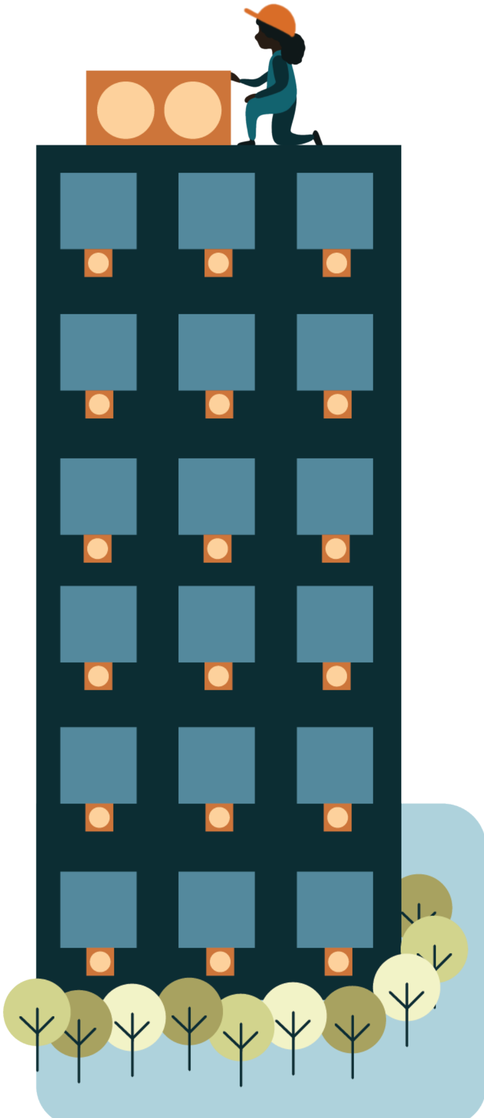
environmental investigation agency



Enabling Ultra-low GWP Cooling and Heating: Updating U.S. Safety Standards and Codes

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This briefing was authored by EIA US in collaboration with Daniel Colbourne, Re-phridge Ltd, for analysis of R-290 charge size needs for the U.S. market.

Table of Contents

Key Acronyms

AC	Air Conditioning
ACL	Allowable Charge Limit
AHRI	Air Conditioning Heating and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTU	British Thermal Units
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefins
HP	Heat Pump
IAPMO	International Association of Plumbing and Mechanical Officials
ICC	International Code Council
IEC	International Electrotechnical Commission
LFL	Lower Flammability Limit
MCL	Maximum Charge Limit
NCC	Nominal Cooling Capacity
NHC	Nominal Heating Capacity
PFAS	Per- and Polyfluoroalkyl Substances
SEER	Seasonal Energy Efficiency Ratio
THC	Technical Harmonization Committee
UL	Underwriters Laboratories

Introduction

As companies develop next generation cooling and heating systems to sustainably meet growing needs around the world, opening up the US market to a broader suite of refrigerant options will enable manufacturers to produce best-in-class technologies, enhancing their leadership and market competitiveness in the global air conditioning and heat pump (AC/HP) sector.

Hydrocarbon-based refrigerants such as propane (R-290) are highly thermodynamically suited for AC/HP applications, cost-effective, and have ultra-low global warming potentials (GWPs), i.e., 100-yr GWP <10. The primary challenge faced by hydrocarbons is the need to incorporate modernized safety requirements in standards and codes.

This briefing and technical analysis herein, outlines the US safety standard and codes process and a feasible path to allow the safe and economically sustainable use of hydrocarbons in a significant majority of new equipment for the US residential and commercial AC/HP sector in various equipment types between 2030 and 2035. Expanded safety research is underway to support harmonization of key US safety standards promulgated by UL (Underwriters Laboratories) and ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) with international standards, and the process for adoption into legislation and regulations codifying these standards in state and local building codes can be expedited and streamlined.

Fully harmonizing the refrigerant safety requirements in two US key safety standards - UL 60335-2-40 and ASHRAE-15 - with International Electrotechnical Commission (IEC) 60335-2-40 provides a realistic path forward. Analysis on R-290 charge size needs concludes that **fully harmonizing with IEC 60335-2-40 would meet the needs for efficient design of between 78-88% of existing US sales of central AC/HP units.**

Several new safety research projects are anticipated to yield timely data for standard and code experts in the coming months. This **new safety research and testing data must be taken up by the newly formed UL technical harmonization committee (THC) that will develop Edition 5 of UL 60335-2-40.** At minimum, members of the UL THC should develop proposals addressing self-contained and indirect systems ("partial harmonization") in UL & ASHRAE standards by 2027 for incorporation into the 2030 model building codes. Addressing the majority of the AC/HP sector will require *full* harmonization with IEC 6-335-2-40, including ducted central AC/HPs and mini-splits. The scope of safety research and testing projects should be expanded with this in mind. Finally, states and local jurisdictions that streamline approval of updated standards in legislation and codes can permit broader adoption of hydrocarbons in new equipment by as soon as 2030.

Transitioning to Ultra-low GWP AC/HPs

The cooling sector has undergone several refrigerant transitions in the past few decades primarily due to environmental risks. The US market for new AC/HPs for residential and light commercial space conditioning and hot water is now transitioning primarily to lower flammability (A2L) hydrofluorocarbons (HFCs) and hydrofluoroolefins (HFOs) such as R-32 and R-454B. These have been introduced as transitional alternatives to meet the near-term reduction in supply of HFCs under the Montreal Protocol's global HFC phase-down and bipartisan federal legislation. Yet, their GWPs remain far too high to meet market needs and climate goals in the coming decade. HFOs also face significant uncertainty due to their degradation by-products and persistence in the environment. Most HFOs are classified as per- and polyfluoroalkyl substances (PFAS) under various regulatory regimes and are coming under increasing public scrutiny. Achieving environmental and economic sustainability, investment certainty, and ending the iterative cycles of refrigerant transitions necessitates wider adoption of alternatives that are both ultra-low GWP (<10) and non-PFAS.

Hydrocarbon-based refrigerants including R-290 and R-600a have GWPs of <1 and have been shown to be highly energy efficient. They are seeing increased market acceptance globally, including for residential and light commercial refrigeration equipment and transport air conditioning. R-290 has also been widely adopted throughout Europe in indirect air-to-water heat pumps (monoblocs), and has been commercialized to a more limited extent globally in mini-splits and ducted systems.

There are several potential scopes and paths forward for US safety standards and codes to consider A3 refrigerants. Current research and testing projects are prioritizing a narrow consideration only in self-contained equipment and indirect systems. This includes room AC/HPs, heat pump water heaters, and residential monobloc air-to-water HPs. However, the most common AC/HP systems in the US building stock are ducted systems. The proportion of new homes being built with central ACs and ductwork has risen in recent decades from around 80% in 2000 to over 97% in 2022.[1] This proportion is much greater in the US than in other regions around the world where ductless split or indirect air-to-water systems are more common. Addressing the US market requires a focus on residential ducted units (most commonly single splits) and commercial packaged rooftop units.

Expanded safety research and testing and full harmonization with the most recent edition of IEC 60335-2-40 offers a second realistic path forward, which analysis concludes would enable 78-88% of new equipment sales in the US AC/HP sector to transition to hydrocarbons.

[1] Kuo, F.-Y. (2023, October 30). HVAC in New Construction in 2022. National Association of Home Builders. https://eyeonhousing.org/2023/10/hvac-in-new-construction-in-2022/

Safety Standards Background

Safety standards are intended to address many different risks associated with cooling and heating equipment, including electrical faults, high pressures and temperatures, toxic materials and others, including the flammability and toxicity of refrigerants. With regard to refrigerants, the standards employ a relative risk framework and several key mitigation concepts and requirements. These concepts have already been applied to enable safe adoption of R-32 and R-454B, which are classified as A2L or "lower flammability", and can be similarly applied to other flammable refrigerants classified as A2 or A3, or "higher flammability", including hydrocarbons.

A key concept for addressing flammability hazards is limiting the total refrigerant amount contained in a refrigerant circuit, or "charge size". This is done to prevent a refrigerant leak from forming a flammable concentration in the event of a major leak (i.e., a concentration exceeding the refrigerant's lower flammability limit (LFL) - the lowest concentration of a gas or vapor in the air that can sustain a flame when ignited by an ignition source). This maximum charge size amount varies depending on the safety classification of the refrigerants, the equipment type and where it is installed, the size of the indoor space (where applicable), and/or other complementary safety requirements to mitigate risk.

For direct expansion systems with refrigerant-containing parts connected to the occupied space, there is a capped maximum charge limit (MCL) amount combined with an allowable charge limit (ACL) per refrigerant circuit for a given piece of equipment, that is based on the refrigerant, LFL, and size of the space. The MCL and ACL are determined by a calculation that accounts for the safety classification of the refrigerant (A2L, A3, etc.), the LFL of the refrigerant, and specific equipment design and installation requirements. A3 refrigerants have lower LFLs (i.e., greater anticipated flammability risk when leaked outside the system) than A2Ls and therefore the MCL and ACL formulas will always produce lower capped charge limits for A3s relative to less flammable classifications such as A2L. A more conservative approach is taken for higher levels of flammability.

In principle, the flammability risk is not only defined by the LFL and the quantity of the refrigerant, but also numerous other factors that can either positively or negatively affect the level of risk. In recognition of this, various features can be applied to equipment that can be used to offset the risk associated with elevating the quantity of flammable refrigerant (of whichever class) within a particular situation. Such features include those that reduce the likelihood of leakage, those that more effectively dilute or exhaust releases, and those that lessen the severity of an unlikely ignition event. Accordingly, other requirements can be employed in standards and codes to increase the ACL and MCL while maintaining or reducing the associated flammability risks. These include installation requirements such as additional circulation airflow to dilute a leak, ensuring ventilation to exhaust leaked refrigerant from a given space, and the use of sensors to detect a leak and then close the associated valve(s) to limit the quantity of refrigerant released.

As described further in the following section, international standards have utilized these safety requirements, among others, to permit larger ACL and MCLs for both A2L and A3 refrigerants. In contrast, US standards have largely limited their application of these concepts to A2L refrigerants and have yet to conduct work focused on advancing safe use of A3 refrigerants.

Progress Under IEC 60335-2-40

International safety standards – particularly IEC 60335-2-40 for air conditioners and heat pump equipment – have advanced considerably further than US safety standards with regard to work on safely enabling A2/A3 refrigerants. After seven years of working group discussions, the 7th Edition of IEC 60223-2-40 was published in 2022 containing significant updates for A2L and A2/A3 refrigerants.[2] Conversely, recent updated editions of key US safety standards, UL 60335-2-40 and ASHRAE 15, have focused primarily on enabling A2L refrigerants, without significant work to address A3s.

The IEC and UL standards have three applicable categories for charge limit equations for fixed installation systems depending on the equipment design. There is a fourth applicable MCL for non-fixed, or portable, systems. These equations and resulting amounts for R-290 and R-32 under the IEC 60335-40 standard versus UL 60335-2-40 are outlined below in **Table 1.**

M1 is the most conservative MCL that applies to systems that have no requirements for mitigation. M2 is the charge limit that applies to typical direct expansion systems that meet certain additional safety requirements and resulting calculations for the ACL for a specific model. Under IEC 60335-2-40, up to 988 grams (nearly 1 kilogram) of R-290 is permitted to be used in a direct expansion system, with the refrigerant circuit located indoors or connected to the indoor space. The ACL for a given system, up to the maximum amount, is subject to additional safety requirements for minimum room size area and other equipment design requirements. The additional requirements considered by the IEC standard to safely use a higher ACL under M2 include:

- enhanced tightness of system design allows for application of a lower assumed leak rate (no compressor located indoors);
- restricting the releasable charge that can leak into the indoor space, for example through use of a leak detector that activates safety-shut-off valves;
- utilizing ventilation or airflow to dilute a leak below the LFL

[2] IEC 60335-2-40:2022. Retrieved March 6, 2025, from https://webstore.iec.ch/en/publication/62837; See also: Mouyal, N. (2022, June 15). Much Awaited New IEC Standard on Refrigerants. IEC E-Tech. https://etech.iec.ch/issue/2022-03/much-awaited-new-iec-standard-on-refrigerants

The third MCL, M3, applies for indirect systems with all the refrigerant-containing parts of the system located outdoors. There is no associated ACL approach with this category as it assumes very low probability of any refrigerant leak entering the occupied space. The IEC standard allows for up to 4.94 kilograms of R-290 in these systems. For indoor systems without fixed installation that may be stored in a confined space (i.e., a portable air conditioner), the standard allows a charge size of up to 304 grams of R-290.

In contrast, UL's most recent fourth edition of the 60335-2-40 standard limits the use of hydrocarbons to a single M1 MCL regardless of the equipment design (i.e., 114 grams for R-290). It does not consider any mitigation approaches or safety requirements to enable charge sizes in accordance with M2 or M3. The ASHRAE-15 standard also significantly restricts A3 refrigerant use in residential and commercial applications to less than 150 grams with any larger amount requiring a one-off approval by a local jurisdiction's code officials (the authority having jurisdiction, or AHJ).

Table 1. Maximum Charge Limits under IEC v UL Safety Standards for AC/HPs

Standard	ASHRAE 34 Refrigerant Safety Classification	Maximum Charge Limit (MCL)			
		Fixed installation			Non-fixed
		M1 (no mitigation)	M2 (minimum room size + other mitigation)	M3 (outdoors/ indirect systems)	
IEC 60335-2-40 Edition 7 (2022)	A2L	6xLFL=1.8kg R32	52xLFL=15.9kg R32	260xLFL=79kg R32	2xM1 = 3.68kg R32
	A2/A3	4XLFL=152g R290	26xLFL=**988g R290**	130xLFL=**4.94kg R290**	2xM1=**304g R290**
UL 60335-2-40 Edition 4 (2022)	A2L	6xLFL=1.8kg R32	52xLFL=15.9kg R32	260xLFL=80kg R32	1xM1=1.8kg R32
	A2/A3	3xLFL=**114g R290**	3xLFL=**114g R290**	3xLFL =**114g R290** (M1 as per Annex GG 2.1)	M1=**114g R290**

Analysis: R-290 Charge Size Needs for the US Market

Most air conditioners and heat pumps for residential and commercial applications currently utilize direct expansion systems. There remains a question as to the R-290 charge size needs of a given size or capacity of equipment and what portion of the current equipment on the US market that can be designed using less than 988 grams of R-290. Thus, an analysis approximating R-290 charge size requirements, particularly for the US market is useful to understand which equipment and what portion of the market could feasibly transition to R-290 if the UL and ASHRAE standards are harmonized with IEC. It can also highlight the potential incremental benefit of work to evaluate further extending charge limits beyond the current IEC standard.

A given charge amount of refrigerant is a key limiting factor in the maximum capacity of equipment that can be designed and operated at high efficiency.[3] A typical residential or light commercial AC requires about 3 pounds (1.3 kilograms) of R-410A per ton (or 12,000 BTU/hr) of cooling.[4] Equipment using R-290 typically requires only about 40-55% of the refrigerant charge compared with the same size equipment using R-410A on account of its lower liquid density.[5] [6] However, manufacturers increasingly pay attention to refrigerant charge reduction when applying flammable refrigerants, so compressors, heat exchangers, circuitry, etc. tends to be optimized for lower charges. Data from European products suggests that less than 0.7 pounds or 320 grams of R-290 are required per ton of 12,000 BTU/hr cooling capacity.[7] This is about a quarter to a third of the typical charge size of R-410A models.

This general estimation would suggest that roughly up to a 3.1ton unit can be designed with 988grams of R-290. Real-life experience, covered further in a case study on one manufacturer

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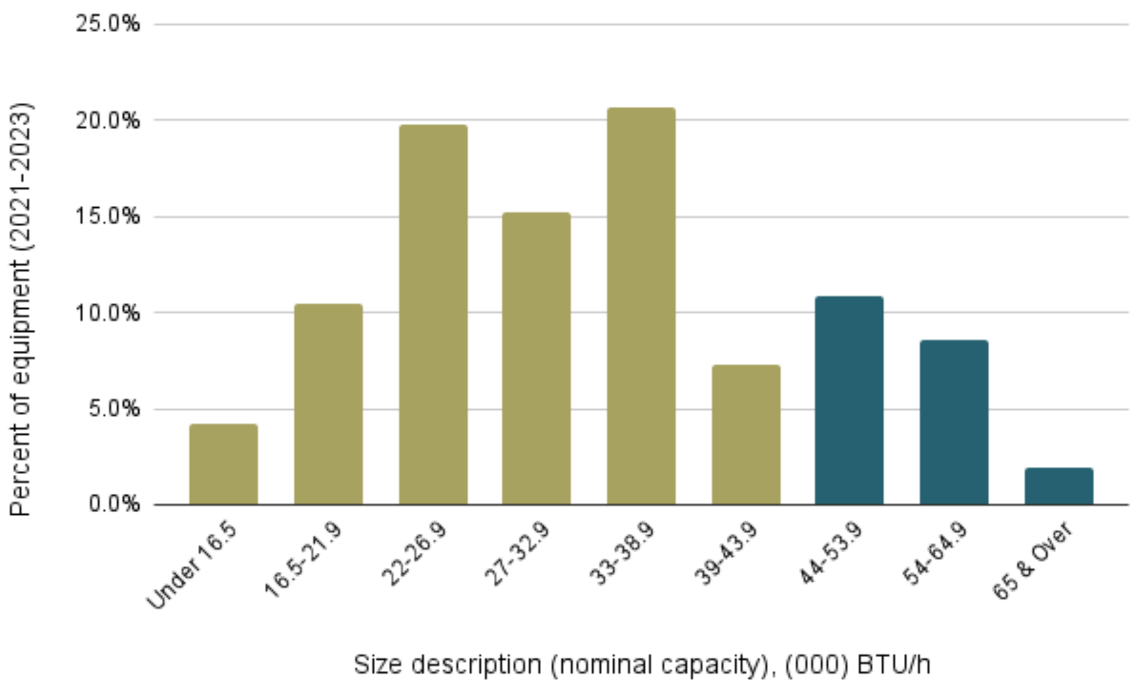
[3] In the US, the cooling or heating capacity of equipment is measured in British Thermal Units per hour (BTU/hr), also commonly expressed in tons where one ton is equal to 12,000 BTU/hr. Internationally, cooling capacity is typically expressed in kilowatts (kW).
[4] Calhoun, Tom. (2019, April 30). How Much Refrigerant? NWA Cooling and Heating. https://nwacoolingandheating.net/how-much-refrigerant/
[5] Frioflor. (2021). Advantages of R290 Refrigerant Over HFC Refrigerant. https://www.frioflor.com/Advantages-of-R290-refrigerant-over-HFC-Refrigerants-id3780111.html
[6] Angel Andrade, Juan Zapata-Mina, Alvaro Restrepo. Exergy and environmental assessment of R-290 as a substitute of R-410A of room air conditioner variable type based on LCCP and TEWI approaches. Results in Engineering. Volume 21, 2024. ISSN 2590-1230. https://doi.org/10.1016/j.rineng.2024.101806. https://www.sciencedirect.com/science/article/pii/S2590123024000598
NIST. Reference Fluid Thermodynamic and Transport Properties Database (REFPROP): Version 10. https://www.nist.gov/srd/refprop
UNEP. Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC 2022 Assessment Report). https://ozone.unep.org/system/files/documents/RTOC-assessment%20-report-2022.pdf
[7] Colbourne, D. (2022). Can Refrigerants with a GWP Below 150 be Used for Split Air Conditioners in Europe? Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.green-cooling-initiative.org/fileadmin/user_upload/2022_Proklima_Split_AC_Assessment.pdf

in Latin America later in this paper, suggests that ducted units can be designed up to 50,000 BTU or over 4 tons using less than 988grams of R-290.

Data published by the Air Conditioning Heating and Refrigeration Institute (AHRI) on new sales of central air conditioners and heat pumps classifies units based on their nominal rated capacity.[8] According to this data, approximately 78% of units sold from 2021-23 fall under 44,000 BTU, or approximately 3.6 tons (shown in green in **Figure 1** below). This general approach to estimating charge size needs relative to US equipment sales has significant limitations and can be further informed by more refined analysis of data on existing equipment using R-290.

Figure 1. US Sales of Central AC/HP Equipment (2020-2023) by Capacity based on AHRI data
Green - 78% of unit sales are in a capacity size less than that suggested to be feasible for R-290 design based on generalized assumptions of R-290 charge size needs and the following analysis



Approach and methodology

A correlation is developed utilizing European charge size data that assumes some optimization of refrigerant charges based on the sample (**Figures 2 and 3**). This correlation is then applied to the AHRI data on US equipment sales, accounting for a significantly expanded length of an

[8] AHRI Sales Data for 2020-2023 Central Air Conditioners and Air-Source Heat Pumps. (n.d.). AHRI. Retrieved March 6, 2025, from https://www.ahrinet.org/analytics/statistics/historical-data/central-air-conditioners-and-air-source-heat-pumps

additional 25 meters (82 feet) of refrigerant piping to approximate a reasonably conservative estimate for US market installations and common equipment types.

The methodology builds on work described in a previous study for European reversible split AC/HPs.[9] In that study, information on product nominal cooling capacity (NCC) or heating capacity (NHC), seasonal energy efficiency ratio (SEER), refrigerant type and charge amount (for a default 5meter (m) interconnecting piping), was used to characterize the specific refrigerant charge for a given piece of equipment (i.e., kilogram of refrigerant per kW of NCC or NHC); see **Figure 3**.

SEER measures the energy efficiency of cooling systems. It's calculated by dividing the total cooling output over a typical cooling season by the total energy consumed. A higher SEER rating means the system is more energy-efficient, using less energy to produce the same amount of cooling.

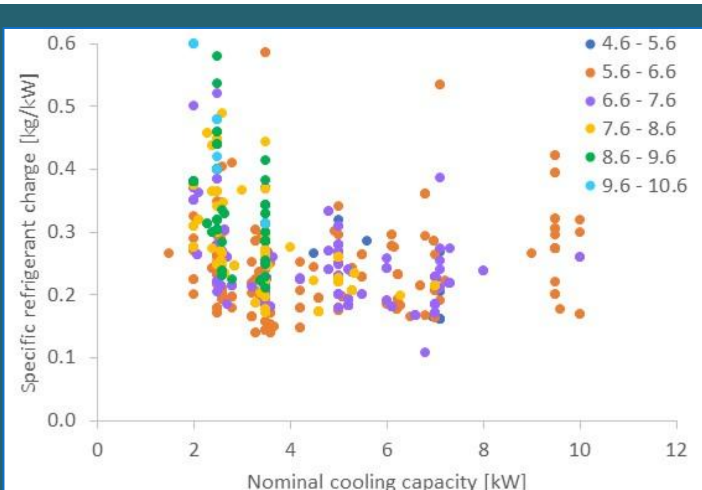


Figure 2. Specific refrigerant charge against NCC, across several incremental ranges of European SEER

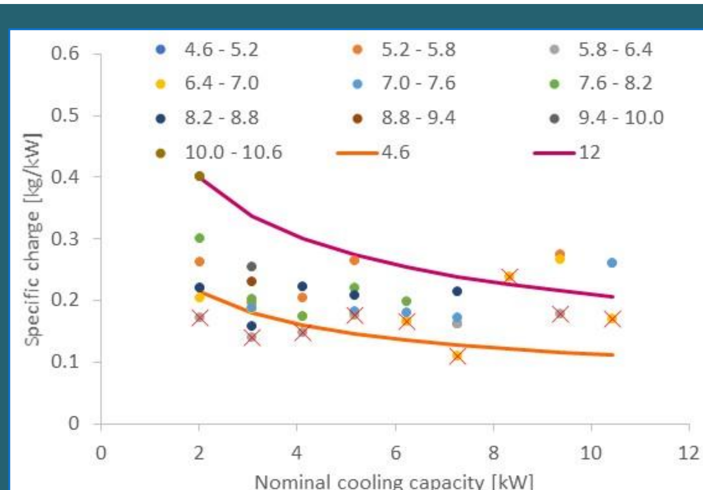


Figure 3. Minimum specific refrigerant charge against European SEER4.6 and 12

From this, an empirical correlation was used to approximate the lowest specific charge based on the AC/HP's European SEER. As many products had specific charges substantially greater than what is calculated with the correlation above, this calculation is considered to provide the best case arising from a manufacturer's concerted efforts for charge reduction. Whilst the correlation shows that the specific charge diminishes with larger NCC, since the source data

[9] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Dr. Daniel Colbourne. (June 2022).Can refrigerants with a GWP below 150 be used for split air conditioners in Europe? https://www.green-cooling-initiative.org/news-media/publications/publication-detail/2022/10/05/can-refrigerants-with-a-gwp-below-150-be-used-for-split-air-conditioners-in-europe

was only available for up to about 12 kW (40,950 BTU) or 20 kW (68,240 BTU) for R-290 systems, the specific charge for systems with a capacity larger than 12 kW (40,950 BTU) was fixed at that for 12 kW (40,950 BTU). The analysis estimates the specific charge for AC/HPs in the range of US SEER 14 to 24. EU SEER data from European units was converted to US SEER equivalent units of BTU/Wh using a factor of 0.293 to convert to W/W as with the European SEER and through a relational determination developed in a recent study.[10] This correlation is then applied to U.S. equipment sales data (2020-2023) collected by the AHRI on annual air conditioning and heat pump shipments from US manufacturers (excluding window and wall type units) according to their cooling or heating capacity.[11]

The AHRI data (**Figure 1**) includes package air conditioners, indoor package, package year-round air conditioners, split system, central air conditioners, package heat pumps and split heat pumps – of which most categories include air- and water-cooled. While the minimum specific charge methodology used may not necessarily be valid for all types within the AHRI data, in many cases the specific charge can be less than air-to-air systems. The opposite may be the case for multi-evaporator systems.

The limitations to this analytical approach include that (i) it does not account for differences in refrigerant use across system types/architectures, and (ii) underlying data on European split systems utilized to develop the correlation differs from the AHRI data on other types of more common US systems. For example, split systems requiring larger quantities of refrigerant depending on the length of refrigerant line sets to indoor units will use more refrigerant per BTU than a typical ducted single split unit. The +25m of piping is added to conservatively manage this limitation.[12]

Results

Figures 4 and 5 show the estimated R-290 charge for the proportion of systems corresponding to the incremental nominal capacity for systems with a SEER of 14 and 24 BTU/Wh. Each graph presents two data sets, one assuming 5 m of interconnecting refrigerant piping and the other with an additional 25 m (30 m total) interconnecting piping. This provides some indication as to what proportion of AC/HP systems are broadly viable within the context of certain refrigerant charge limits.

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[10] Park, W. Y., Shah, N., Choi, J. Y., Kang, H. J., Kim, D. H., Phadke, A. (2020). Lost in translation: Overcoming divergent seasonal performance metrics to strengthen air conditioner energy-efficiency policies. J. Energy for Sustainable Development, Vol. 55, pp. 56-68

[11] Central Air Conditioners and Air-Source Heat Pumps. (n.d.). AHRI. Retrieved March 6, 2025, from https://www.ahrinet.org/analytics/statistics/historical-data/central-air-conditioners-and-air-source-heat-pumps

[12] +25 meters (82 feet) is estimated based on approximate practical limitations for refrigerant line sets in split systems. 50 feet is a common industry benchmark thus this is considered a conservative estimate. https://www.hvacrpipe.com/blog/what-is-the-maximum-allowable-length-for-an-ac-line-set

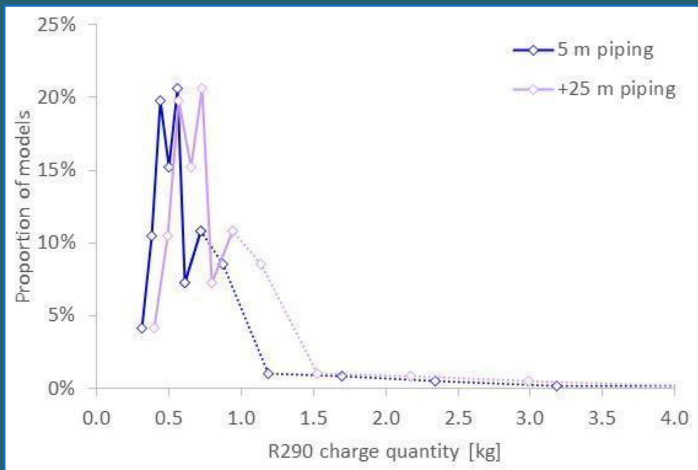

Figure 4. Proportion of models distribution for charge based on SEER_USA = 4.1 W/W (14 BTU/Wh) (SEER_EU = 5.6)

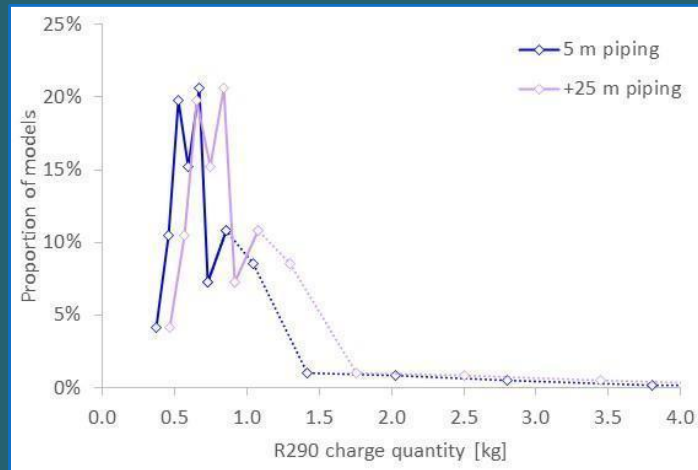

Figure 5. Proportion of models distribution for charge based on SEER_USA = 7.05 W/W (24 BTU/Wh) (SEER_EU = 7.4)

The proportion of AC/HP units that could fall under a current charge limit of nearly 1 kilogram and a greater proposed charge limit of 1.5 kilogram are shown in **Table 2**. For low SEER units, almost all products could be viable with the ~1 kilogram limit, but with a higher SEER, almost one-quarter would not be feasible, especially when considering longer interconnecting pipe lengths. However, in the case of a 1.5kilogram charge limit (equivalent to 40 × LFL) the vast majority could be satisfied.

Table 2: Proportion of units that could use R-290 below a specified charge limit

US SEER	4.1 W/W, 14 BTU/Wh		7.05 W/W, 24 BTU/Wh	
Charge limit	5 m piping	+25 m piping	5 m piping	+25 m piping
1.0 kilogram (current IEC 60335-2-40)	97%	88%	88%	78%
1.5 kilogram	98%	97%	98%	97%

The results of this analysis provide a useful estimation that harmonizing with the current international safety standard to allow a 988gram MCL - which has been developed with a decade's worth of research, testing, and international cooperation - can potentially transition 78 to 88% of US equipment on the market to ultra-low GWP A3 alternatives like R-290, including direct central ACs and HPs.

If US safety standards only partially harmonize with the IEC by addressing indirect systems, a widespread transition to A3s would mean the US will need to rely and invest heavily on replacing existing central AC/HPs with new system architectures such as air-to-water and hydronic systems where the A3 refrigerant can be contained outdoors and only water or a secondary heat transfer fluid enters the building. Even under full IEC harmonization, to enable R-290 in the remaining ~10-20% of equipment would either necessitate these systems designed as indirect systems or require further updates to safety standards.

To ensure full market coverage of higher capacity equipment above approximately 50,000 BTU/hr, the MCL for R-290 would need to be extended to at least 1.5 kilograms in the safety standards. Initial proposals to further extend charge limits to 1.5 to 2 kilograms have been introduced in the IEC committee, though in early stages and would require additional research and risk assessments to advance discussion. From a commercialization perspective, it is more cost-effective when all products within a specific product range can be manufactured to utilize the same refrigerant. For example, where a manufacturer has 10 products each of incrementally larger capacity, having to use a different refrigerant in the largest model would impose an additional financial detriment and thus another barrier to implementation that could potentially hinder market adoption.

This analysis also suggests that most products would require further optimization of charge sizes where the amount of refrigerant needed for a given equipment model/type is minimized. There has been ongoing national and international research on topics related to this optimization, such as using narrow-tube or microchannel heat exchangers[13] and optimized compressors. Further research and demonstration to optimize charge sizes would be supportive of a transition to R-290 or other A3 refrigerants. Ultimately, applied research and demonstration is needed to physically determine what is viable for different types of AC/HP systems.

Case Study: R-290 Ducted Split and Rooftop AC in Latin America

Real world equipment design using R-290 can also provide useful insight into potential market adoption in the US, where ducted systems are the norm in most US households and commercial occupancies. Thermotar, a manufacturer based in Colombia that also produces equipment for the US market, manufactures a limited number (100-200 per year) of R-290 ACs for the Latin American markets with capacity up to 5 ton/60,000 BTU/hr.[14] Depending on the model, Thermotar's Starlight ducted AC split systems utilize between 610 grams (35,830 BTU/hr), 820

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[13] See: Zanetti, Emanuele; Azzolin, Marco; Bortolin, Stefano; Busato, Giulio; and Del Col, Davide. (2018). "Design And Testing Of a Microchannel Heat Exchanger Working As Condenser And Evaporator" International Refrigeration and Air Conditioning Conference. Paper 2033. https://docs.lib.purdue.edu/iracc/2033
[14] Ibid.

grams (47,770 BTU/hr), or 1010 grams (59,710 BTU/hr) of R-290.[2] Their residential rooftop package system operates charge sizes between 590 grams (35,830 BTU/hr), 800 grams (47,770BTU/hr), and 990 grams (59,710 BTU/hr).[15]

This equipment is designed in accordance with applicable safety standards used in the region, such as the Colombian national standard NTC 6228 (which is broadly based on ISO 5149, with improvements).[16] Among the safety features included are hermetic design of the electrical box of the condensing unit to avoid interaction between electrical components and refrigerant in the event of a leak; electronic control cards and ultrasonic sensor for microleak detection in the evaporator unit; and a leak detection system that pumps down system in the case of a leak, disabling compression.[17]

In terms of cost, Thermotar R-290 systems are typically 10–15% more than those using A2L refrigerants.[18] This is primarily due to the higher cost of R-290 compressors, which can be overcome through expanded compressor manufacturing and economies of scale.[19] Thermotar's R-290 units offer significantly better efficiency and energy cost reductions over time, operating 30% more efficiently than R-410A equipment.[20]

This case study provides further demonstration of a rea-world application of R-290 showing that that ducted systems up to and above 50,000 BTU/hr can and have been designed with less than the 988 grams of R-290 allowed under IEC 60335-2-40, while achieving significant gains in energy efficiency. Given the limited number of units produced, it is likely that economies of scale would further reduce price differences with A2L units.

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[15] Colbourne, D. (2018, July 12). Development of Thermotar R290 Ducted Split and Rooftop Air-conditioning Units. 30th OEWG, Vienna. https://ozone.unep.org/system/files/documents/DEVELOPMENT%20OF%20THERMOTAR%20R290%20DUCTED%20SPLIT%20AND%20ROOFTOP%20AIR-CONDITIONING%20UNITS.pdf

[16] Barragán, Fabiola & Torres, Maria. (2023). Normas Técnicas Colombianas sobre el manejo seguro de sistemas de refrigeración y refrigerantes. Letras ConCiencia TecnoLógica. 29-39. 10.55411/26652544.241.

[17] Thermotar Manufacturing Group. (2023, December 1). Centralized Air Conditioning with Natural Refrigerant (R290)—Case Study | Green Transition in Private Sectors for Sustainable Cold Chain and Space Cooling. https://www.youtube.com/watch?v=zbi0MTegjHI

[18] Correspondence with Thermotar, April 2025.

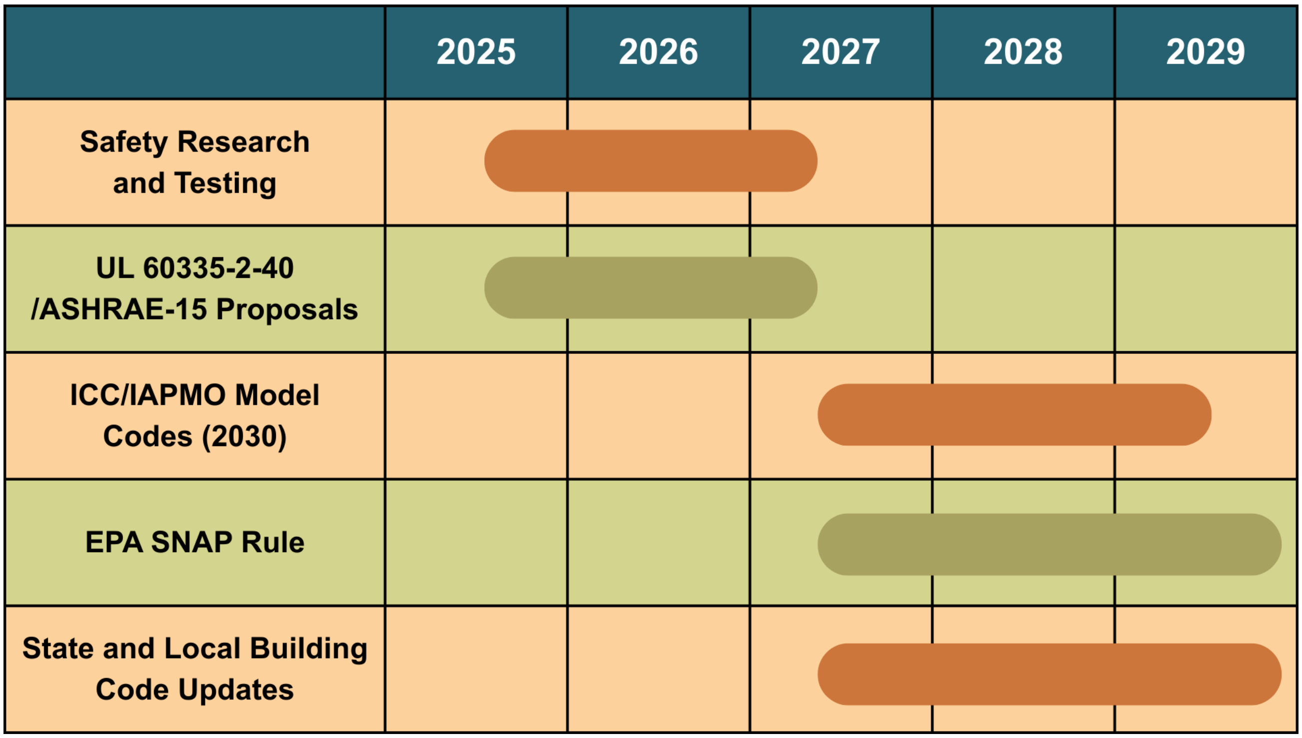
[19] GIZ. (2022). Can refrigerants with a GWP below 150 be used in split air conditioners for Europe? https://www.green-cooling-initiative.org/fileadmin/user_upload/2022_Proklima_Split_AC_Assessment.pdf R-600a compressors in domestic refrigerators are at not lower cost than HFC compressors.

[20] Thermotar Manufacturing Group. (2023, December 1). Centralized Air Conditioning with Natural Refrigerant (R290)—Case Study | Green Transition in Private Sectors for Sustainable Cold Chain and Space Cooling. https://www.youtube.com/watch?v=zbi0MTegjHI

Path Forward: US Safety Standards & Codes

Figure 6 outlines a feasible timeline for completing each step required to update the safety requirements for A3 refrigerants under US safety standards and codes. Further detail is provided below on the expectations for each step in this process and various potential outcomes for the scope of updates that may be completed by 2030.

Figure 6. Feasible Timeline for Standard and Code Updates



UL and ASHRAE Standards Committees

The path to enabling A3 refrigerants requires updates being made to both UL 60335-2-40 and ASHRAE-15 standards. These nationally recognized standards each have their own separate voting committees for approving updates and both can be updated on a continuous basis through continuous maintenance proposals. However, it is often the case that significant updates such as those that will be required for A3 refrigerants are considered and developed by specialized committees formed to discuss the next edition of the standard.

UL recently announced formation of a Technical Harmonization Committee (THC) to begin meeting in October 2025 to develop Edition 5 of UL 60335-2-40. This committee is expected to consider proposals on a range of topics related to equipment safety, including requirements related to flammable refrigerants. This presents an important near-term opportunity for stakeholders to engage in the process of developing proposals to enable A3 refrigerants in

AC/HP equipment for the US market. The UL THC proposals will ultimately need to be voted on by the UL 60335-2-40 standards technical panel before being published as Edition 5.

ASHRAE 15 and its sub-committee for residential systems ASHRAE 15.2 may also concurrently consider proposals for A3 refrigerants. A proposed Addendum e for residential indirect systems such as monoblocs was previously under consideration but not advanced by the ASHRAE 15.2 subcommittee pending additional safety research and testing data.

Safety Research and Testing

Several safety research and testing projects on A3s are now underway to inform standard and code developments. The projects include a combination of physical testing on leak scenarios and computational fluid dynamics (CFD) modeling and will consider safety mitigation approaches for equipment design and installation to evaluate their effectiveness in mitigating risks. Oak Ridge National Laboratory is undertaking two research projects on A3 refrigerants looking at self-contained AC/HPs and small to medium sized commercial chillers and air-to-water systems. The California Air Resources Board also recently released a Request for Proposals for a similar project that includes safety research into A3 refrigerants in residential air-to water or monobloc systems.[21]

It is imperative that these projects be carried out in close consultation with standard and code experts in order to inform the exact scenarios and parameters of the tests and modelling and ensure their usefulness to inform specific safety standard proposals. These projects are expected to take 12-18 months to produce final results. However, through close coordination and consultation, standards committees may also be able to access information throughout the research and testing project implementation to inform discussions and iteration on proposals under development.

Other useful safety data may become available from technology demonstration projects to be implemented in the coming year. The California Energy Commission is slated to announce awards of a recent Grant Funding Opportunity for Next-Generation Heat Pumps Using Low-GWP Refrigerants that may include projects utilizing A3 refrigerants.[22]

It is important to emphasize that the research and testing projects currently in the process of being funded and implemented include only a small portion of the current US market and

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[21] California Air Resources Board, F-Gas Reduction Incentive Program, Solicitation for Third-Party Services for a Risk Assessment of Residential Monobloc Air-to-Water Heat Pumps Using A3 Refrigerants (September 2025) https://ww2.arb.ca.gov/sites/default/files/2025-09/A3%20Monobloc%20Solicitation%20Final%20ADA.pdf

[22] California Energy Commissions, GFO-24-305: Next-Generation Heat Pumps Using Low-GWP Refrigerants, at https://www.energy.ca.gov/solicitations/2025-03/gfo-24-305-developing-next-generation-all-electric-heat-pumps-using-low

equipment types. They do not include the most commonly used AC/HP systems including ducted residential single-split systems, mini-splits, or commercial packaged and rooftop units. Additional resources and funding would be required to expand the scope of research into these other equipment types.

Streamlining Adoption into State and Local Codes

Codes are adopted separately across all state and some local jurisdictions, primarily based on model codes developed by two code organizations. The model mechanical codes adopted by state and local jurisdictions are developed by the International Code Council (ICC) and the International Association of Plumbing and Mechanical Officials (IAPMO). ICC and IAPMO code development cycles operate in three-year cycles, with the 2030 code development process beginning in 2027. [23] [24] The following cycle of model code development begins in 2030 for publication of the 2033 model codes.

The refrigerant provisions in these model codes can be updated to help streamline incorporation of updated safety standards and support more efficient adoption into state and local code regulations, by simply referencing nationally recognized safety standards rather than specifying the quantitative charge limits and thereby minimizing the need for repeated updates with each new edition of these standards.

Both model codes – the International Mechanical Code (published by ICC) and Uniform Mechanical Code (published by IAPMO) – deal with requirements related to systems using flammable refrigerants in Chapter 11. The provisions concerning flammable refrigerants in these codes are typically directly adopted to reference specific charge limits from the safety standards. These can be updated to allow for products that are "used and installed according to nationally recognized safety standards – UL 60335-2-40 and ASHRAE-15", rather than setting specific charge size limitations in the code text themselves. This approach has the advantage of streamlining the code adoption. Ideally safety standards proposals for A3 refrigerants should be developed and finalized by UL and ASHRAE committees by early 2027 in order to be directly considered by the IAPMO and ICC committees.

This approach is already supported by legislation passed in more than 20 states that stipulates that existing codes should not prevent the use of refrigerants approved under nationally recognized safety standards and under the federal Significant New Alternatives Policy (SNAP)

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[23] The International Association of Plumbing and Mechanical Officials (IAPMO). Code Development Timeline. https://iapmo.org/codes-standards-development/code-development

[24] International Code Council (ICC). Icc Code Development Process. Shttps://www.iccsafe.org/wp-content/uploads/ICC-CDP-How-It-Works.pdf

Program.[25] This approach was taken to support timely adoption of A2L refrigerants and can provide a similar near-term solution for allowing market adoption of equipment using A3 refrigerants while state and local codes are still in the process of being updated. This may allow for A3 equipment to be commercialized even before revised model building codes are published (in 2030 or 2033 respectively), provided updated safety standards and an Environmental Protection Agency (EPA) SNAP regulation are finalized. Ultimately, this is a temporary solution and state and local codes must still eventually be updated through the usual process of state and local fire and safety code commissions to directly reference the updates safety standards.

Scope of Safety Standard Proposals

Three potential paths forward for proposals updating US safety standards are identified, with varying scopes for system types covered and extent of market addressed, as summarized in **Figure 7** and further elaborated on below.

Figure 7. A3 Safety Standards: Scope & Technology Pathways

Partial Harmonization with IEC 60335-2-40 - Low-hanging Fruit

- **Narrow updates to safety standards enable A3s in self contained (up to 988g) and indirect systems (up to 4.94kg)**
- **Covered by currently funded safety research and testing projects**
- **Majority of AC/HP sector is unaddressed, fails to align with global markets**
- **Any transition to A3s for central AC/HPs (split & packaged) would rely on re-design as indirect (air-to-water) systems**

Full Harmonization with IEC 60335-2-40 - Realistic Path

- **Full harmonization with IEC for all system types enables self contained and indirect systems up to 4.94kg plus up to 988g in direct expansion split or packaged systems for central AC/HPs**
- **Potentially enables broader adoption of A3s in 78-88% of new central AC/HPs to be designed**
- **Central AC/HP systems up to ~40-50k BTU/hr enabled (depending on charge optimization and system type)**
- **Remaining 10-20% of central AC/HP market relies on indirect systems for A3 use or gets displaced by other system architectures.**

Beyond IEC 60335-2-40 - Global Leadership by US Industry

- **US safety standards consider proactive examination of extended A3 charge limits beyond IEC for direct systems up to 1.5kg, considering additional mitigation needed**
- **Enables ~97% of new central AC/HPs as currently designed to used A3s without reliance significantly on system changes/indirect systems, some charge optimization still required**
- **Early IEC proposal under discussion, additional safety research and testing likely required.**

[25] Environmental Investigation Agency (EIA). (August, 2025) State Code Legislation Primer. Enabling Climate-Friendly Refrigerants in State and Local Building Codes. https://eia.org/wp-content/uploads/2025/05/EIA-State-Code-Legislation-Primer.pdf

Full harmonization provides a realistic path forward for enabling a national market transition to A3 refrigerants by 2035 with faster adoption feasible in states with expedited code updates. It is important to note that these pathways are not mutually exclusive. A near term decision to proceed with a narrower scope to meet 2027 model code deadlines does not preclude subsequent proposals to further harmonize or even go beyond the IEC standard in future.

1. Partial harmonization with IEC 60335-2-40:

Proposals are developed that consider expanded A3 charge sizes only in small self-contained and indirect system types leaving a majority of current system types not yet addressed or considered. Self-contained equipment would consider window units, packaged terminal units (PTAC/HPs), and heat pump water heaters (HPWHs) which use relatively small charge sizes. Indirect systems would include either residential monobloc or commercial air-to-water systems such as chillers. These equipment types are covered by existing research projects and could be advanced relatively quickly to meet code deadlines.

2. Full harmonization with IEC 60335-40:

Proposals are developed in the UL committee that achieve full consistency with IEC 60335-2-40 for Annex GG of the standard for A3 refrigerants, and cover all common types of direct expansion systems beyond smaller self-contained systems, including ducted and ductless central AC/HPs, up to the 988gram maximum charge limit as well as indirect systems up to 5 kilograms. This approach has the benefit of bringing the US market into alignment with the vast majority of other regions that follow and utilize the IEC standard. Finalizing a proposal to fully harmonize with IEC 60335-2-40 would require additional resources be directed to risk assessment and research on additional scenarios and equipment types.

3. Beyond IEC 60335-2-40:

Proposals are developed to consider requirements needed to safely design systems with greater than 988 grams, up to 1.5 kilograms in a direct expansion system; thereby taking an approach that would address nearly all common residential and commercial AC/HP applications in the US market and around the globe; there is some precedent for this with A2L refrigerants where UL committees have developed national deviations that go beyond what is enabled under IEC, particularly in refrigeration applications. Horizontal safety standards ISO 5149 and EN378 also enable up to 1.5 kilograms, subject to manufacturers carrying out a risk assessment.[26]

[26] GIZ. (2018). International Safety Standards in Air Conditioning, Refrigeration and Heat Pumps at https://www.giz.de/en/downloads/giz_2018_Safety_Standards.pdf

Conclusions

Full harmonization with IEC 60335-2-40 is a realistic path to enable a vast majority of newly manufactured US air conditioners and heat pumps to use R-290 and other ultra-low GWP A3 refrigerants nationwide. At minimum, the US standards should advance near-term proposals to enable A3s in self-contained and indirect system types, though this represents a small portion of equipment currently used in the sector. Standard and code updates can be finalized and adopted before 2030 in states that pursue proactive adoption of updated code legislation and regulations.

EIA urges all interested stakeholders to engage with discussions in UL and ASHRAE standards committees as described herein and to support additional safety research and testing for common equipment types that would enable a 'full harmonization' or 'beyond IEC' scenario to be fully vetted and considered. If safety research and proposals to fully harmonize with IEC cannot be finalized by the 2027 deadline for inclusion in 2030 model codes, this work should be continued and finalized as soon as possible for inclusion in 2030 code proposals for 2033 model codes.

Appendix A. Additional information on safety standards related to storage and transportation.

Existing regulations for the transportation and storage of flammable refrigerants do not pose a significant barrier to adoption of A3s, although there may be additional requirements across local jurisdictions. The storage of A3 refrigerants is already safely regulated under existing regulations from The National Fire Protection Association (NFPA) 1 and 55 and the International Fire Code (IFC).[27] Refrigeration systems do not follow the same requirements as barbeque grills and instead follow the same requirements as A2Ls. NFPA considers A3 refrigerants to be the same as A2Ls under NFPA 1 for charge limits for propane cylinder restrictions for rooftops.[28] Refrigerants, including R-290, are not covered by the Liquefied Petroleum Gas Code (NFPA 58) but must still adhere to ASHRAE 15 and local mechanical codes.[29] In the US, some local jurisdictions may require that flammable refrigerants be transported in explosion-proof cabinets vented to the vehicle's exterior. Department of Transportation (DOT) transit regulations depend on the quantities being shipped and may require additional logistical considerations.

[27] NFPA 55, Compressed Gases and Cryogenic Fluids Code. (2023). https://www.nfpa.org/product/nfpa-55-code/p0055code
[28] The National Fire Protection Association (NFPA) 1, Fire Code. (2024). https://www.nfpa.org/product/nfpa-1-code/p0001code
[29] NFPA 58, Liquefied Petroleum Gas Code. (2024). https://www.nfpa.org/product/nfpa-58-code/p0058code