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# Heat Pumps: Enablers of Decarbonization

## Heat Pumps: The solution to many of humankind's essential challenges

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## 1. ABSTRACT

This study evaluates the potential of heat pumps to decarbonize different end uses, including cold chain food storage, space conditioning, water purification, and thermal energy storage. Prior experimental research and reduced order models are used to evaluate reductions in primary energy consumption or carbon emissions. Realistic pathways to implement heat pumping at the residential scale are discussed.

## 2. INTRODUCTION

Global climate change and burgeoning worldwide energy demand, especially for space-conditioning in developing countries, are twin drivers for innovation in the current energy utilization sector. In the push toward decarbonization, electrification alone may not yield immediate reductions in carbon emissions because fossil-free renewable options are still in the ramp up phase. A more judicious process that leverages innovation in energy conversion, storage, recovery, and end use is likely to yield the desired reductions in carbon emissions. Recent advances in multi-component heat and mass transfer and microscale heat exchange devices have enabled compact and energy efficient heat pump cycles that are primarily, or even entirely, thermally driven. In this work, the performance and viability of heat pumps for a variety of end uses at the residential scale are evaluated and discussed. Waste heat driven sorption heat pumps to provide cooling in severe ambient conditions will be shown to reduce the carbon footprint at kW to MW scales. Additional applications of heating pumping, including the development of diurnal and seasonal thermal storage systems, will be discussed. Adsorption chillers driven by biomass, solar or waste heat for use in the cold chain to reduce food spoilage in developing countries with uncertain electricity infrastructure will also be presented. Other initiatives to be discussed include simultaneous space-conditioning and water purification systems at the residential scale. These representative applications demonstrate the vast potential for innovations and impact of heat pumping concepts in energy and emissions, water consumption, and the food supply chain.

## 3. METHDOLOGY

This work considers four end uses for heat pumping: space conditioning, food preservation (cold chain food storage), thermal energy storage, and water purification for residential-scale end uses. In space conditioning applications, ammonia-water absorption heat pumps have been shown to yield the highest primary energy coefficient

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of performance (COP) [1], which not only indicates higher energy efficiency, but also yields substantial reductions in carbon emissions, especially if the heat pump can be driven by biomass or solar thermal energy. In cold chain food storage, vapor compression is typically the cycle that is chosen to preserve food at a lower temperature due to their large COP. However, vapour absorption systems, at the cost of being less efficient and larger in size, may be able to provide cooling with lower carbon emissions, and importantly provide cooling in rural areas where large electricity demands may not be sustainable. Finally, thermal energy storage and water purification are recently explored end uses that leverage different portions of heat pump cycles. For example, long term thermal energy storage cannot be easily sustained with conventional sensible or latent energy storage systems, but the chemical reactions associated with sorption heat pumps can be achieved with minimal heat losses, since the nominal heat transfer rate mainly occurs at the time the chemical species mix. Water purification can be achieved in water-based vapor sorption system by leveraging the several distillation processes present in the cycle, while simultaneously providing space conditioning [5]. Table 1 shows several recent investigations that apply heat pumps to these end uses. Based on these findings and system level modelling of these different heat pumps, reductions in overall electricity consumption and carbon emissions are determined.

**Table 1 Parameters of the experimental program**

| Reference | Heat Pump | End Use | COP/Efficiency |
|---|---|---|---|
| Kini et al. [2] | $NH_3$-$H_2O$ Absorption | Space conditioning | 0.67 |
| Almasri et al. [3] | $H_2O$-Silica Gel Adsorption | Food preservation | 0.5 – 0.72 |
| Garimella et al. [4] | $H_2O$-LiBr Absorption | Thermal energy storage | 0.11 over 8 months |
| Boman and Garimella [6] | $H_2O$-NaOH Absorption | Water purification | 1.6 |

## 4. RESULTS

Figure 1 shows a projected reduction in United States carbon emissions supposing all thermal end uses in the building and transportation sector are provided by carbon neutral heat pumps. Two different energy demand models are utilized as described in Garimella et al. [5]. Briefly, carbon emissions from these sectors are determined by calculating the effective composition of the electric grid each year, which yields an effective annual $CO_2$ emission estimate. It is first clear from this result that net zero carbon emissions are still not predicted to occur by 2050, motivating the need for further carbon neutral technology development. Fortunately, figure 1 suggests a substantial reduction in carbon emission with heat pump integration - on the order of 1.7 to 3-fold. It is worth noting that these estimates serve as an upper bound, as carbon neutral heat sources mainly come in the form of biomass and solar energy, where the availability of both highly depend on the local environment. Additionally, many thermally driven heat pumps typically incur larger capital costs due to the increased number of components and decreased power density, which are only sometimes offset by the reduced operating costs. To bridge this gap, continued research and development in fundamental heat and mass transfer, component development, and cycle design and control are required to further reduce capital costs and increase power density.

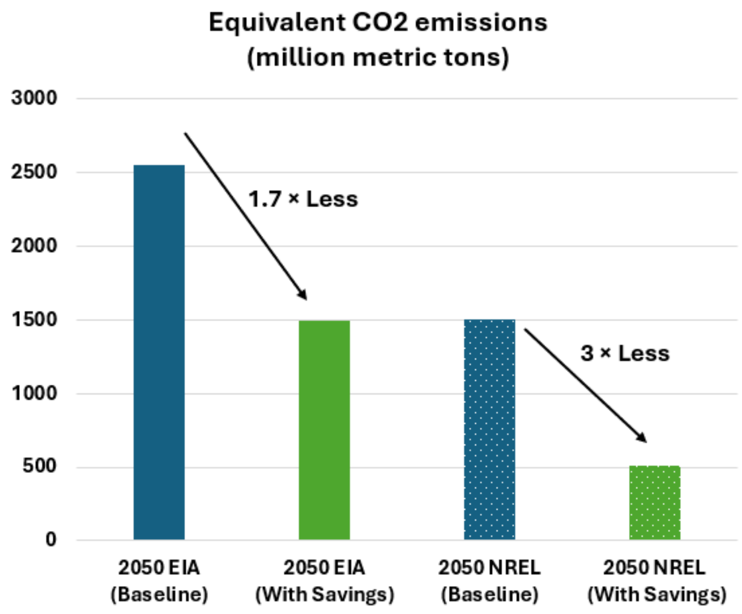


**Fig. 1** Projected reduction in carbon emissions in the United States by utilizing all available thermal energy in the residential sector, using the approach as described in Garimella et al. [6].

## 5. CONCLUSIONS

The reach of heat pumps to decarbonize several applications was explored. Recent advances in component development and system-level integration of thermally driven heat pumps have allowed for efficient and carbon neutral space conditioning, food storage, thermal energy storage, and water purification. Combining all the possible end uses of heat pumps to decarbonize the electric grid could yield up to 3-fold reduction in carbon emissions as the world approaches its goal of net zero carbon emissions.

## REFERENCES

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