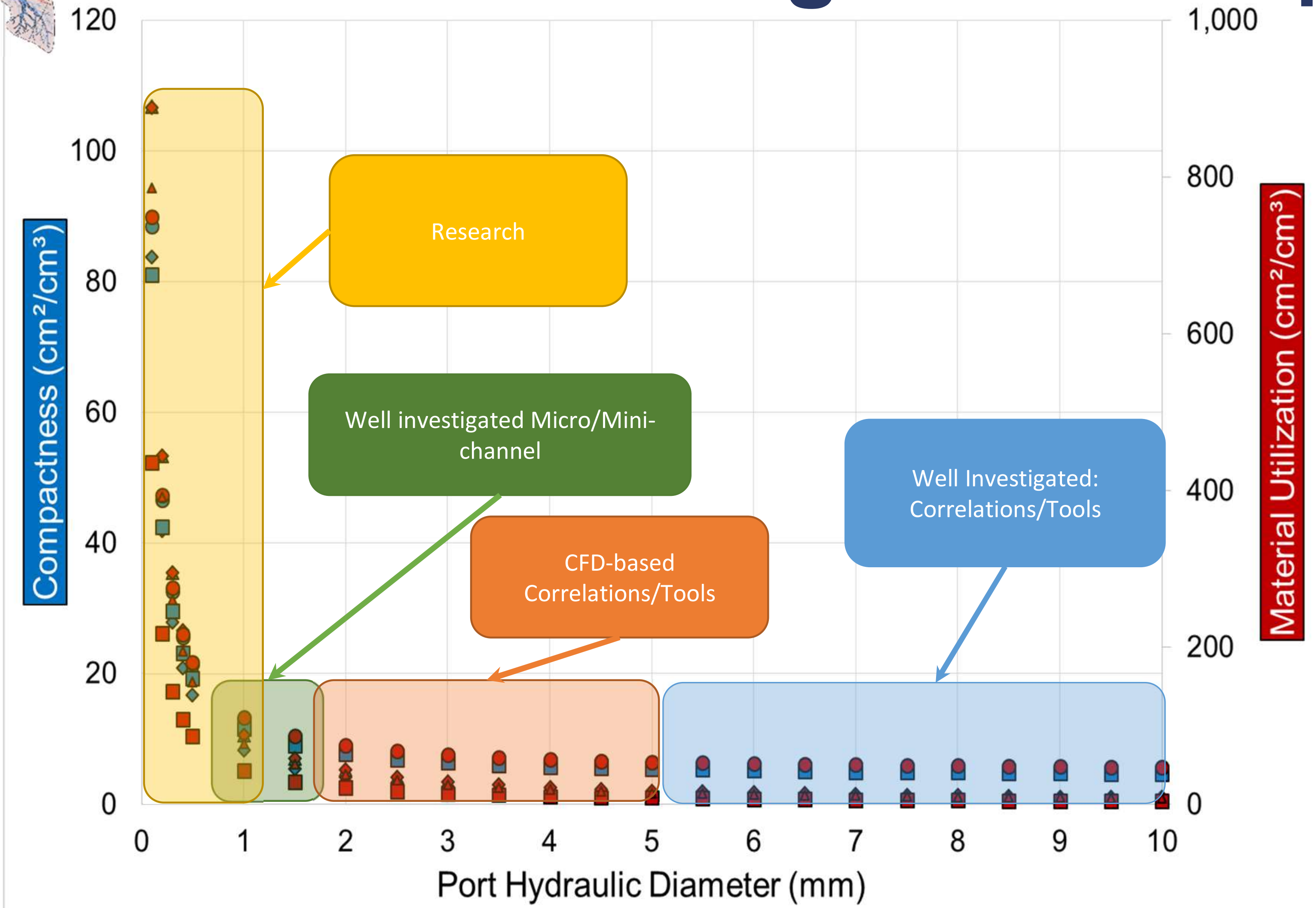
- Significant Size Reduction
  - 24,000 rpm, 400Hz
  - 200,000 rpm
- Oil-free Technology
- Isothermal Compression, for small molecules, CO_2, NH_3
- No Moving Parts?!

All Heat Pumps require
Heat Transfer Technology!

Future of Heat Exchangers

Heat Exchanger Road Map

240



Bacellar, D., Aute, V., Huang, Z., and Radermacher, R., 2016, Airside friction and heat transfer characteristics for staggered tube bundle in crossflow configuration with diameters from 0.5 to 2.0mm, Technical Note, Intl J. of Heat and Mass Transfer, Vol. 98, pp. 448-454

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Mathematically Rigorous Optimization…

…allows engineers to innovate.

Because:

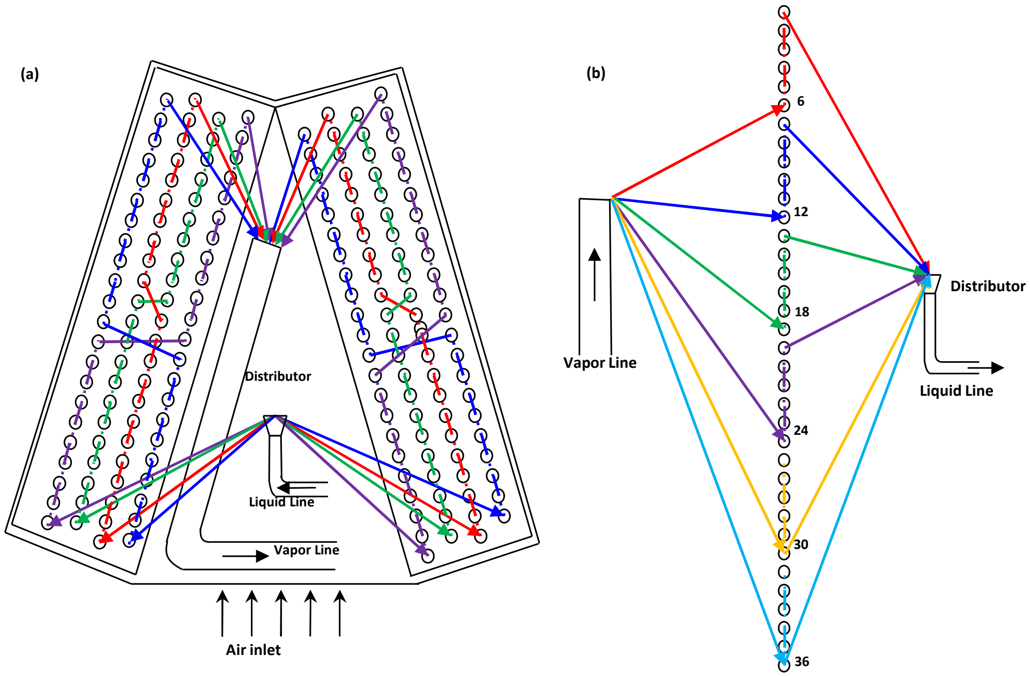
Whatever a computer can simulate, a computer can optimize,

Freeing humans to do what humans do best:

Create and Innovate!

Mathematically Rigorous Optimization of an Air-conditioner

The HX component model uses a finite volume HX simulation tool



*Alabdulkarem, A., Hwang, Y., Radermacher, R., 2013. System Drop-In Tests of Refrigerants R-32, D2Y-60, and L41a in Air Source Heat Pump. Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Low-GWP Alternative Evaluation Program

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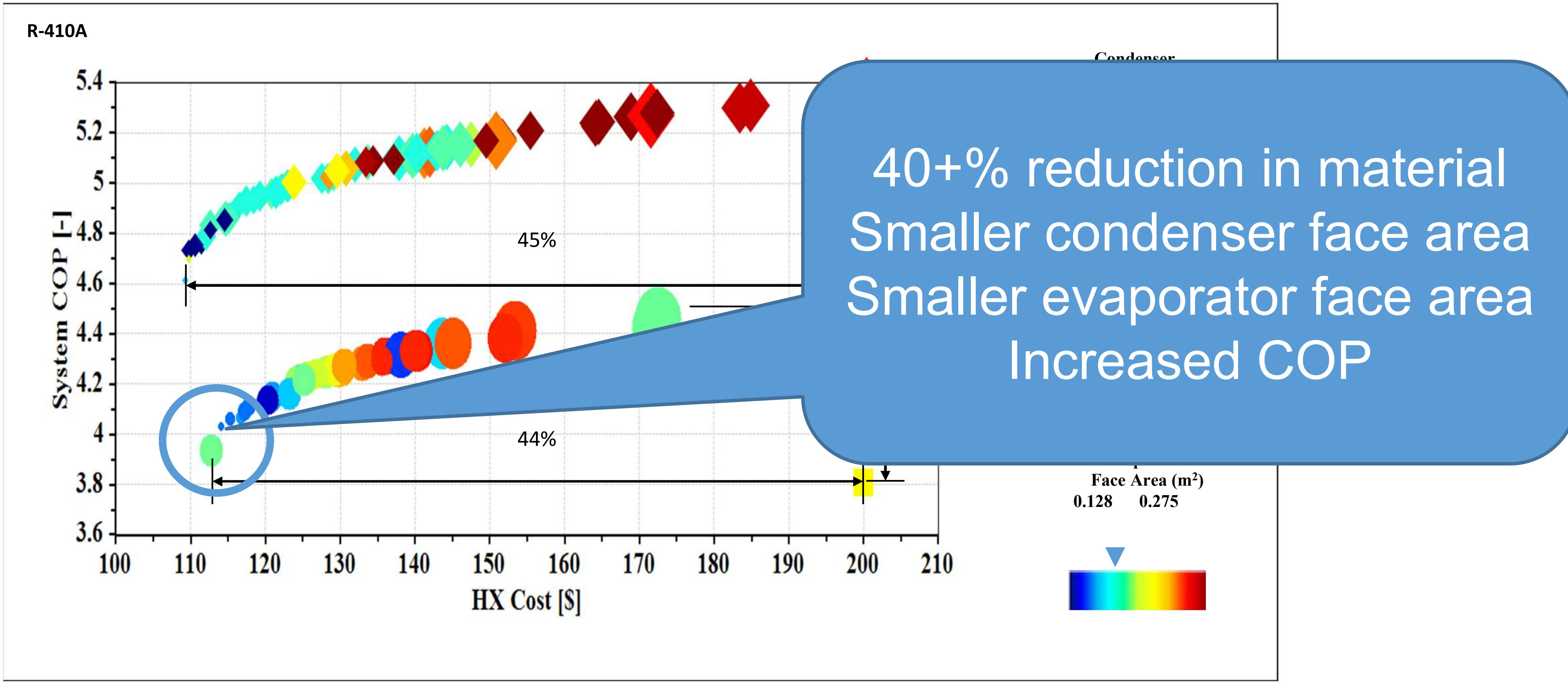
Heat Exchanger Optimization Results



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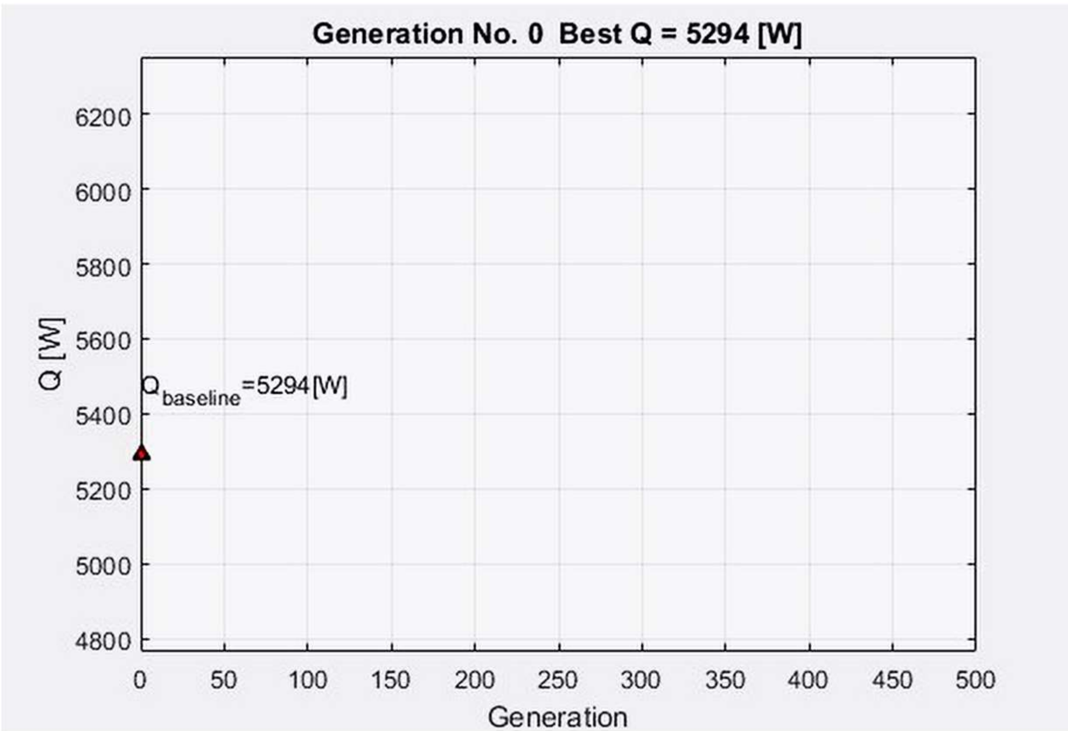
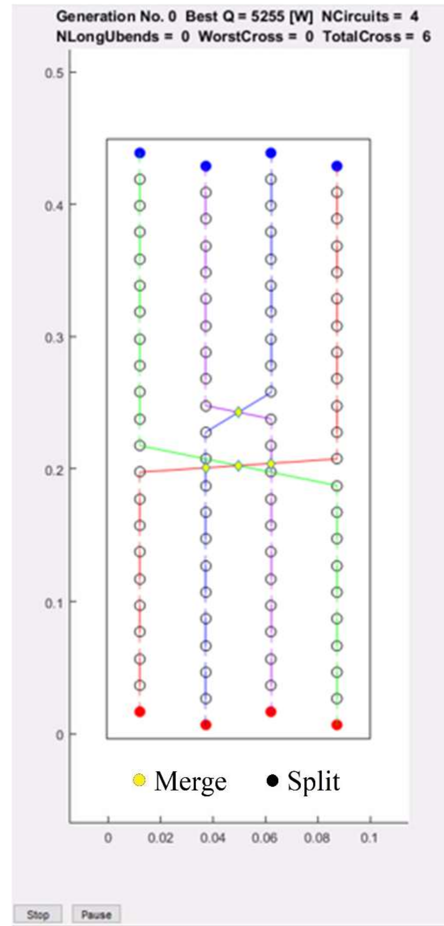
Heat Exchanger Circuitry Optimization

- $Q_{baseline}$=5294W, Q_{opt}=5424W (2.5%↑)
- $DP_{baseline}$=11.7 kPa, DP_{opt}=8.6 kPa (26.5%↓)
- The optimal has 1 merging U-bend





GA Setting: NGeneration=500, Population size = 200, Replacement ratio = 20%

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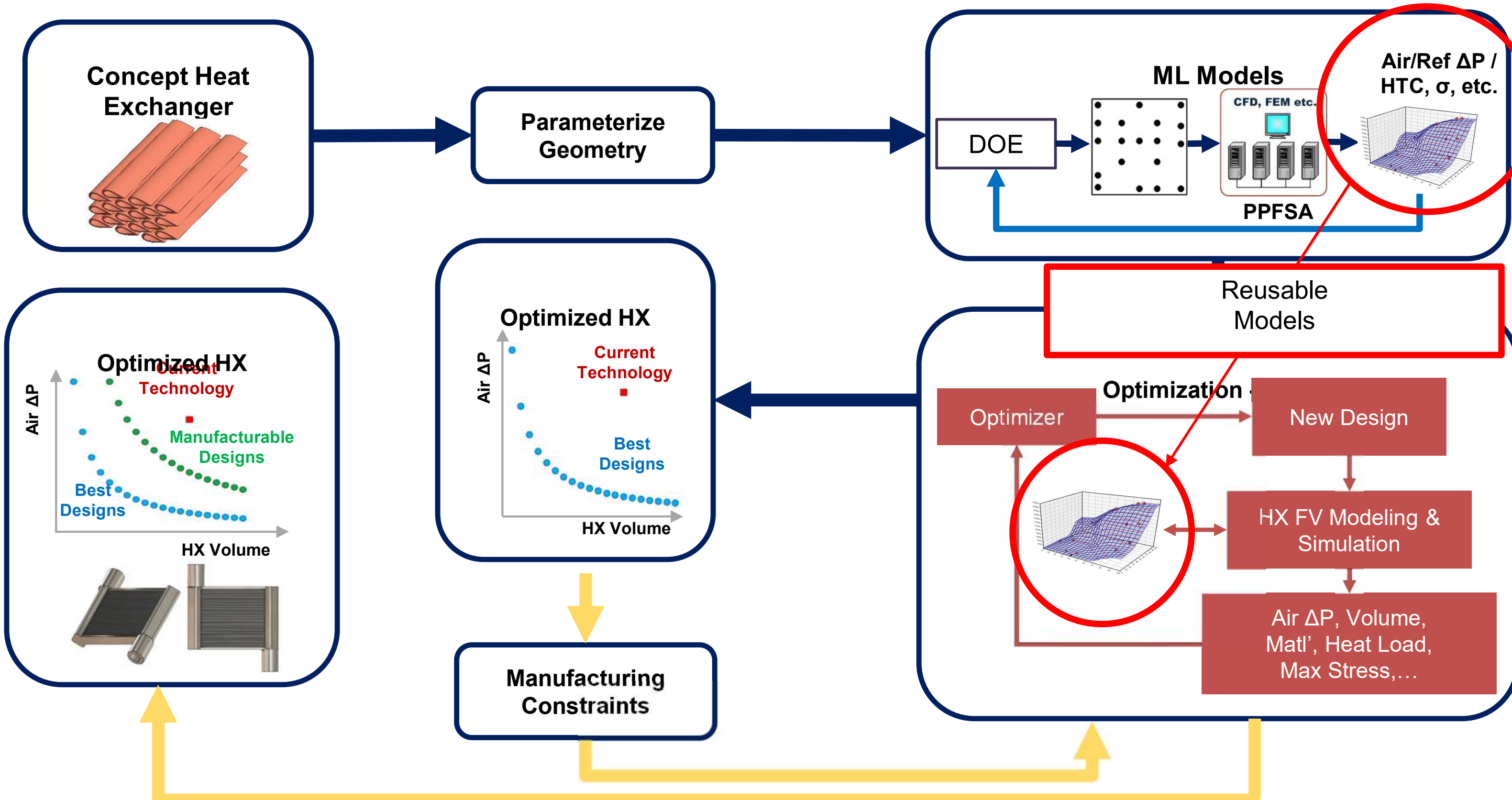
HX Innovation Framework



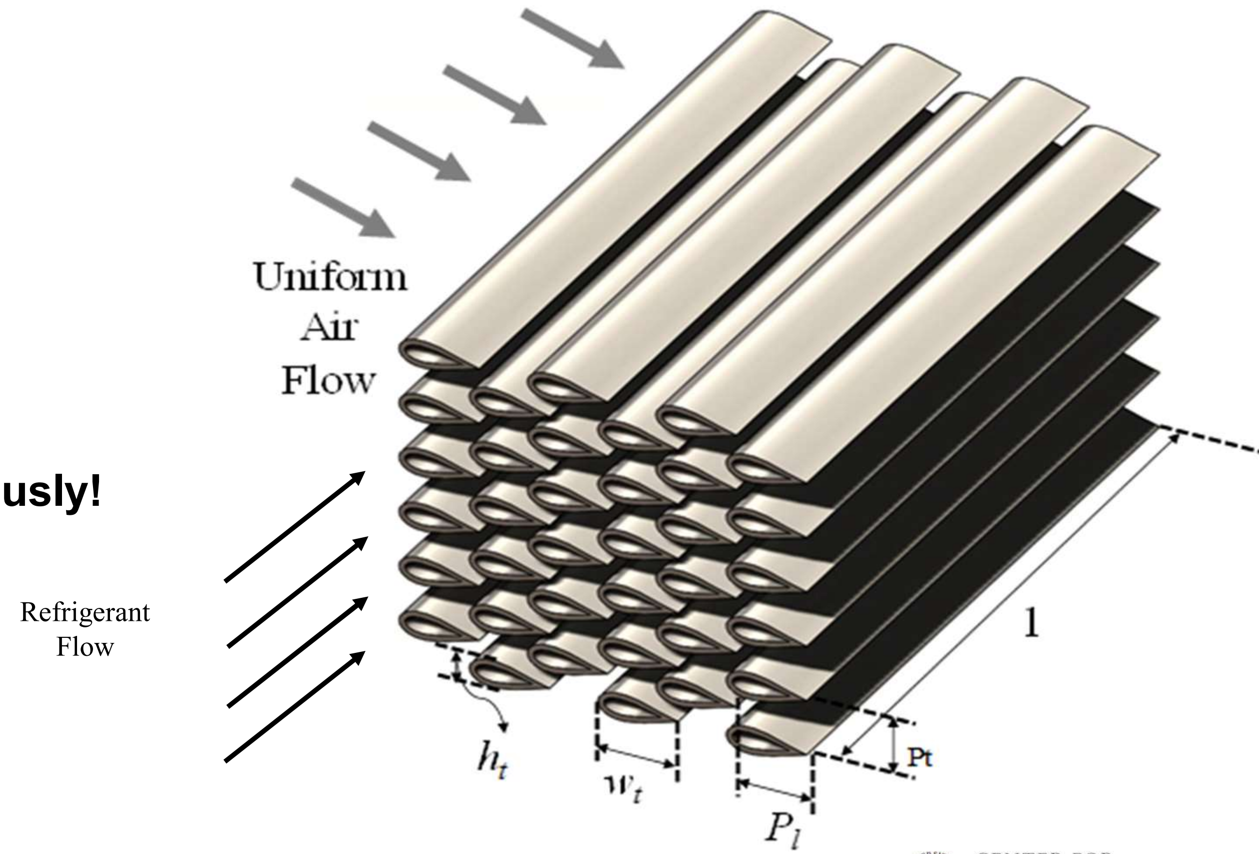
PPFSA = Parallel Parameterized Fluid & Structural Analysis; MOGA = Multi-Objective Genetic Algorithm; FV: Finite Volume.
Contributors: Drs Aute, Abdelaziz, Saleh, Bacellar, Huang, Eldeeb, Tancabel

Lower-GWP Evaporators

Approximately:

- **Airside dP 40% ↓**
- **Envelope Volume 50% ↓**
- **Face Area 30% ↓**
- **Material Volume 40% ↓**
- **Charge Reduction 25% ↓**

Not necessarily all simultaneously!



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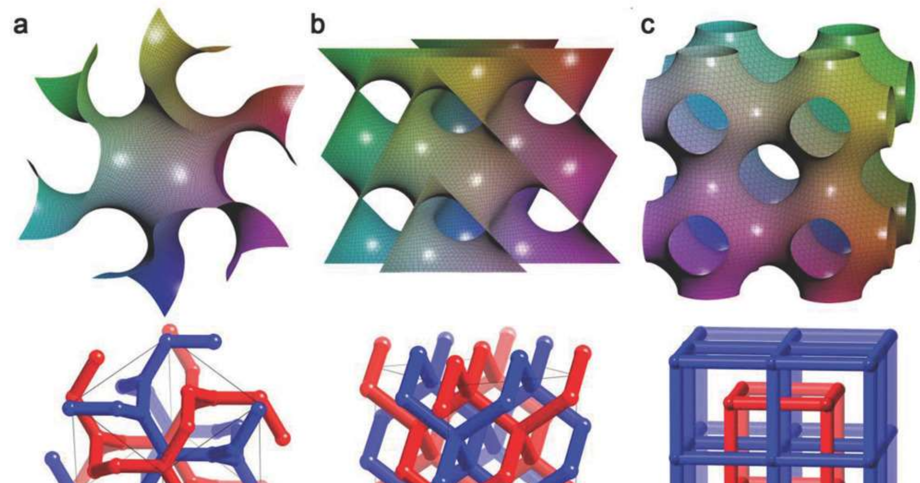
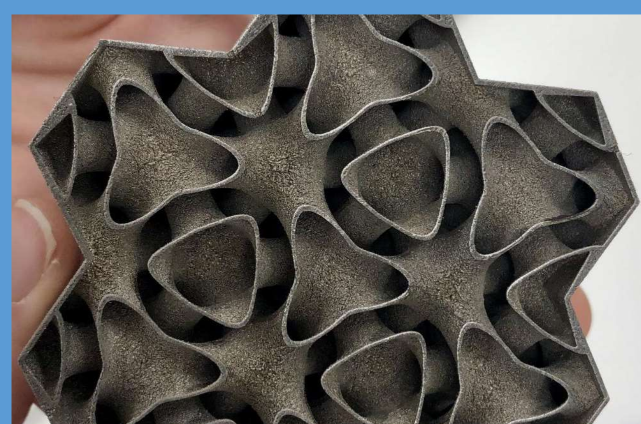
Triply Periodic Minimal Surfaces (TPMS)

- **TPMS[10] can pack significant surface area in a given volume**
- **Balanced Bi-continuous TPMS divide 3D Euclidean space into “two” domains that are:**
  - Congruent
  - Interpenetrating
  - Intersection-free
  - Infinitely repeating
- **Benefits of TPMS**
  - Can provide high compa designs
  - Minimizes pressure drop continuous flexures





High temperature & pressure sCO_2 cycles Metrics: 3.76 kW/kg (vs. 1.6), 10MW/m^3 (vs. 2)
Ref: UPHEAT Project: GE (Lead), UMD & ORNL

Future of Heat Exchangers

- All Technologies need Heat Exchangers!
- Much smaller dimensions
- Conform to irregular shapes → can be located out-of-the-way
- Filters increasingly important
- Oil-free compressors required
- Transformation of design and manufacturing methods
- Heat exchangers may not be product of traditional HVAC manufacturers
- **Lots of room for creativity!**

Future of Heat Pumps

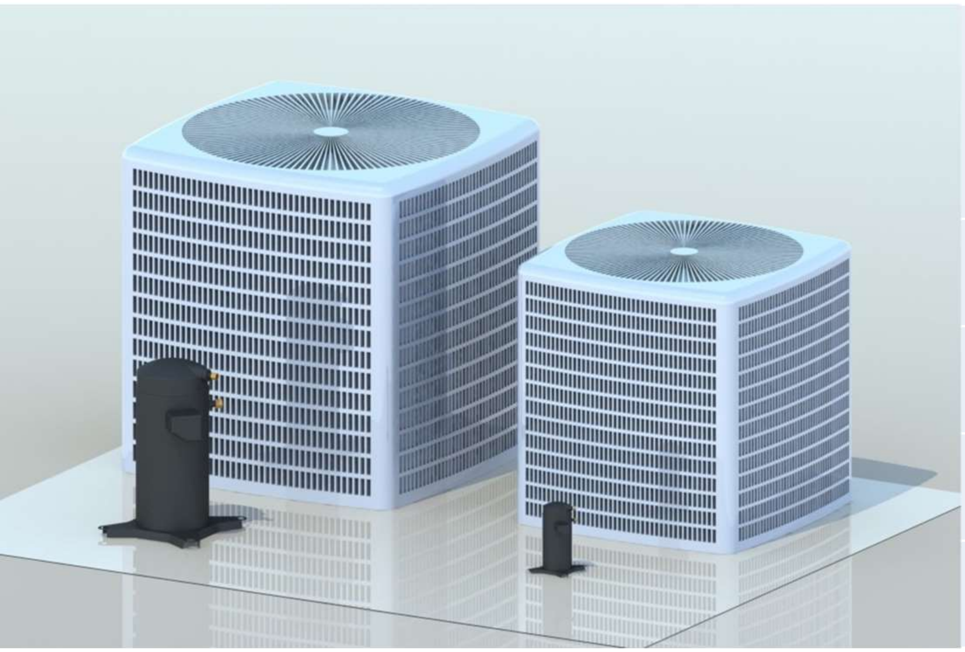
Silicon Valley et al…

Moving a Single Lever Connects:

- Refrigerant piping
- Power,
- Controls,
- Condensate hose

No HVAC Installer Needed!

Coming back to NA Heat Pump…



Conventional Technology (10kW)	Proposal
40	4
40	20
40	16
120	40

…may have half the volume, a third of the weight and operate in houses with no net energy consumption!

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All of this and more is brought to you in part by the Annexes of the

IEA Heat Pump Collaboration Program

Thank you!

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