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The key role of propane in a sustainable cooling sector

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Split air conditioners (ACs) are the most used appliance for space cooling worldwide. The phase-down of refrigerants with high global warming potential (GWP) prescribed by the Kigali Amendment to the Montreal Protocol has triggered a major effort to find less harmful alternative refrigerants. HFC-32 is currently the most common refrigerant to replace HFC-410A in split ACs. The GWP of HFC-32 is about one-third that of HFC-410A but still considerably higher than that of a growing number of nonfluorinated alternatives like propane with a GWP of <1, which have recently become commercially available for split ACs. Here, we show that a switch to propane as an energy-efficient and commercially available low-GWP alternative in split ACs could avoid 0.09 (0.06 to 0.12) °C increase in global temperature by the end of the century. This is significantly more than the 0.03 (0.02 to 0.05) °C avoided warming from a complete switch to HFC-32 in split ACs.

hydrofluorocarbon | Kigali Amendment | split air conditioners | low-GWP alternatives | propane

Split air conditioners (ACs) are currently the most used appliance for space cooling worldwide (1, 2). In 2016, space cooling accounted for around 10% of total electricity demand worldwide (2). If the current trends continue, the energy demand from air conditioners would more than triple by 2050 and the stock of ACs would increase from about 0.9 billion in 2017 to over 3.7 billion in 2050 (Fig. 1*A*). The significant climate impact of split ACs does not only come from a mainly fossil fuel–based electricity supply but also results from the widespread and rapidly growing use of halogenated refrigerants such as HCFC-22 (global warming potential over 100 y [GWP_{100}] = 1,960) and HFC-410A (GWP_{100} = 2,256), which today have a significant share of the overall greenhouse gas (GHG) emissions caused by split ACs (3). Many HFCs have a very high GWP (4) and are subject to global phase-down under the Kigali Amendment (KA) (5, 6). In advance of KA obligations, several split-AC manufacturers have turned to HFC-32 (GWP_{100} = 771) as a lower GWP alternative to HFC-410A. However, the GWP of HFC-32 is still higher than that of a growing number of low-GWP refrigerants introduced commercially in the years following the introduction of HFC-32 in the refrigerant landscape.

For a number of years Asian and European manufacturers have been using the natural refrigerant propane (also known under its commercial name HC-290 with GWP_{100} <1) in hermetically sealed portable ACs. Energy-efficient split ACs using propane as a low-GWP alternative to HFC-410A (or HCFC-22) are commercially available in the Chinese and Indian markets and account for about 2% of annual sales of split ACs in India (7). Split ACs using propane perform similarly to those using HFC-32 (8) and are more efficient than currently widespread appliances using HFC-410A and HCFC-22 (7–10). Furthermore, split ACs based on propane perform better in warm climates (9). An assessment of the Life Cycle Climate Performance studies indicates that ACs using propane have the lowest climate impact compared to other low-GWP alternatives of HFC-410A in this sector (11), primarily due to the lower refrigerant emissions (during the usage phase in the equipment's lifetime and end-of-life phase) followed by lower energy consumption as compared to other low-GWP alternatives (12). Further details are provided in *SI Appendix*. In comparison to HFC-410A–based units, propane split ACs have higher production costs by about 6 to 10% (7–9), because they need additional safety measures. However, their operating costs are lower since they are more efficient and use 40 to 60% less refrigerant (propane) than HFC-410A. In addition, HFC-32 is flammable, unlike HFC-410A, but propane is more flammable than HFC-32, and its flammability is rated at grade A3 (7, 8). We highlight the significant GHG mitigation potential and associated climate impact in terms of avoided warming while switching toward propane in split ACs instead of a continued use of fluorinated gases.

Results

With the continued use of HFC-410A refrigerant in split ACs, our estimates show that global annual HFC emissions from split ACs would increase from 0.4 Gt CO_2eq in

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The authors declare no competing interest.

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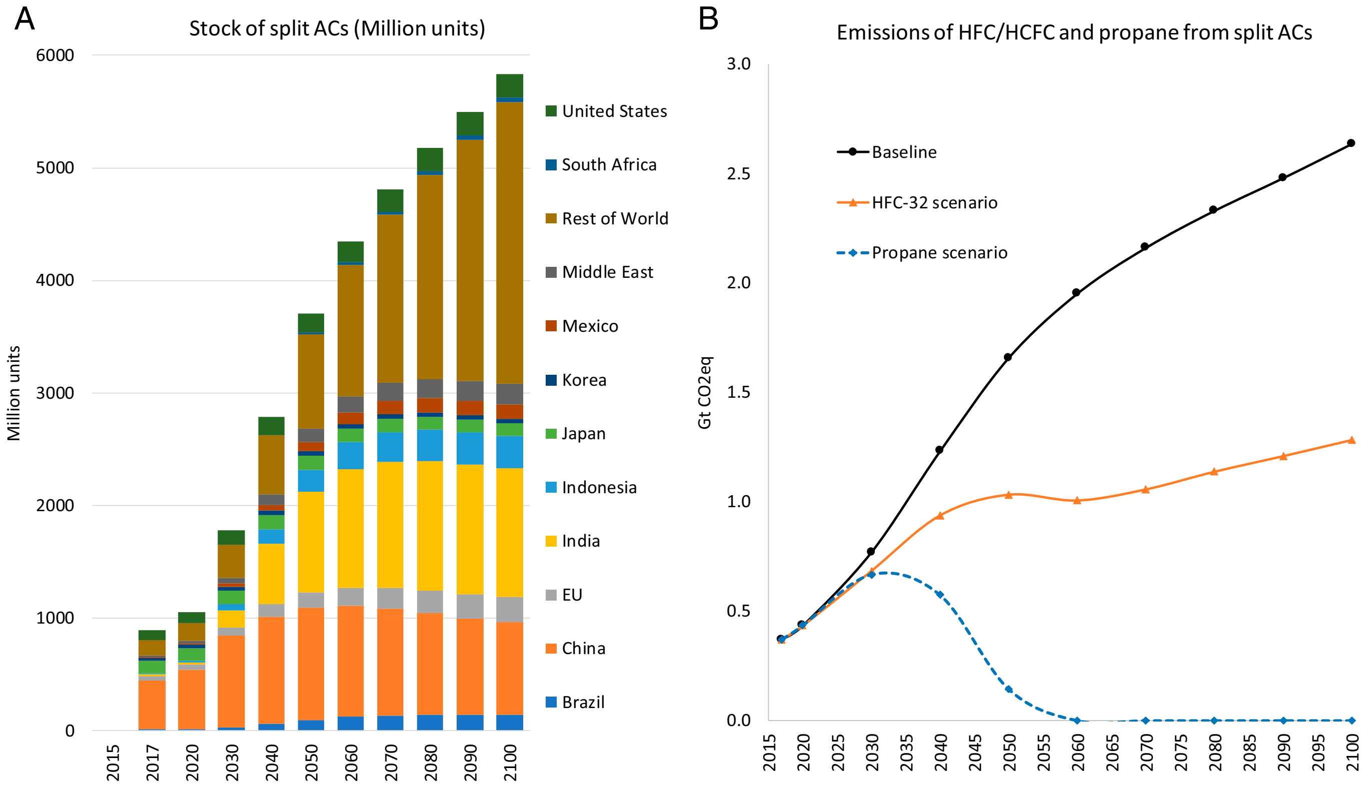

Fig. 1. Stock and emissions from split ACs. (*A*) Stock of split ACs and (*B*) emissions of HFC/HCFC and propane from split ACs.

2017 to 1.7 Gt CO_2eq in 2050 and 2.6 Gt CO_2eq in 2100 (Fig. 1*B*). Transitioning to HFC-32 in split ACs would reduce these emissions on an annual basis by 38% in 2050 and 51% in 2100, whereas switching to propane would reduce them by nearly 100% in 2060. Transitioning from HFC-410A to HFC-32 can reduce the global cumulative HFC emissions from split ACs by 44% between 2017 and 2100, whereas adoption of propane could instead achieve a cumulative reduction by 88% over the same period. Fig. 2 presents the climate impact of the adoption of propane or HFC-32 as alternative refrigerants relative to the "baseline" HFC-410A scenario. A full switch toward propane in split ACs will avoid 0.09 (0.06 to 0.12) °C increase in global temperature by the end of the century, whereas the replacement of HFC-410A with HFC-32 would avoid 0.03 (0.02 to 0.05) °C warming.

Discussion

Market assessments (13) show that accelerating the transition to more energy-efficient split ACs, propane as a refrigerant can play a key role in creating a more sustainable split AC sector. Propane exhibits significant environmental advantages through good energy performance and a GWP close to zero. A recent study by the European Commission (7) concluded that propane in split ACs up to 7 kW can be classified as a technically valid alternative to HFC-driven split ACs; however, some national regulations prohibit their use, primarily due to regulations restricting the use of refrigerants with higher flammability. Leapfrogging from HCFC-22 or HFC-410A units to high-efficiency appliances using propane reduces energy consumption and GHG emissions (10) and thus provides a significant opportunity to contribute to national climate action plans. For example, to achieve the European Union's ambitious 2050 climate neutrality targets, early and aggressive action is needed. In the short-term, converting new air-conditioning systems to more environment-friendly refrigerants can reduce their climate impact significantly. As time is running out to avoid climate tipping points (3), propane could be deployed in small AC units (<7 kW) faster than it will become available for larger-capacity systems ensuring proper safety, standards, and training.

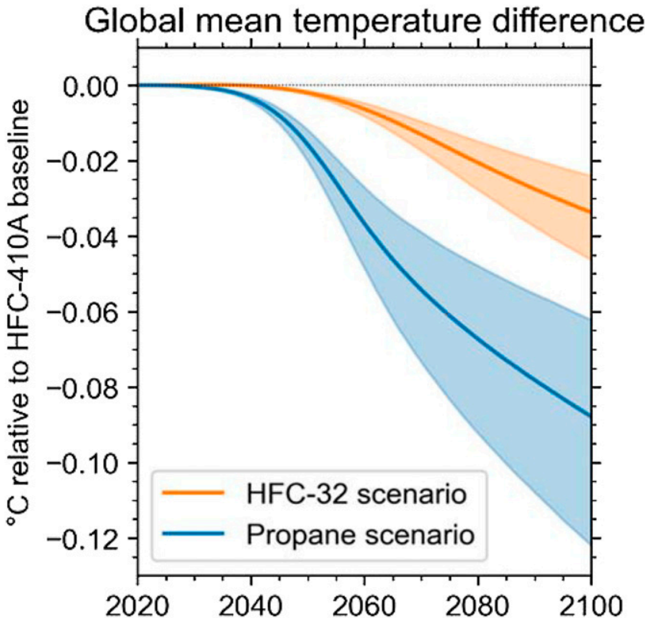

Fig. 2. Model-simulated temperature differences relative to the HFC-410A baseline for scenarios that transition toward HFC-32 (orange) and propane (blue) in the split-AC sector. Shaded regions represent the 5 to 95% uncertainty range around the best estimate due to uncertainties in climate response and radiative forcing.

Materials and Methods

For this study, baseline HFC emissions in the split-AC sector have been developed using the GAINS methodology (14). To analyze the impact of low-GWP alternatives two additional scenarios considering a transition toward HFC-32 and propane have been developed. Further details are provided in *SI Appendix*. The pathways derived from the HFC-410A baseline, and the replacement of split-AC refrigerants with HFC-32 and propane, are run in the emissions-driven FaIR climate model emulator (15, 16). Emissions of other species (e.g., CO_2) follow the SSP2-4.5 pathway (17). For the scenario of transition toward propane, we have added the propane emissions to the global total of emitted volatile organic compounds. This affects ozone formation and contributes a small positive forcing, but this increase is an order of magnitude smaller than the reduction in HFC forcing by elimination of HFC-410A.

Data, Materials, and Software Availability. Climate assessment data have been deposited in Zenodo (https://doi.org/10.5281/zenodo.6538428) (18).

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