Opportunities for Simultaneous Efficiency Improvement and Refrigerant Transition in Air Conditioning

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Key Findings

- Urbanization, electrification, increasing incomes, and falling air conditioner prices are expected to have a large-scale impact on both the direct emissions from refrigerant leakage and the indirect emissions from energy consumed by AC systems.
- Improving China's MEPS will have large downstream impact given that it accounts for ~40% of global AC sales and produces ~70% of global supply.
- India, Brazil, and Indonesia also account for roughly 10% of global AC sales with expected growth rates of ~10+% per year.
- China, India and Thailand are major global manufacturers.
- Existing standards and labeling requirements for room ACs have either significant room for improvement, are outdated, or are currently under development.
- Combining fixed-speed and variable-speed AC categories can help reduce future energy use by accounting for large seasonal variations in climate and part-load operating conditions
- Increased levels of AC ownership will also affect needed electricity generation capacity and peak load, particularly in economies with expanding populations and hot climates.

Key Findings

- Shifting from the ‘low-efficiency technology and high-GWP refrigerants’ to ‘higher efficiency technology and low-GWP refrigerants’ would save between 340–790 GW of peak load globally in 2030.
- There is a significant opportunity to simultaneously raise the MEPS requirement and add in a voluntary or mandatory low-GWP criteria for ACs.
- Aligning timelines for standards work with timelines for refrigerant management plans can enhance coordinated policy actions.
- Market transformation programs such as bulk procurement programs are useful to drive down the costs of efficient technology through economies of scale.
- Maximizing the energy efficiency improvements of Montreal Protocol investments by coordinating efforts can help keeping costs low for consumers and manufacturers during equipment redesign and manufacturing line retooling for refrigerant transition.
- Updating standards and reviewing them periodically can ensure the effectiveness of MEPS and low-GWP criteria requirements in the market.
- The major perceived barriers to low-GWP alternatives include safety (i.e., flammability and toxicity), first cost and return on investment, and reliability.

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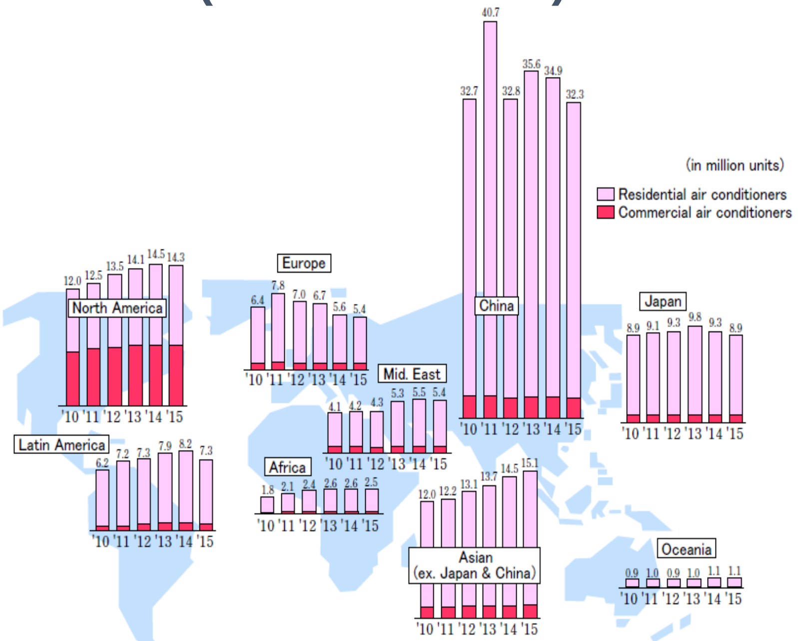
Summary of Global AC Market

AC demand by region between 2010 and 2015 (in million units)



Source: Japan Refrigeration and Air-Conditioning Industry Association, 2016.

- Air conditioner systems represent a ~100 million plus unit global market annually.
- Total demand for residential ACs was estimated by the Japan Refrigeration and Air Conditioning Industry to be about 79 million units in 2015.
- China alone was responsible for ~38% of the total global residential AC demand in 2015, followed by a ~17% share for other Asian economies, excluding Japan.
- Room AC systems generally range in capacity from 1.75–18 kWth (0.5 to 5 refrigeration tons) and can be centralized to serve the entire home or distributed to serve individual rooms.
- Individual room (i.e., window, mini-split and portable) AC systems are common throughout most of the world. About ~83% of the global room AC demand is for mini-split ACs.

Room AC Demand in 2015

- A5 Parties shown below together represent 65% of the global demand for room ACs.

	Room AC Demand	Split ACs	Fixed or Variable (inverter)	Refrigerant
China	30.2M	~99%	Variable (~65%)	R-22, R-410A
India	3.9M	~82%	Variable (~10%)	R-22, R-410A, R-32, R-290
Other Asia Total	9.8M	~89%	Fixed-speed dominant (~90%)	R-22 dominant
Indonesia	2.1M	~100%	Fixed (~95%)	R-22, R-410A, R-32 (~40%)
Vietnam	1.6M	~100%		R-22 (~60%), R-32 (~20%)
Thailand	1.3M	~100%	Fixed (82%)	R-22, R-32 (~50%)
Malaysia	0.8M	~100%	Fixed-speed dominant	R-22 dominant, R-32 (starting)
Philippines	0.7M	~35%		R-22 (~70%), R-32 (starting)
Pakistan	0.6M	~95%		
Bangladesh	0.2M	~82%		
Latin America Total	6.6M	~77%	Fixed-speed dominant	
Brazil	3.4M	~80% (small ACs)	Fixed (~90%)	
Argentina	1.2M	~90%		R-410A dominant
Mexico	0.9M	~65%	Fixed-speed dominant	R-22 dominant, but transitioning to R-410A
Venezuela	0.3M	~76%		
Chile	0.1M	~64%		
Africa Total	2.3M	~85%		R-22 (~90%)
Egypt	0.7M	~90%		
Nigeria	0.5M	~82%		
South Africa	0.2M	~84%		
Middle East Total	4.7M	~50%		
Saudi Arabia	2.0M	~34%		
UAE	0.6M	~46%		

Common Refrigerants Used in Room ACs

- Commonly used refrigerants in room ACs:

Type	Refrigerant	Safety Class*	GWP 100 Years**	ODP
HCFC	R-22	A1	1,760	0.034
HFC blends	R-410A	A1	1,900	None
	R-407C	A1	1,600	None

Notes:
* The A1 safety class is for refrigerants that are non-flammable and of lower toxicity. See "Refrigerant safety classes in ASHRAE Standard 34-2013" in slide 8 for more details on the definition of the A1 safety class.
** GWP over a 100-year time horizon, as defined in IPCC5 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report

- Under the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, Hydrochlorofluorocarbons (HCFCs) were scheduled to be completely phased out by 2030 in non-A5 and A5 parties (with a small servicing tail of only 2.5% allowed from 2030–2040).
- Hydrofluorocarbons (HFCs) are used as alternatives to CFCs and HCFCs. HFCs do not contain any chlorine atoms and have near-zero ozone depletion potential (ODP), unlike CFCs and HCFCs, but many of them are very powerful greenhouse gases (GHGs)—up to thousands of times more damaging to the climate than CO_2.
- In 2016, the Parties to the Montreal Protocol adopted the Kigali Amendment to the Montreal Protocol to agree on a global schedule for phasing down HFC refrigerants.

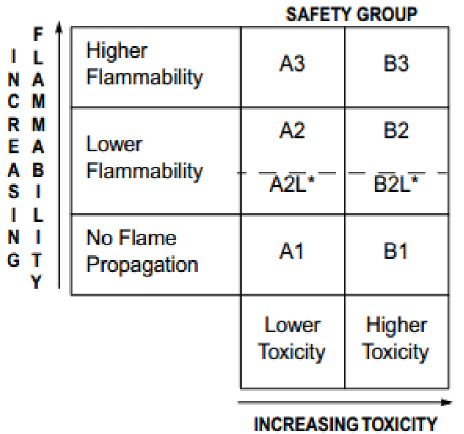
Low-GWP Refrigerant Alternatives for Room ACs

- Low-GWP refrigerant alternatives considered for room air conditioners:

Refrigerant	Proposed to replace	Safety Class	GWP 100 Years
HFC-32 (R-32)	R-404A, R-410A	A2L	677
HC-290 (R-290)	R-22, R-404A, R-407C	A3	5
HC-1270 (R-1270)	R-22, R-407C	A3	2
R-444B	R-22, R-404A, R-407C	A2L	300
R-446A	R-410A	A2L	460
R-447A	R-410A	A2L	570
R-452B	R-410A	A2L	676
ARM71-a	R-410A	A2L	460
ARM20-b	R-410A	A2L	251

Notes:
We are using the term "low-GWP" here and henceforth throughout the report to mean lower than the baseline refrigerant it is replacing

Refrigerant safety classes in ASHRAE Standard 34-2013



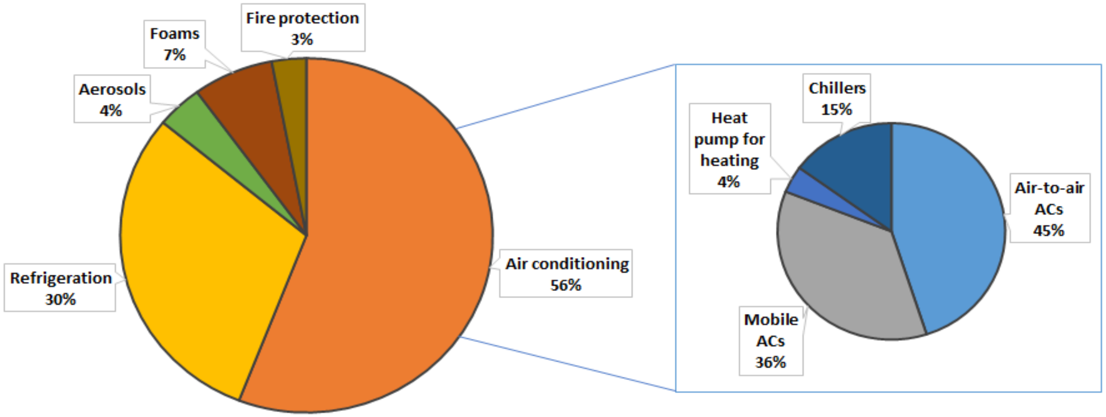
* A2L and B2L are lower flammability refrigerants with a maximum burning velocity of ≤ 3.9 in./s (10 cm/s).

- ACs with R-32 are produced by a number of manufacturers in China, Indonesia, Japan, Thailand and other parties.
- ACs up to 5 kW with R-290 are already commercialized in China and India, and are expected to penetrate the global market.
- R-1270, R-444B, R-446A, R-447A, R-452B, ARM71-a, and ARM20-b have also been considered as low-GWP refrigerant alternatives for ACs, although there has not been much interest from AC manufacturers to date.

HCFC Phase-out Management Plans (HPMPs) and Kigali Amendment

- Most of the signatory parties to Montreal Protocol have already met their targets for Stage I of the HCFC Phase-out Management Plans (HPMPs).
- The Executive Committee of the Multilateral Fund of Montreal Protocol stated that it is expected that for approximately 95 A5 Parties Stage II HPMPs will address: (1) the remaining HCFC consumption mainly in the room AC sector and (2) those remaining HCFC-based manufacturing sectors not addressed in Stage I for Parties with HCFC manufacturing.
- In the 28th meeting of the parties to the Montreal Protocol, all 197 Parties adopted the Kigali Amendment to the Montreal Protocol and agreed to reduce HFC emissions by 85% by establishing a schedule for all non-A5 and A5 Parties to phasedown HFC production and use.

Markets using HFCs, % of tonnes CO_2e 2012



Source: United Nations Environment Programme (UNEP) Ozone Secretariat (2015).

Current HPMP Status for selected A5 Parties

Party	HPMP Stage I	HPMP Stage II	Baseline Consumption (ODP tonnes)
Argentina	17.5% by 2017 –implementation of the second tranche	unknown	401
Brazil	10% by 2015 –implementation of the fifth tranche	35% reduction target by 2020	1,327
Chile	10% by 2015 –implementation of the fifth and final tranche	35% in 2020 –implementation of the first tranche	88
China	10% by 2015	35% reduction target by 2020	18,865
Egypt	10% by 2015 –implementation of the second tranche	unknown	386
Indonesia	20% by 2018 –implementation of the third tranche	35% and 50% in 2020 and 2023 –implementation of the first tranche	404
India	10% by 2015 –implementation of the third tranche	67.5% in 2022 –implementation of the first tranche	1,608
Malaysia	15% by 2016 –implementation of the third tranche	unknown	516
Mexico	10% by 2015 – final	67.5% in 2022 –implementation of the second tranche	1,149
Nigeria	10% by 2015 –implementation of the fifth and final tranche	unknown	345
Pakistan	10% by 2015 – completed	35% in 2020 –implementation of the first tranche	247
Philippines	35% by 2020	unknown	162
Saudi Arabia	40% by 2020 –implementation of the fourth tranche	unknown	1,469
South Africa	35% by 2020 –implementation of the third tranche	unknown	370
Thailand	15% by 2018 –implementation of the third tranche	unknown	928
Venezuela	10% by 2015 – completed	35% in 2020 –implementation of the first tranche	186
Vietnam	10% by 2015 –implementation of the third tranche	35% in 2020 –implementation of the first tranche	221

HFC Phasedown Schedule

	A5 Group 1	A5 Group 2	Non-A5
Baseline	2020-2022	2024-2026	2011-2013
Formula	Average HFC consumption	Average HFC consumption	Average HFC consumption
HCFC	65% baseline	65% baseline	15% baseline*
Freeze	2024	2028	-
1st step	2029 – 10%	2032 – 10%	2019 – 10%
2nd step	2035 – 30%	2037 – 20%	2024 – 40%
3rd step	2040 – 50%	2042 – 30%	2029 – 70%
4th step			2034 – 80%
Plateau	2045 – 80%	2047 – 85%	2036 – 85%

Source: Ozone Secretariat Conference Portal, 2016.

* For Belarus, Russian Federation, Kazakhstan, Tajikistan, Uzbekistan 25% HCFC component of baseline and different initial two steps (1) 5% reduction in 2020 and (2) 35% reduction in 2025.

Notes:

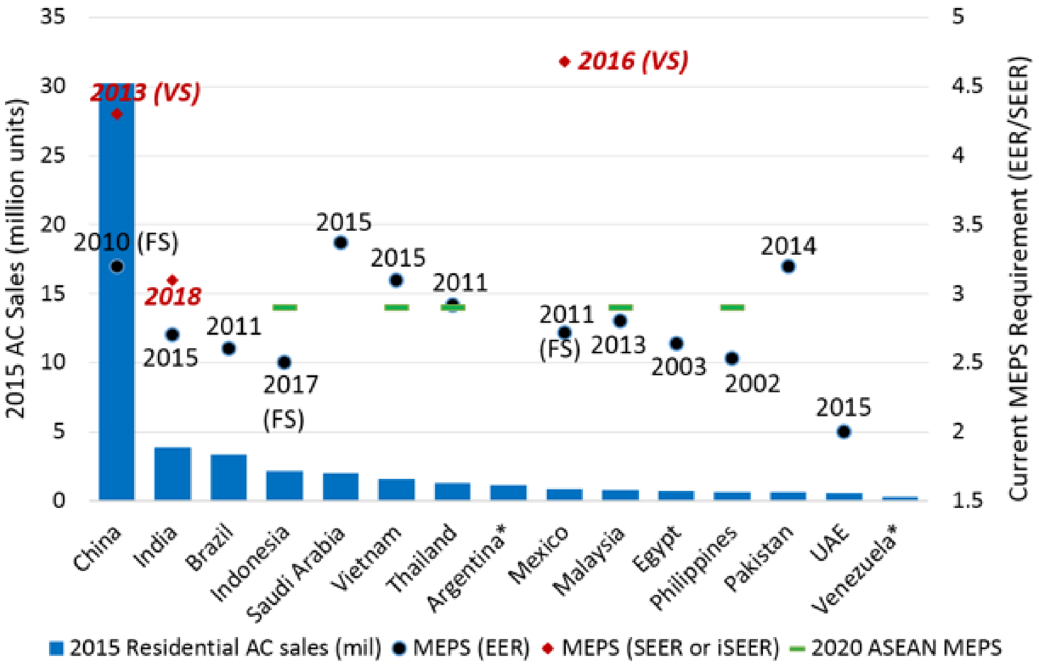
1. Group 1: Article 5 parties not part of Group 2
2. Group 2: GCC (Saudi Arabia, Kuwait, UAE, Qatar, Bahrain, Oman), India, Iran, Iraq, Pakistan
3. Technology review in 2022 and every 5 years

Technology review 4-5 years before 2028 to consider the compliance deferral of 2 years from the freeze of 2028 of Article 5 Group 2 to address growth in relevant sectors above certain threshold.

- The earliest action on the above schedule is expected to be in 2019 in the non-A5 parties.
- The market is expected to move significantly faster than the above schedule, as with the previous CFC and HCFC transitions.

Global Summary of Room AC MEPS

- Existing standards and labeling requirements show significant room for improvement for room ACs:



- Some A5 Parties do not have MEPS requirements for ACs.
- Some A5 Parties have not updated their AC MEPS since the early 2000s, such as the Philippines and Egypt.
- Some A5 Parties, including China, Brazil, Thailand, Mexico for fixed-speed, Malaysia, and Pakistan, adopted their AC MEPS in the early 2010s, and all of these MEPS are due for a revision.

- Further improvement on China's MEPS would be critical given that it accounts for ~40% of global AC market sales and produces ~70% of global supply.
- India, Brazil, and Indonesia together also account for roughly 10 percent of the global AC sales market share with expected AC growth rates of over 10 percent per year with much lower stringency levels.

Impact of the Simultaneous Transition in Efficiency and Low-GWP Refrigerants on Peak Load

- Estimated peak load reduction (GW) in 2030 from 30% efficiency improvement and low-GWP refrigerant transition

	Reduction from Efficiency Improvement	Reduction from Refrigerant Transition	Reduction from Efficiency Improvement and Refrigerant Transition	Number of Avoided 500 MW Peak Power Plants
Brazil	14-32	2.3-5.4	15.4-36	31-72
Chile	0.44-1.0	0.1-0.2	0.5-1.1	1-2
China	118 -277	20-46	132-310	265-619
Colombia	1.9-4.3	0.3-0.7	2.1-4.8	4-10
Egypt	2.6-6.2	0.4-1.0	3.0-7.0	6-14
India	27.3-63.8	4.56 -10.63	31-71	61-142
Indonesia	17.8-41.5	3.0-7.0	20-46	40-93
Mexico	1.8-4.2	0.3-0.7	2.0-4.7	4-9
Pakistan	1.2-2.9	0.21-0.48	1.0-3.0	3-6
Saudi Arabia	1.7-4.0	0.3-0.7	2-4.4	4-9
Thailand	5.2-12.2	0.9-2.0	6-13.7	12-27
United Arab Emirates	0.71-1.7	0.1-0.3	0.8-1.9	2-4
Vietnam	5.8-13.4	1-2.2	6.4-15	13-30
Global	304-710	51-118	340-793	680-1,587

Source: Shah, N., Wei, M., Letschert, V., Phadke, A. (2015). Benefits of leapfrogging to superefficiency and low global warming potential refrigerants in room air conditioning. Energy Technologies Area. Lawrence Berkeley National Laboratory. LBNL-1003671.

Barriers to Alternative Refrigerants

- Safety is a key concern to expanded production and use of alternative refrigerants.
- Most low-GWP alternative refrigerants rated flammable or lower flammability that can cause ignition or explosion with accidental release.
- Studies conducted in Japan, China, and the U.S. for alternative refrigerants indicates that average risks associated with the use of the studied A2L refrigerants are significantly lower than the risks of common hazard events.
- Today's safety standards are under revision now to include the risk of A2L and A3 refrigerants in modern AC equipment.
- IEC standard 60335-2-40's safety requirements currently under revision, and new standards for A2L refrigerants are expected to be available in July 2017.
- Changing refrigerants also requires system design changes before a product can be commercialized; even for refrigerants as drop-in replacements, small refinements are needed.
- Performance test results of alternative refrigerants suggest that the initial cost barrier is addressable through both manufacturing advances and efficiency improvements that reduce lifecycle costs.
- Sectoral standards on installation, servicing, storage and transportation of R290 ACs are being developed and expected to be issued.

Conclusion

- Urbanization, electrification, increasing incomes, and falling air conditioner prices are expected to have a large-scale impact on both the direct emissions from the chosen refrigerants and the indirect emissions from energy consumed by AC systems.
- A simultaneous focus on efficiency improvement and transition to the use of low-GWP alternative refrigerants in new ACs can maximize the reduction of energy, peak electricity, and GHG emissions associated with air-conditioning use and minimize the cost of doing so.
- Existing standards and labeling requirements for room ACs have either significant room for improvement, are outdated, or are currently under development.
- Adding low-GWP criteria to MEPS that apply to entire market provide opportunity at a large-scale, with possibility for faster market transformation through labeling and procurement programs.
- Improving China's MEPS holds large downstream impact given that it holds 40% of global AC market sales and produces 70% of global supply.
- Using SEER instead of EER may better approximate annual average efficiency of ACs by accounting for performance during part-load conditions.
- Increased levels of AC ownership will also affect needed electricity generation capacity and peak load, particularly in economies with expanding populations and hot climates.

Conclusion

- Combining fixed-speed and variable-speed AC categories can help reduce future energy use by accounting for large seasonal variations in climate and part-load operating conditions.
- Aligning timelines for standards work with timelines for refrigerant management plans can enhance coordinated policy actions.
- Market transformation programs such as bulk procurement programs are useful to drive down the costs of efficient technology through economies of scale.
- Maximizing the energy efficiency improvements of Montreal Protocol investments by coordinating efforts can help keeping costs low for consumers and manufacturers during equipment redesign and manufacturing line retooling for refrigerant transition.
- Updating standards and reviewing them periodically can ensure the effectiveness of MEPS and low-GWP criteria requirements in the market.
- The major perceived barriers to low-GWP alternatives include safety (i.e., flammability and toxicity), first cost and return on investment, and reliability.

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More Information

Full report can be downloaded from

http://escholarship.org/uc/item/2r19r76z

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