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WHITEPAPER

Advancing A2L Refrigerants in the European Union (EU)

Exploring the drivers, safety standards and applications of lower-GWP A2L alternatives in the European commercial refrigeration sector.

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Abstract

For more than a decade, the EU's F-gas regulations have helped to lead global efforts to reduce greenhouse gas (GHG) emissions of hydrofluorocarbon (HFC) refrigerants in the commercial refrigeration and HVAC industries. Following the mandates of the Kyoto Protocol, the EU was among the first regions to take actions aimed at reducing the use of HFCs and limiting global warming potential (GWP). In 2008, 15 EU member countries committed to reducing GHGs by 8 percent by 2012.

In the following decade, global climate actions and corporate sustainability initiatives have accelerated the transition to the next generation of lower-GWP refrigeration technologies—including both natural refrigerants CO2 and R-290 and synthetic A1 and A2L alternatives. For most synthetic refrigerants, achieving lower-GWP levels below both 300 and 150 GWP thresholds results in physical properties and chemical instabilities that produce lower degrees of flammability.

With a "lower flammability" classification, A2L refrigerants are among these emerging lower-GWP alternatives. Thus, A2L commercial refrigeration requires adherence to architecture- and installation-specific safety measures based on the type of refrigeration equipment, facility size and other characteristics.

This white paper will explore the drivers and regulatory requirements behind the increased adoption of A2L refrigerants in EU commercial refrigeration, review the most common applications for A2L refrigerants, and explain how safety standards impact system design and installation strategies.

Global regulations drive climate initiatives

In the EU, the governance of F-gases is driven by international environmental treaties, including the Kyoto Protocol and the Kigali Amendment to the Montreal Protocol.

The Doha Amendment to the Kyoto Protocol— Following the Kyoto Protocol's initial 2008-2012 commitment period, the Doha Amendment established a second commitment period from 2013-2020. Currently, 147 parties have deposited their instrument of acceptance, surpassing the 144-party threshold needed to enter the Doha Amendment into force in 2020.

The Kigali Amendment to the Montreal Protocol— The Kigali Amendment was adopted by 197 members in 2016 to address the global phasedown of HFC refrigerants. This international treaty leverages the Montreal Protocol—which was originally introduced to phase out ozone-depleting substances (ODS)—to expand its scope and address the GWP of harmful HFCs. Although countries in the EU were among the first to ratify adoption of the Kigali Amendment in 2018, the EU F-gas regulation and HFC phasedown have been in effect since 2014—pledging to reduce the consumption of HFCs by 79 percent over the next decade through reductions in HFC supplies.

The next revision of the EU's F-gas regulation is being drafted to align with the Kigali Amendment's HFC phasedown—extending beyond 2030 and following the European Green Deal—which will likely result in exceeding the 85 percent HFC reduction required under the Kigali Amendment.

The Paris Climate Agreement—Under the guidance of the United Nations (UN), the Paris Climate Agreement was adopted by 196 countries in 2015 and went into effect in 2016. This binding international agreement unites member nations into a common cause to undertake the ambitious efforts to combat climate change and adapt to its effects. Its goal is to limit global warming to 1.5 °C compared to pre-industrial levels by 2050. Doing so will require countries to aggressively reduce GHGs and achieve a climate-neutral carbon footprint throughout the world by mid-century.

Countries and private companies alike have pledged to meet these decarbonization goals, declaring public sustainability benchmarks for achieving net zero by 2030, 2040 and 2050. Transitioning to the next generation of lower-GWP refrigerants is a key part of achieving these objectives and is expected to contribute to a 0.4 °C global warming reduction.

Relative flammability of A2L refrigerants

In Europe, refrigerants are categorized according to their toxicity and flammability potential under the International Organization for Standardization (ISO) 817 standard. North America uses a similar convention for refrigerant classification as defined by the ASHRAE 34 standard (see Figure 1).

Most refrigerants in use today are non-toxic, but the range of flammability varies as we move to lower-GWP options. For example, R-290 has a "higher flammability" rating (or A3), while most lower-GWP synthetic alternatives have a "no flame propagation" or "lower flammability" (or A2L) rating.

Lower-GWP synthetic refrigerants may be composed of singlecompound hydrofluoroolefins (HFOs) or various blends of HFO refrigerants and select lower-GWP HFCs. Achieving GWP levels below 300 typically results in a degree of lower flammability and subsequent A2L classification. It is important to remember that flammable refrigerants are not new to the commercial refrigeration industry; R-290 set the precedent for the use of flammable refrigerants in commercial refrigeration and has been used for nearly two decades.

Refrigerant safety group classification

Increasing Flammability ↑	Safety Group		
	Higher Flammability	A3	B3
	Flammable	A2	B2
	Lower Flammability	A2L	B2L
	No Flame Propagation	A1	B1
		Lower Toxicity	*Higher Toxicity*
		Increasing Toxicity →	

Figure 1: Relative flammability and toxicity of refrigerant classifications, per ISO 817 and ASHRAE 34.

To understand the difference between these classifications,safety standards use the following flammability categorization metrics:

- **Lower flammability limit (LFL)—**The LFL of A2Ls is roughly eight times higher than R-290. Because it is unlikely to ignite at comparable concentrations of R-290, this allows for potentially larger charge sizes in higher-capacity applications.
- **Burning velocity (Su) and heat of combustion (HOC)—**Su and HOC are significantly lower in A2Ls (Su below 10 cm/s; HOC below 19 MJ/kg) than R-290 (Su = 46 cm/s; HOC = 46.3 MJ/kg), resulting in a much lower severity of ignition events.
- **Another metric for evaluating flammability—** though not a criterion used in all safety standards— is ***minimum ignition energy (MIE)***. R-290 has a very low MIE (0.35 mJ) and can be ignited by lower energy sources such as static electrical discharge. A2L MIEs are significantly higher (from tenths to hundredths of mJ), typically not igniting unless exposed to an open flame or strong electrical energy source. Thus, A2Ls are considered to be safer to use around certain electrical components.

In practical terms, this data suggests that compared to the A3 R-290, A2L refrigerants are more difficult to ignite and have a lower severity of ignition events. However, appropriate precautions must be taken within commercial refrigeration and HVAC applications to prevent the refrigerant forming in flammable concentrations.

Safety standards provide a foundation for global A2L adoption

Around the world, evolving safety standards are establishing new requirements for the design, construction, qualification and installation characteristics of A2L refrigeration systems.

In Europe, commercial refrigeration architectures and equipment follow European-based safety standards that are designed to minimize the risk of forming flammable concentrations in the event of refrigerant leaks. This starts by establishing refrigerant charge recommendations per equipment or system type according to applicable safety standards. Commercial refrigeration follows two standards:

- **EN 60335-2-89** applies to self-contained equipment (factory charged and sealed). This standard is harmonized with European regulations (Machinery Directive) and is based on IEC 60335-2-89.
- **EN 378** applies to remote refrigerating systems (split systems and cold rooms). Although the generic standard EN 378 is not based on the international ISO 5149 standard, these two standards have become aligned over the last decade.

In the U.S., UL 60335-2-89 (2nd Edition) is the primary safety standard upon which other federal regulations rely. UL 60335- 2-89 goes beyond the international standard IEC 60335-2-89 (2019) to include remote architectures in addition to selfcontained equipment.

Regional differences in A2L safety standards

Although international, European and North American safety standards are all designed to ensure safe use of A2L refrigerants, each region has different guidelines and requirements. Be sure to follow applicable standards per the purview of the governing bodies.

International safety standards for flammable refrigerants

	INTERNATIONAL	EUROPE	UNITED STATES	JAPAN	AUSTRALIA and NEW ZEALAND
GENERAL STANDARD	ISO: TC86 SC1, ISO 5149	CEN: TC182WG6, EN 378	ASHRAE: SSPC 15, ASHRAE 15	METI: High Pressure Act, Electrical Safety Act	Standards Australia / Standards New Zealand: JTC ME-006, AS/NZS 5149
PRODUCT STANDARD	IEC: TC61 SC61C, IEC 60335-2-24, IEC 60335-2-89, TC61 SC61D, IEC 60335-2-40	CENELEC: CLC61, EN 60335-2-24, EN 60335-2-89, EN 60335-2-40	UL: STP's, UL250, UL60335-2-24, UL471, UL60335-2-89, UL474, UL484, UL60335-2-40	JIS: C 9335-2-24, C 9335-2-89, C 9335-2-40	Standards Australia / Standards New Zealand: JTC EL-002, AS/NZS 60335.2.24, AS/NZS 60335.2.89, AS/NZS 60335.2.40

Figure 2: The use of flammable refrigerants is governed by regional safety standards.

Applicable standards East Asia, Australia and New Zealand

JAPAN

- Self-contained regulated with **JIS C9335-2-89** March 2021 (aligned with IEC60335-2-89:2019)
- Remote systems (including condensing units) with flammable regulated with **High Pressure Act** and the **Electrical Safety Act**

CHINA

- Self-contained **GB4706.102-2010** (identical adoption of IEC60335-2-89:2007)
- Remote systems **GB9237** and **EN 378**
- Condensing units **GBT21363-2018**

AUSTRALIA and NEW ZEALAND

- Self-contained **AS/NZS 60335.2.89:2020** (identical adoption of IEC60332-2-89:2019)
- Remote systems **JTC ME-006 AS/NZS 5149**

Figure 3: Asia Pacific countries follow safety standards for self-contained, remote systems and condensing units (CUs).

Determining allowable refrigerant charges

It is important to understand that the specific allowable charges are determined by the system architecture and other key factors, including:

- LFL of the refrigerant used (individual A2Ls have specific LFL ratings)
- Volume of cold storage room or other occupied space that potentially could be subjected to flammable refrigerant concentrations
- Safety and/or risk management measures applied in the equipment and/or installation

Applying A2Ls in system architectures

Safety standards are designed to help ensure the safe use of A2L refrigerants in the following commercial refrigeration systems:

- Self-contained equipment (display cabinets)
- Remote systems, including:
  - Split systems (semi-centralized, distributed systems)
  - Condensing units connected to cold rooms

Comparison of A2L charge limits per regional standard

	Self-contained (integral display cases)		Walk-in Cold Room With Condensing Unit		Split Systems (semi-centralized/distributed)	
International Standard	**IEC 60335-2-89:2019**		**ISO 5149:2014**		**ISO 5149:2014**	
European Standard	**EN 60335-2-89:2022**		**EN 378:2018**		**EN 378:2018**	
	Up to150g	No measure	6 LFL to 39 LFL	Mc < 20% LFL.V • No measures Mc > 20% LFL.V • Must run a risk assessment (Risk management for tight room not included in EN 378) • UL 60335-2-89: 2021 concept could be a reference	6 LFL to 39 LFL	Mc <20% LFL.V • No measures Mc <21% LFL.V (QLMV) • Constructive requirement 21% LFL.V to 52% LFL.V (QLAV) • Constructive requirement + one safety measure* Mc >52% LFL.V (QLAV) • Constructive requirement + two safety measures**
	150g to 13 LFL (Limit to 1.2kg)	• Mc < 25% LFL.V • Annex CC compliance (≤ 50% LFL for >5 min)	39 LFL to 195 LFL	• Must run a risk assessment (Risk management for tight room not included in EN378) • UL 60335-2-89: 2021 concept could be a reference	39 LFL to 195 LFL	Mc< 21% LFL.V (QLMV) • Constructive requirement (Room area max 250 m²) 21% LFL.V < Mc < 52% LFL.V (QLAV) • Constructive requirement + one safety measure* Mc >52% LFL.V (QLAV) • Constructive requirement + two safety measures**
	Above 13 LFL non-applicable (Limited of 1.2kg)					
U.S. Standard	**UL 60335-2-89:2021**		**UL 60335-2-89:2021**		**UL 60335-2-89:2021**	
	Up to 150g	No measure	150g to 8 LFL (Closed) / 13 LFL (Open)	Mc <25% LFL.V	150g to 8 LFL (Closed) / 13 LFL (Open)	Mc< 25% LFL.V
	• 150g to 8 LFL (Closed) • 150g to 13 LFL (Open)	• Mc <25% LFL.V • Annex CC compliance (≤50% LFL for > 5 min)	8 LFL (Closed) / 13 LFL (Open) to 52 LFL	Constructive requirement Mc <25% LFL.V • No measures 25% LFL.V < Mc <50% LFL.V • Air circulation + leak sensor, SSOV	8 LFL (Closed) / 13 LFL (Open) to 52 LFL	Constructive requirement Mc <25% LFL.V • No measure 25% LFL.V < Charge < 50% LFL.V • Air circulation + leak sensor, SSOV
	Above 8 LFL (Closed) / 13 LFL (Open) non-applicable		52 LFL to 260 LFL	Constructive requirement Mc <50% LFL.V • Ventilation + leak sensor, SSOV	52 LFL to 260 LFL	Constructive requirement Mc <50% LFL.V • Ventilation + leak sensor, SSOV

(*); 2 safety measures are required for underground/ (**); not applicable for underground
Mc: system charge; V: room volume; LFL: lower flammability limit; SSOV: safety shut-off valve

Figure 4: A2L system charges are defined per the governing regional safety standard.

Consider how safety and regulatory compliance can be achieved in these common system architectures.

Self-contained equipment (factory charged and sealed)

F-gas regulations require self-contained units (aka integrated cases) for commercial use (hermetically sealed equipment) to use refrigerants that are less that 150 GWP. The third edition of IEC 60355-2-89, the international standard published in 2019, established a maximum charge limit for A2Ls of 1.2 kg for selfcontained units with open-and closed-door cabinets; this version is adopted as European standard EN 60335-2-89: 2022 and was published in 2022.

Risk assessment is based on the principle that equipment is hermetically sealed during the manufacturing process and qualified to not produce a flammable atmosphere surrounding the unit in case of leaks.

Note: Industry experts expect guidelines for increased charge limits in a 2023 update to this international standard.

Split systems (remote)

For single-compressor (or single-pack) units, the F-gas regulations require applications to use refrigerants that are less than 2,500 GWP. The refrigerant GWP rating for multi-pack systems (with more than one compressor), is based on the kW consumption.

- For systems < 40 kW, the allowable GWP is 2,500.
- For systems > 40 kW, the allowable GWP is 150 (with one exemption: the primary refrigerant circuit used in a cascade system).

EN 378 is the applicable safety standard for split systems. It establishes charge limits per circuit based on the A2L's LFL, the volume of refrigerated space and/or cold room, and the mitigation strategies employed.

- No additional safety mitigation—Allowable charge is less than 20 percent of LFL per room volume up to a maximum of 39 LFL.
- Following construction requirements—Allowable charge is the quantity limit with minimum ventilation (QLMV)—~21 percent of LFL—per room volume (with a maximum floor area limitation of 250 m2).
- Using one additional risk mitigation measure*— Allowable charge is the quantity limit with additional ventilation (QLAV)—~52 percent of LFL—per room volume up to a maximum of 195 LFL.
- Using two additional risk mitigation measures* — Allowable charge is greater than QLAV — 50 percent LFL — per room volume up to a maximum of 195 LFL.

*Additional mitigation measure options include: leak detector, air circulation, mechanical ventilation and SSOV.

Safety management for A2L remote systems

Per applicable EU safety standards—EN 378, Annex C.3—risk mitigation strategies are required when A2L system charges and a room volume create the potential risk for flammable concentrations. If system charges are above recommended limits, the architecture and/ or installation must implement the following risk management requirements.

Architecture requirements

- Refrigeration compressor and/or condensing unit must be located outdoors.
- Provision can only be used in an occupied space where the A2L charge does not exceed 195 LFL.
- The rated cooling capacity of an indoor unit is not more than 25 percent of the total cooling capacity.

Construction requirements

- Indoor heat exchanger and system controls are designed to prevent ice formation damage.
- Indoor refrigerant-containing parts are protected against fan breakage (or the fan has a fail-safe design).
- Only permanent joints are allowed in the occupied space, except for site-made joints directly connecting the indoor unit to the piping.
- Refrigerant-containing pipes in the occupied space are protected against accidental damage.
- Doors of the occupied space are not tight-fitting.
- Effect of flow down is mitigated for the lowest floor connected.
- When the refrigerant charge divided by room volume exceeds QLMV, alternative provisions to ensure safety are provided.

Safety management and risk mitigation measures

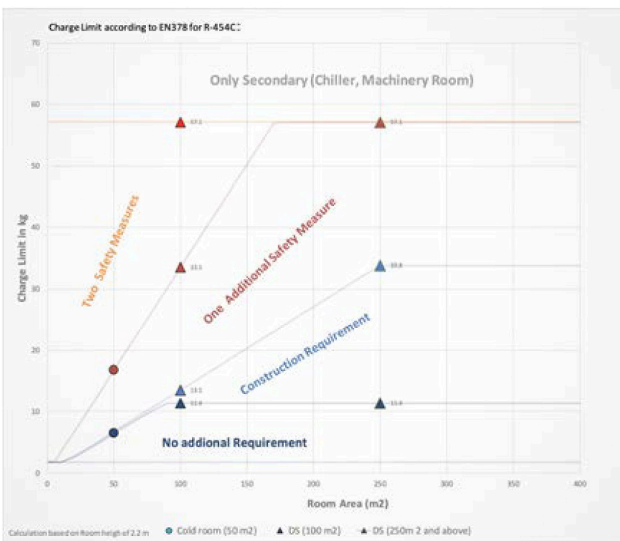
The following mitigation measures are recommended to offset the potential risk of flammability, as per applicable safety standards.

- **Leak detection—**Devices and/or sensors for monitoring halogenated refrigerants must comply with EN 14624. The refrigerant detection device must activate an alarm signal at a leak rate not exceeding 25 percent of the LFL.
- **Safety shut-off valve—**SSOV must be located in the refrigeration circuit, outside the occupied space. In the event of a refrigerant leak, the SSOV shuts off the refrigerant flow so that the amount of refrigerant leaked into the occupied space is less than the QLMV.
- **Air circulation—**Indoor space must meet minimum airflow circulation requirements.
- **Ventilation—**Indoor space must meet minimum airflow ventilation requirements, including a sufficient exchange with an outdoor air source.
- **Alarm—**Alarm system shall provide audible and visible warnings, such as a buzzer 15 dBA above the background level and a flashing lamp. A response procedure will designate an authorized person to take appropriate action.

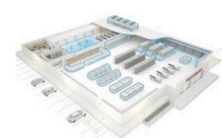
Figure 5 is an example of how charge limits for a specific A2L refrigerant are determined in a commercial refrigeration application, either for self-contained equipment or remote systems.

Example of EU A2L charge limits with risk mitigations

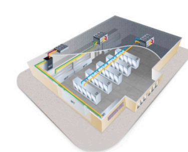
EN 378



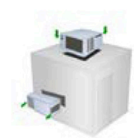
In large supermarket -250 m² and above (R-454C)
- Up to 11.4 kg, no additional measures
- to 33.5 kg, constructive recuirement applies
- to 57.1 kg, one additional measure



Example of a split system (semi-centralized/ distributed) in small store - 100 m² (R-454C)
- Up to 11.4 kg, no additional measures
- to 13.5 kg, constructive recuirement
- to 33.5 kg, one additional safety measure
- to 57.1 kg, two additional measures



Example of a cold room with CU -50 m² (R-454C)
- Up to 6.8 kg, no additional measures
- Above 6.8 kg, risk mitigation shall apply; UL60335-2-89 could be used as a reference



IEC 60335-2-89
- Charge limit= 25% LFL x room volume
- Minimum room area for 1.2 kg (R-454C) = 7.4 m²

Self-contained (integral display cabinet) (R-454C)
- 150 g to1.2 kg - Annex CC

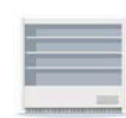


Figure 5: Risk mitigation measures are dependent upon the specific A2L refrigerant, charge limit, system architecture and room area.

Semi-centralized distributed systems

Semi-centralized systems (aka racks) that utilize A2Ls offer a distributed, lower-GWP alternative to larger-charge centralized systems. As a remote system, the same F-gas GWP requirements and safety management provisions for split systems (mentioned previously) apply to semi-centralized systems.

CUs connected to cold rooms

CUs that are connected to cold rooms are subject to the same F-gas GWP requirements and safety management provisions that apply to split and semi-centralized systems. However, since many cold rooms are tightly enclosed indoor spaces, construction requirements alone are not sufficient when considering A2L charge increases.

In scenarios where the charge limit exceeds 20 percent LFL per room volume, the cold room must be equipped with mechanical ventilation capabilities triggered by a leak detector (risk assessment is needed; UL 60335-2-89 may be followed).

Food retail case study

In the UK, Copeland is helping food retailers to deploy A2L refrigeration strategies safely and successfully. Food retailer ASDA has adopted an all-A2L refrigeration architecture based on a distributed approach. ASDA's transition started by replacing older cases with those that were A2L-compatible. Then, as legacy centralized HFC systems were decommissioned and replaced by semi-centralized distributed systems, newer cases could be retrofitted to the new A2L refrigeration architecture.

By 2019, ASDA had transitioned all its HFC-based stores to this lower-GWP distributed approach. Their chosen A2L refrigerant option provided an ideal balance of safety, energy efficiency and capacity that enabled ASDA to maximize refrigeration system value and performance. In doing so, ASDA complied with the EU's F-gas regulatory requirements, met applicable safety recommendations, and laid the foundation to transition to even lower GWP A2Ls in the future, if needed or desired.

Lowering refrigerant charges and moving to a distributed, remote system design also helped ASDA to achieve one of its primary safety objectives: to limit the potential for refrigerant leaks. Preventing leaks not only minimizes safety risks, but it also ensures that systems are operating at full capacity and efficiency.

ASDA's A2L display cases are equipped with a modular leak detection alarm system integrated into the case controller. If leaks are detected, the system activates an alarm that triggers an SSOV, which stops refrigerant flow. In addition, leak thresholds are set at a very low level to limit the potential for refrigerant forming in flammable concentrations.

Qualifying the next generation of A2L refrigerants

Copeland is committed to supporting our European original equipment manufacturer (OEM) and end user customers who are making the safe transition to A2L refrigerants. In addition to leading the development of system protection, line components and supervisory controls, our Copeland™ scroll and semi-hermetic compressor lines are qualified to use the following lower-GWP A2Ls:

- R-454A (239 GWP)
- R-454C (148 GWP)
- R-455A (148 GWP)
- R-1234yf (4 GWP)

R-454A, R-454C and R-455A have individually distinct thermodynamic properties and excellent performance characteristics that are comparable to legacy A1 HFC refrigerants such as R-404A or R-448A/R-449A. R-1234yf has similar performance to R-134a. Note that performance characteristics will vary depending on the specific application, so consult your Copeland application engineer to determine the optimal A2L refrigerant for your application.

To take the worry out of compliance, Copeland has developed a user-friendly software tool that allows you to calculate refrigerant charge based on the selected A2L refrigerant and specific system architecture: Climate.Emerson.com/En-gb/Tools-Resources/Refrigerant-Charge-Calculator.*

Copeland's E3 supervisory control platform and connected leak detection devices provide built-in A2L refrigeration system optimization logic to oversee safety management, such as shutting off the compressor and other components or activating shut-off and/or isolation valves.

To learn how Copeland is helping Europe transition to the next generation of A2L refrigeration technologies, please contact our application engineers or visit our website, Climate.Emerson.com/En-us/Products/Refrigeration/Low-GWP-Refrigeration/A2L-Refrigerants.

*Copeland is pleased to provide this tool to assist refrigeration professionals in selecting the proper equipment to meet their specific refrigeration requirements. We have used our best efforts to ensure the accuracy of the data used to create this tool, including the use of performance data provided by the evaporator manufacturer whenever possible. However, Copeland does not design, manufacture or sell evaporator equipment. Accordingly, you are solely responsible for evaluating and determining the suitability of any equipment identified by our tool, including the level of reliability required of such equipment, and you accept full responsibility for the selection, purchase and installation of all equipment identified by our calculator. You are specifically advised to confirm evaporator performance capabilities with the evaporator manufacturer or manufacturer's representative to ensure the equipment will meet your specific requirements before purchasing and installing the equipment in your end-use refrigeration environment. While we have made every attempt to ensure that the information used in our box load calculator has been obtained from reliable sources and is both accurate and current, errors can occur. Copeland is not responsible for any errors or omissions or for the results obtained from the use of this information. All information generated by our tool is provided "as is" with no guarantee of completeness, accuracy, or of the results obtained from the use of this information, and without any warranty of any kind, express or implied.

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