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Refrigerants, naturally!



Choosing the Best Natural Refrigerant for Your Application

A Guide for the Refrigeration, Air-Conditioning and Heat Pump Sector

PROCESS COOLING AND HEATING

COOLING AND HEATING FOR COMFORT

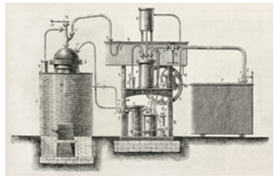
STORAGE AND PRESERVATION

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Introduction



01



02

01. Industrial Cooling Illustration
02. Rows of large commercial HVAC systems

Purpose and Audience
This guide provides practical information for system builders, consultants, operators, and end users in the refrigeration, air conditioning, and heat pump (RACHP) sector. It serves as a quick reference for selecting the optimal natural refrigerant for specific applications, with links to detailed eurammon resources for further reading.

Why This Guide?
The refrigeration industry is undergoing a fundamental transformation. After decades of using synthetic refrigerants - from CFCs to HCFCs to HFCs – it is increasing the use of natural refrigerants. So the industry is returning to where it began: natural refrigerants.

History of refrigeration
– the role of natural refrigerants

The roots of modern refrigeration lie in natural substances: from the very first mechanical refrigeration experiments in the 18th century, engineers and inventors turned to materials found in nature to produce cold.

In 1805, Oliver Evans conceived the first closed-cycle refrigeration machine, and Jacob Perkins built on this in 1835 to patent the first practical vapour-compression refrigerator, which laid the engineering foundations that the entire industry still rests on.

Throughout the 19th century, inventors worked with several substances: ammonia (R717), carbon dioxide (R744), methyl chloride (R40), sulphur dioxide (R764), and hydrocarbons were all explored and deployed. Carl von Linde's groundbreaking ammonia compressor of 1877 established ammonia as the workhorse of industrial refrigeration.

By the late 1920s, roughly a quarter of all smaller refrigeration systems ran on a variety of natural and flammable refrigerants, while ammonia dominated more than 90% of large commercial and industrial plants. The shift came in the 1930s when halocarbon refrigerants (CFCs) were commercialised and gradually replaced natural refrigerants - not primarily because of fire risk, but to address toxicity concerns and the commercial appeal of seemingly simpler synthetic fluids. This displacement was never complete, and it ultimately carried far graver consequences: ozone depletion and accelerating climate change.

The Montreal Protocol, signed in 1987, forced a reckoning - and with it a re-emergence of natural refrigerants, catalysed by campaigns such as Greenpeace's "Greenfreeze" initiative, which drove virtually all European domestic appliance manufacturers back to isobutane (R600a) in the early 1990s.

Today, driven by environmental regulations and climate commitments, natural refrigerants are the future-proof refrigerant choice for sustainable heating and cooling.

Naturally cool:
eurammon's filmlet

List of Acronyms: A-I

ACRONYM	MEANING
AC	Air Conditioning
ACHP	Air Conditioning and Heat Pumps
ATEX	Atmosphères explosibles (explosive atmospheres) – EU Directives 1999/92/EC and 2014/34/EU
CFC	Chlorofluorocarbon
CO_2eq	Carbon dioxide equivalent
EN	European Standard (Europäische Norm)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GMP	Good Manufacturing Practice
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
IEA	International Energy Agency
IEC	International Electrotechnical Commission

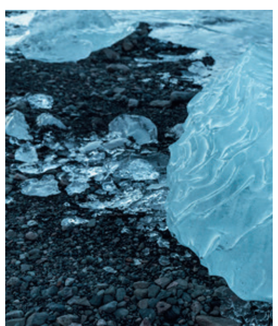
List of Acronyms: I-U

ACRONYM	MEANING
IIAR	International Institute of All-Natural Refrigeration
IIR	International Institute of Refrigeration (Institut International du Froid)
ISO	International Organization for Standardization
NIST	National Institute of Standards and Technology
ODP	Ozone Depletion Potential
OSH	Occupational Safety and Health
PED	Pressure Equipment Directive (Directive 2014/68/EU)
PFAS	Per- and polyfluoroalkyl substances
RACHP	Refrigeration, Air Conditioning and Heat Pumps
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (Regulation (EC) No 1907/2006)
TEAP	Technology and Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TFA	Trifluoroacetic acid
UNEP	United Nations Environment Programme

Why Opt for Natural Refrigerants



01



02

01. Industrial Refrigeration System
02. Natural Refrigerants

Natural refrigerants are substances that occur in nature and are used in refrigeration and air conditioning systems, and in heat pumps.

Unlike synthetic refrigerants, which can have harmful effects on the environment, natural refrigerants are environmentally acceptable and contribute to a sustainable operation of RACHP equipment.

They have negligible global warming potential (GWP), zero ozone depletion potential (ODP) and are no PFAS chemicals. Therefore, the use of natural refrigerants enables compliance with GWP-, PFAS- and ODP- based regulations, such as the F-gas regulation, the Kigali-Amendment and the upcoming PFAS restriction under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals).

The “Natural 5” include Ammonia, Carbon Dioxide, Hydrocarbons, Water and Air. The RACHP sector contributes to climate change through direct emissions from refrigerant leakage during operation, maintenance, and end-of-life of appliances, and indirect emissions from energy consumption during manufacturing, operation, recycling and/or disposal processes.

By using natural refrigerants, CO2eq direct emissions caused by refrigerant leakage are eliminated. Indirect emissions from energy consumption depend on the energy source: fossil-fuel-based electricity generates significantly higher CO2eq emissions than electricity from renewable sources. The use of natural refrigerants allows negligible GWP and also enables the reduction of indirect emissions.

The phase-out of refrigerants under the F-Gas Regulation typically leads to significant price increases prior to the bans taking effect, which does not affect natural refrigerants.

They are widely available commodity substances, and in most applications they deliver equal or better efficiency, which lowers the indirect emissions of the total equivalent warming impact (TEWI) of a modern RACHP system.

Natural Refrigerants at a Glance: Three Key Advantages:

Negligible GWP, zero ODP

Natural refrigerants have negligible GWP, zero ODP, and contain no PFAS chemicals.

Regulatory Compliance

Their use ensures compliance with the F-Gas Regulation, Kigali Amendment and upcoming PFAS restrictions under REACH.

Lower TEWI

Eliminating leakage emissions and offering equal or better efficiency reduces the TEWI of RACHP systems.

Overview of Natural Refrigerants

The following natural refrigerants can be used across all refrigeration, air-conditioning and heat pump applications:

Hydrocarbons

– Including R50 (Methane), R1150 (Ethylene), R1270 (Propylene), R170 (Ethane), R290 (Propane), R600 (Butane), R600a (Isobutane) and R601a (Isopentane). Applications range from domestic and light commercial refrigeration, air-conditioning and heat pumps, to low-temperature and ultra-low temperature industrial systems

R744 (Carbon Dioxide)

– Characterised by a low GWP and high working pressures with therfore high compactness; Mainly used in commercial refrigeration and industrial heat pumps

R717 (Ammonia)

– Used primarily in industrial refrigeration and large-scale heat pumps; also applied in some commercial systems

R718 (Water)

– A safe and non-toxic refrigerant, primarily used in high temperature heat pumps

R729 (Air)

– Safe and non-toxic, primarily used for low temperature cryogenic refrigeration

Others

– Noble gases, such as R704 (helium), for specialized applications

R50, R1150, R1270, R170, R290, R600, R600a and R601a
Hydrocarbons

R744
Carbon Dioxide

R717
Ammonia

R718
Water

R729
Air

R704
Helium

Natural Refrigerants Cover the Entire RACHP Spectrum

Figure 1 plots the two parameters that determine the choice of refrigerant for a specific system - namely, the operating temperature range and system capacity - for each of the key natural refrigerants.

Together, they cover a temperature range of approximately -130°C to +200°C, with no gaps. Furthermore, they span system capacities ranging from less than a kW for 'plug-in' equipment to over 20 MW for industrial installations.

Across much of this range, the application areas of different refrigerants overlap, meaning that multiple options are technically feasible.

The final choice is then based on site-specific criteria — such as efficiency, safety class, charge limits, constraints regarding the plant room and location, and component availability and costs - as outlined on pages 18ff

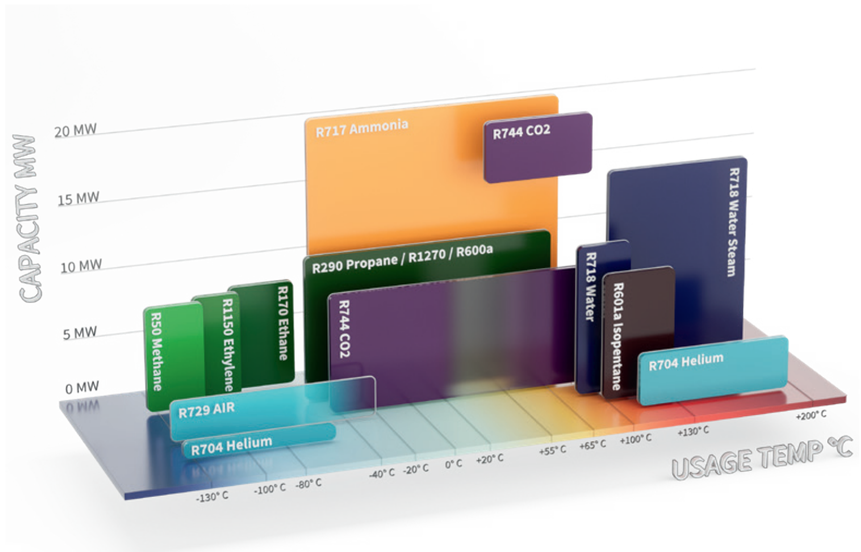


Figure 1a: Practical application ranges for natural refrigerants by temperature and system capacity Source: Eurammon e.V.

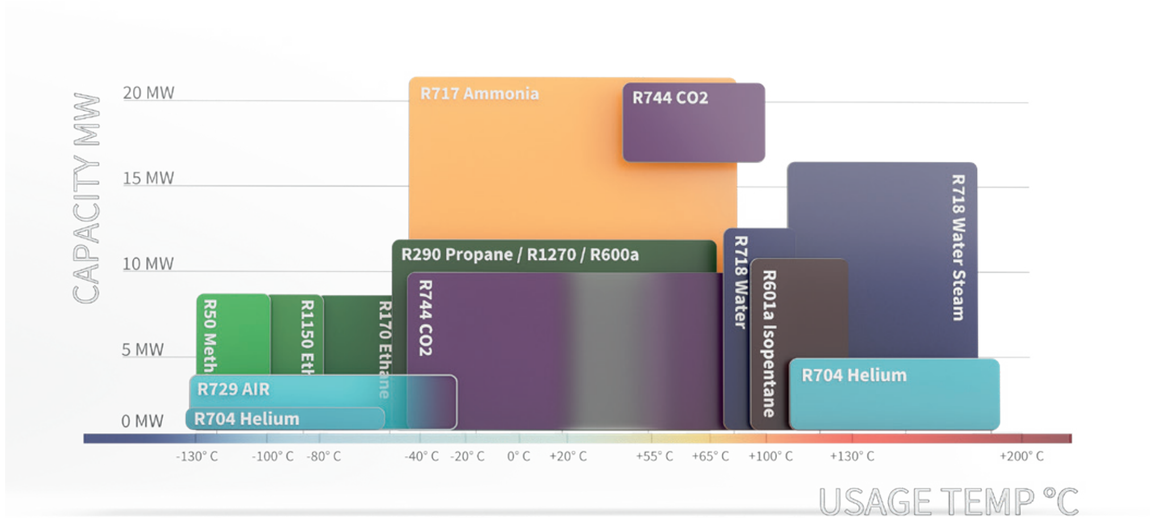


Figure 1b: Different perspective - Figure 1a

Pressure Level and System Design

Temperature and capacity for the application narrow the choice for a refrigerant. The application temperature affects the required refrigerant temperatures and, consequently, their vapor pressures. Figure 2 shows the saturation pressure each natural refrigerant demands across its operating range, and so translates the selection made in Figure 1 into consequences for components, materials and design effort. The curve of each refrigerant gives the low-side pressure at the evaporating temperature and the high-side pressure at the condensing temperature.

Two thresholds matter. Operation below atmospheric pressure, approximately 1 bar(a), means that any leak draws air and moisture into the system rather than releasing refrigerant outwards. Non-condensable gases then collect in the condenser and raise the condensing pressure, cutting efficiency, while moisture corrodes components and degrades the oil. This calls for specific measures: welded rather than mechanical joints, purge equipment to remove non-condensables, driers, and systematic leak and vacuum testing. R718 operates this way across its entire range, which is one reason it remains confined to specific high-temperature and absorption applications.

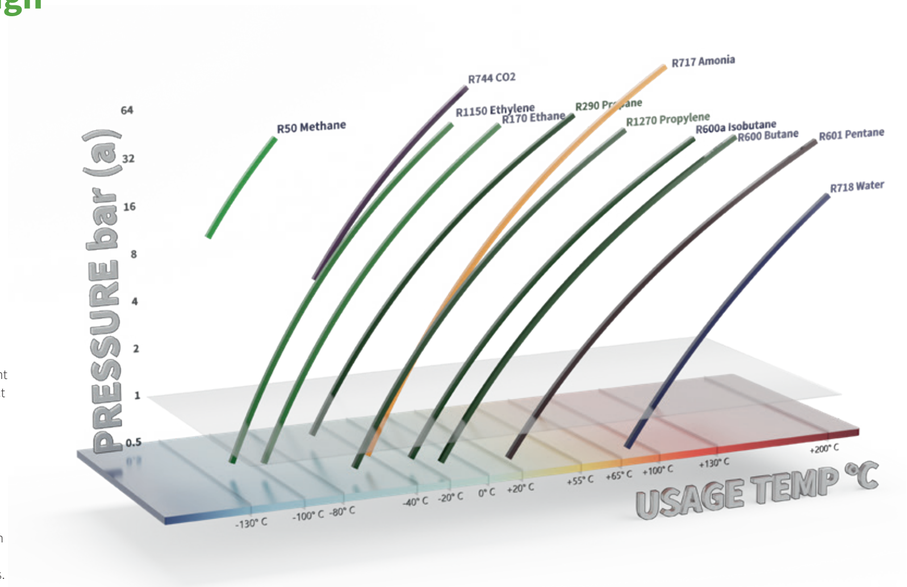


Figure 2a: Vapour pressure curves of selected natural refrigerants as a function of temperature Source: Eurammon e.V, based on data from NIST

Operating Limits of Conventional Vapour-Compression Refrigeration

At pressures above roughly 30 bar(a), system design becomes more complex and costly because components must be rated for the higher pressure - but the same high pressure makes the vapour dense, so R744 systems are markedly more compact than equivalent systems using other refrigerants.

The pressure level does not rule a refrigerant out, it determines considerations to be taken into account for system design and components.

This diagram illustrates the pressure–temperature relationships that help define the operating limits of conventional vapour-compression systems using natural refrigerants.

Saturation pressure is plotted on a logarithmic scale against temperature. The curves indicate the evaporating and condensing pressures at the corresponding temperatures.

Air (R729) and helium (R704) are not shown, as they are used in gas refrigeration cycles without a phase change.

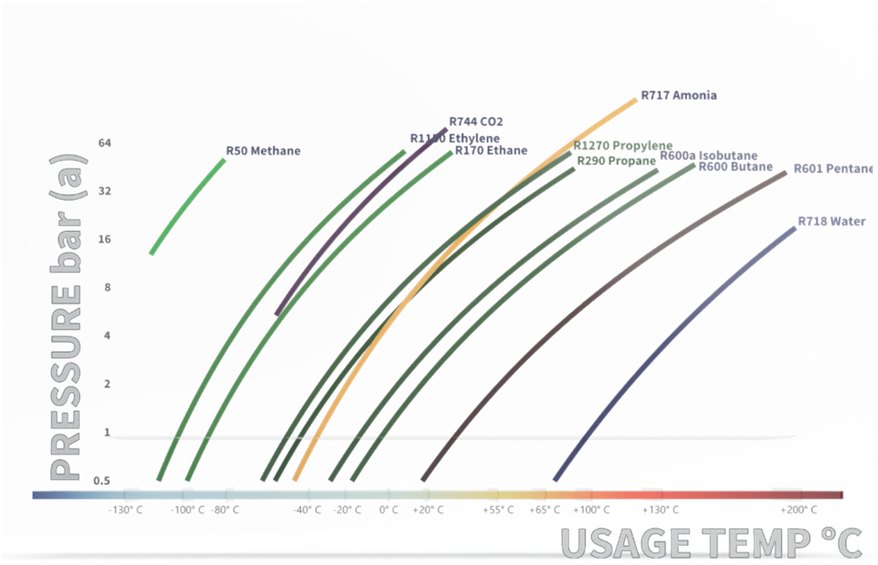


Figure 2b: Different perspective - Figure 2a

Below Tables Summarize the Characteristics of the Most Common Natural Refrigerants:

R50, R1150, R1270, R170, R290, R600, R600a and R601a

Hydrocarbons

Hydrocarbon-based blends are used in selected RACHP applications to keep ultra-low GWP while tuning performance characteristics (for example pressure level, capacity, or retrofit behavior) for specific system designs.

Further reading: eurammon Factsheet Hydrocarbons

Hydrocarbons	**GWP 100[1]**
R50	**27.9**
R170	**0.437**
R290	**0.02**
R600	**0.0006**
R600a	**0**
R601a	**0**
R1150	**4**
R1270	**0**

Typical applications
Ultra low temperature application down to -130°C
Low temperature refrigeration down to -80°C, petrochemical
Split ACs, commercial refrigeration, heat pumps
Refrigeration, blend component
Domestic refrigerators, industrial heat pumps
Heat pumps, foam blowing
Cryogenic applications, cascade systems
Industrial chillers, process cooling

Properties	**For all hydrocarbons**
ODP	0
Safety class [2]	A3 (flammable)
Thermo/performance	Excellent thermodynamic properties; compatible with standard refrigeration oils
Safety	Flammability managed through charge limits and safety design; well-established standards (IEC 60335-2-24, IEC 60335-2-89) [1]
Historical use	In early refrigeration systems in the late 19th and early 20th centuries

A3 Highly flammable

Factsheet:
Hydrocarbons

R744

Carbon Dioxide

Further reading: eurammon Information Paper: Carbon Dioxide R744

R744	**Carbon dioxide**
Chemical formula	CO_2
GWP	1
ODP	0
Safety class [2]	A1 (lower toxicity, non-flammable)
Typical applications	Supermarket refrigeration, transport cooling, heat pumps, cascade systems, mobile air-conditioning
Thermo/performance	Works efficiently in low temperature cascade systems with R717; excellent for heat pump applications with high temperature lifts
Safety	Ideal for public spaces; high operating pressures require specialised components
Historical use	By the 1930s, approximately 80% of marine refrigeration used R744

A1 Non-flammable

[2] According to ISO 817.

Information Paper:
Carbon Dioxide R744

R717

Ammonia

Further reading:
eurammon Information Paper: Ammonia R717

R717	**Ammonia**
Chemical formula	NH3
GWP	0
ODP	0
Safety class [2]	B2L (toxic, low flammability)
Typical applications	Industrial refrigeration, cold storage, ice rinks, heat pumps
Thermo/performance	Excellent thermodynamic properties – highest efficiency among common refrigerants
Safety	Self-alarming odour allows immediate leak detection (threshold 5–50 ppm); lighter than air (rapid dispersion)
Historical use	Over 150 years of proven industrial use; in the 19th century R717 was considered the backbone of the food industry

B2L Toxic + mildly flammable

[2] According to ISO 817.

Factsheet:
Ammonia - a natural refrigerant

R718

Water

Further reading:
eurammon Information Paper: Water R718

R718	**Water**
Chemical formula	H_2O
GWP	0
ODP	0
Safety class [2]	A1 (lower toxicity, non-flammable)
Typical applications	Evaporative cooling, absorption chillers, high-temperature heat pumps
Thermo/performance	High latent heat of vaporisation
Safety	No toxicity or flammability concerns
Historical use	Used as a refrigerant for thousands of years

A1 Non-flammable

[2] According to ISO 817.

R729

Air

Further reading:
eurammon Information Paper: Air R729

R729	**Air**
Chemical formula	Mixture (N_2/O_2)
GWP	0
ODP	0
Safety class [2]	A1 (lower toxicity, non-flammable)
Typical applications	Cryogenic applications, aircraft cabin cooling, pharmaceutical storage, low temperature cryogenic refrigeration, grinding, hardening of metals and deburring of plastics; freeze-drying, biological and medical storage
Thermo/performance	Ideal for ultra-low temperature applications (-40°C and below)
Safety	No toxicity or flammability concerns
Historical use	In early vapour-compression or air-cycle designs in the 19th and early 20th centuries; aviation

A1 Non-flammable

[2] According to ISO 817.

R704

Helium

Further reading:
eurammon Information Paper: Helium R704

R704	**Helium**
Chemical formula	He
GWP	0
ODP	0
Safety class [2]	A1 (lower toxicity, non-flammable)
Typical applications	High-temperature heat pumps
Thermo/performance	Lowest boiling point of all substances (4.2 K / -269°C); enables cooling close to absolute zero
Safety	Non-toxic and non-flammable; risk of asphyxiation in enclosed spaces due to oxygen displacement
Historical use	First liquefied in 1908 by Heike Kamerlingh Onnes; enabled the discovery of superconductivity in 1911

A1 Non-flammable

[2] According to ISO 817.

Application Selection Guide

Natural refrigerants can cover all RACHP applications. The figures in this section support refrigerant selection at three levels of detail: Figure 3 shows the established options for each temperature range, Figure 4 sets out the selection criteria in sequence, and Figures 5a–5c detail the technologies and documented installations for each application area.

Refrigerant options by temperature range
Figure 3 divides the RACHP sector into four areas by the temperature level at which they work: ultra-low temperatures, refrigeration and air conditioning for cooling, and heat pumps for heat delivery. It shows which natural refrigerants are established in each temperature range. Most refrigerants are suitable for more than one application.

Natural Refrigerant Options by Typical Application



Figure 3: Natural refrigerant options by application temperature range. Source: eurammon e.V.

Refrigerant Selection Decision Points

Refrigerant selection involves multiple interdependent criteria. Figure 4 structures the process into sequential decision points, allowing operators, planners and end users to narrow the options to the most suitable natural refrigerant for a specific system. Whichever refrigerant is selected , the overall system design must fit the purpose.

Step 1:
Determine temperature requirements

a) Above 100°C
→ Consider R718, R717, R744

b) 0°C to 100°C
→ Consider R290, R717, R744, R600a

c) -40°C to 0°C
→ Consider R717, R744, R290

d) Below -40°C
→ Consider R717, R744 (cascade), R729, R170, R1150

Step 2:
Evaluate cooling & heating capacity

a) Small
→ R290, R600a, R744

b) Medium
→ R290, R744, R717

c) Large
→ R717, R717/R744 cascade

d) More details: see Figure 5

Step 3:
Consider system design

a) Direct expansion
→ All natural refrigerants possible

b) Indirect/secondary loop
→ Reduces refrigerant charge and enables the use of efficient flooded-ammonia systems in more applications.

c) Cascade systems
→ R717/R744 combination for wide temperature ranges

d) System design needs to be adapted to outer conditions, for example outside temperature ranges etc

Step 4:
Assess local market conditions

a) Availability of compressors & components

b) Local supply of refrigerants

c) Competence of local technicians & designers

d) Efficiency for particular temperature lift and system design

Figure 4: Natural refrigerant selection for RACHP applications. Source: eurammon e.V.

Established Technologies and Practice Examples

The pages below set out the selection sequence for the three application areas covering the RACHP sector in more detail:

cold rooms, process cooling with a secondary fluid and heat pumps.

Read from left to right, each tree addresses application area, temperature range, and capacity, which leads to the natural refrigerants established for that area, their safety classification, the corresponding technology, and, where available, a documented eurammon case study.

Where a branch offers several refrigerants, all are technically proven; the choice between them is made on charge limits, machinery-room constraints, heat recovery potential and cost.

Eurammon's case study library documents installations across Europe and beyond. It provides operators, planners, and system designers with documented performance data, system configurations, and lessons learned. Links to practice examples for all application areas are included in Figure 5 below. An empty case-study field means no case study has yet been published for that branch, not that the technology is unproven.



Application
Cold rooms 1/2

Temperature Range
+15 °C to 0 °C → Chilled rooms

- Cooling Capacity **<20 kW**
  - A3 Isobutane **R600a** → **Direct expansion** Small hermetic plug-in or compact isobutane unit with very low refrigerant inventory
  - A3 Propane **R290** → **Direct expansion** Compact low-charge propane monoblock with hermetic compressor and room evaporator
  - A1 CO_2 **R744** → **Direct expansion** Small transcritical CO2 condensing unit supplying one or several MT evaporators
- Cooling Capacity **>20 kW**
  - A3 Propane **R290** → **Direct expansion – number up** Multiple independent low-charge hydrocarbon condensing units
  - B2L Ammonia **R717** → **Direct expansion / pumped recirculation** Packaged low-charge ammonia condensing system, specialist industrial solution
  - A1 CO_2 **R744** → **Direct expansion** CO2 condensing unit supplying multiple evaporators

Case Study: Eco-friendly CO2 Refrigeration Plant for S-Market, Finland

Temperature Range
0 °C to -40 °C → Freezer rooms

- Cooling Capacity **<20 kW**
  - A3 Propane **R290** → **Direct expansion** Compact low-charge propane monoblock with hermetic compressor
  - A1 CO_2 **R744** → **Direct expansion** Compact transcritical CO2 condensing unit supplying one or several LT/freezer evaporators

Case Study: RefoBlast Vienna

- Cooling Capacity **20-200 kW**
  - B2L Ammonia **R717** → **Direct expansion / pumped recirculation** Low-charge ammonia condensing system supplying multiple remote evaporators → **Indirect expansion** Decision tree „Process cooling with secondary fluid“
  - A1 CO_2 **R744** → **Direct expansion** Central transcritical CO2 low temperature unit supplying multiple evaporators, optionally with an ejector or heat recovery integration

Case Study: Fernhurst Australia

Case Study: Super Best Supermarket

Temperature Range **-40 °C to -160 °C** on pages 24-25: **Deep cold**

Application
Cold rooms 2/2

Temperature Range
-40 °C to -160 °C

Deep cold

Cooling Capacity
<100 kW

A3	Propane **R290**	**→ Natural refrigerant cascade** Two stage vapour-compression cascade using R290 for high-temperature and R170 for low temperature stage
A1	Helium **R704**	**→ Free piston Stirling refrigeration** Hermetically sealed regenerative Stirling refrigeration system using helium as the working gas
A1	Air **R729**	**→ Open-cycle air refrigeration / reverse Brayton cycle** Open cycle turbo compressor system supplying ultra-cold air to the chamber **→ Indirect expansion** Decision tree „Process cooling with secondary fluid“
A1	CO_2 **R744**	**→ Natural mixed refrigerants autocascade** R50/R170/R1150/R290/R1270+R744/R728 Single-compressor autocascade, internal phase seperation

Application
Process cooling 1/2

Temperature Range
20 °C to 4 °C

Medium temperature

Cooling Capacity
<500 kW

A3	Propane **R290**	**→ Low charge vapour-compression chiller** Packaged air / water or water / water
B2L	Ammonia **R717**	**→ Low-charge ammonia chiller** Packaged low-charge ammonia chiller, ammonia remains inside the refrigeration unit
A1	CO_2 **R744**	**→ Transcritical CO_2 chiller** Unit supplying chilled water or glycol, heat recovery can be integrated, air- or water-cooled heat rejection

Case Study: Supermarket Integral System

Case Study: ABN Amro Data Centre

Cooling Capacity
>500 kW

A3	Propane **R290**	**→ Number up - Low charge vapour-compression chiller** Packaged air / water or water / water | Penta Infra HAM0
B2L	Ammonia **R717**	**→ Central low-charge ammonia chiller** Central water-cooled ammonia chiller with low refrigerant charge and secondary chilled water distribution
A1	CO_2 **R744**	**→ Central transcritical CO2 chiller** Large transcritical CO2 unit with multiple compressors, optional heat recovery

Case Study: Penta Infra HAM01

Case Study: Schwarz IT Data Center

Application
Process cooling 2/2

Temperature Range
4 °C to -40 °C

Deep cold

Temperature Range
< -40 °C

Deep cold

Application
Heat Pumps 1/2

Temperature Range
50 °C to 70 °C

Heated Room

Cooling Capacity
5 kW to multi-MW

A1 — Water **R718 / LiBr**
→ **Thermally driven absorption chiller**
Absorption refrigeration using water as refrigerant and LiBr as absorbent

B2L — Ammonia **R717**
→ **Low-charge ammonia glycol/brine cooler**
Packaged ammonia vapour-compression chiller with reciprocating or screw compressor and secondary glycol/brine circuit

Case Study: L.A. FARM Greek Dairy

B2L /A1 — Ammonia/CO2 **R717/ R744**
→ **Direct expansion / pumped recirculation**
Low-charge ammonia condensing system supplying multiple remote evaporators
→ **Indirect expansion** Decision tree „Process cooling with secondary fluid“

Case Study: Tingvalla Ice Stadium

A3 — Propene **R1270**
→ **Low-charge vapour-compression glycol/brine cooler**
Packaged air- or water-cooled chiller with one/multiple low-charge circuits, and a suitable low-temperatur (sic) heat transfer fluid

Case Study: Biotechnology Applications, Roche

Cooling Capacity
5 to 500 kW

A1 — Air **R729**
→ **Closed-cycle air refrigeration**
Closed reverse-Brayton cycle with integrated heat exchanger, a sepearate (sic) ultra-low-temperature heat-transfer fluid is pumped to the process

Case Study: Solvent Condensation for Pharma

A3 — Propene/Ethane **R1270 / R170**
→ **Two-stage cascade liquid cooler**
Two-stage vapour-compression cascade with R1270 high-temperature and R170 low-temperature, a pumped secondary fluid supplies the process

Heating Capacity
up to 1 MW

A3 — Propane **R290**
→ **Vapour compression heat pump**
Modular or packaged propane heat pump with independent low-charge circuits

B2L — Ammonia **R717**
→ **Vapour compression heat pump**
Industrial low-charge ammonia heat pump using waste heat/groundwater/surface water/ refrigeration waste heat

Case Study: Office Heating and Cooling, Vienna

A1 — CO_2 **R744**
→ **Transcritical heat pump**
Transcritical CO2 heat-pump with gas cooler and multiple compressors for district-heating or process-hot-water generation

Application
Heat Pumps 2/2

Temperature Range
70/90 °C
→ **Hot Water**
Heating Capacity
>500 kW

- A3 — Isobutane **R600a**
  → **Vapour-compression heat pump**
  Industrial isobutane heat pump with safety concept for hot water production
- B2L — Ammonia **R717**
  → **Vapour-compression heat pump**
  Industrial high-pressure ammonia heat pump with reciprocating compression
- A1 — CO2 **R744**
  → **Transcritical heat pump**
  Industrial transcritical CO2 heat pump for high temperature hot water or district heating

Case Study:
London District Heating

Temperature Range
90/120 °C
→ **Process heat**

Heating Capacity
100-500 kW

- A3 — n-Butane/ Isobutane **R600/ R600a**
  → **High-temperature vapour-compression heat pump**
  Hydrocarbon heat pump with reciprocating compressor for high-temperature hot water or indirect steam production
- A1 — CO_2 **R744**
  → **Transcritical heat pump**
  High pressure CO2 heat pump recovering lower-temperature waste heat and directly prodcuing high-temperature process heat

Heating Capacity
>500 kW

- B2L/ A1 — Ammonia/Water **R717/ R718**
  → **Hybrid absorption-compression heat pump**
  Ammonia water hybrid heat pump combining mechanical compression and absorption/ desorption for large temperature lifts
- A3 — Butane **R600/ R600a**
  → **High-temperature vapour-compression heat pump**
  Industrial hydrocarbon heat pump for high-temperature hot water or indirect steam production

Temperature Range
120/160 °C
→ **Process steam**
Heating Capacity
>500 kW

- A1 — Helium **R704**
  → **High temperature heat pump**
  Stirling cycle using helium as a refrigerant, closed-loop system
- A1 — Water **R718**
  → **Open cycle water-vapour heat pump**
  Process steam itself is mechanically compressed to a higher pressure for direct reuse as process steam
- A3 — n-Pentane/ Isopentane **R601/ R601a**
  → **High temperature heat pump**
  Waste heat captured at 80 °C to produce 138 °C steam using n-pentane refrigerant and screw compressor

Refrigerants by Industry

Natural refrigerants are applied across a wide range of sectors, each with its own technical requirements and priorities. The table below provides an overview of the most relevant natural refrigerants used per sector, along with key topics specific to their application.

Sector	Natural Refrigerants	Key Topics
Logistics	R717, R717/R744 cascade, R729	Large-scale cold storage, energy efficiency benchmarks
Food & Beverage Manufacturing	R717, R744	Breweries, dairies, food and meat processing — hygiene-compatible system designs
Other Manufacturing	R290, R729, R717	Injection molding, cryogenic hardening of tools, carbon dioxide recovery
District Heating/ Cooling	R717	Large heat pump integration into district energy networks
Data Centres	R290, R717, R718	Free cooling and heat recovery integration, Power Usage Effectiveness, reliability
Leisure & Sports	R717, R744	Ice rinks with indirect brine loops, public area safety
Commercial Refrigeration	R744, R290, NH_3/CO_2	Transcritical CO_2 in supermarkets, energy savings
Pharma-ceuticals	R717, R729	Precise temperature control, GMP compliance, reliability
ACHP	R290, R744	Split AC systems, residential and industrial heat pumps

Regulatory Framework

The main regulations, standards and international frameworks to consider when deciding on the refrigerant for a RACHP system include:

Kigali Amendment to Montreal Protocol

The Kigali Amendment (adopted in 2016; in force since 1 January 2019) establishes the global phase-down of HFC production and consumption through differentiated country schedules. Parties are divided into three groups with differentiated obligations: (1) Non-Article 5 (developed countries), (2) Article 5 Group 1 (most developing countries), and (3) Article 5 Group 2 (10 high-ambient-temperature countries: Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, UAE).Overall, the Amendment is designed to reduce global HFC use by more than 80% over ~30 years and is estimated to avoid around 0.3–0.5°C of global warming.

Year	Key Requirements
2024	First reduction steps start for Article 5 Group 1 countries
2028	Reduction steps start for Article 5 Group 2 countries
2036	Developed countries reach an 85% reduction level (15% of baseline remaining)
2045	Article 5 Group 1 countries reach an 80% reduction level
2047	Article 5 Group 2 countries reach an 85% reduction level

EU F-Gas Regulation 2024/573

The F-Gas Regulation and the directives and standards below apply in the EU. Comparable national rules exist in other markets, and many follow the EU model.

The revised EU F-Gas Regulation (entered into force March 2024) establishes strict GWP limits and phase-down schedules as listed in the following:

(EU) Nr 517/2014

F-Gas Regulation (EU) 2024/573

a) New Baseline quantity: 176.700.479 to (=96,5 %)

b) 2027: Prohibition of new Chiller >12 kW with F-Gases GWP ≥ 750 (red, „F-Gases GWP ≥ 750" unterstrichen)

c) 2030: Prohibition of new Stationary refrigeration equipment with F-Gases GWP ≥ 150

PO) Phase-Out of HFC 2050

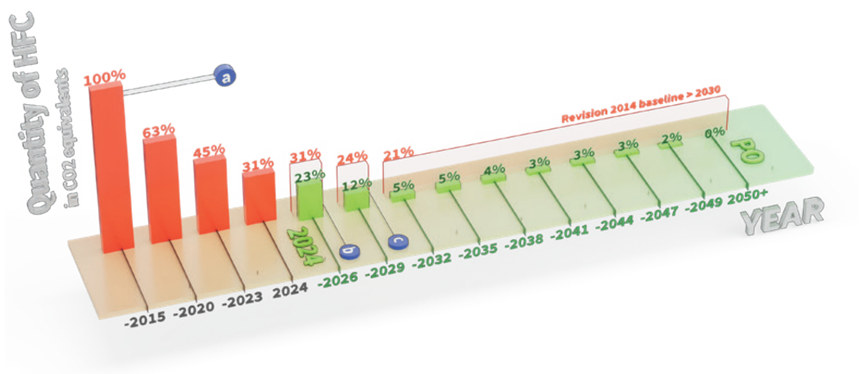


Figure 6: Revision 2024 of the (EU) F-Gas Regulation and Phase-Out of HFC. Source: Regulation - EU - 2024/573 - EN - EUR-Lex

European Directives on Health & Safety

Directive	Scope
Directive 1999/92/EC (ATEX Workplace Directive)	Requirements to protect workers where explosive atmospheres may occur
Directive 2014/34/EU (ATEX Product Directive)	Rules for placing on the market equipment and protective systems intended for use in potentially explosive atmospheres
Directive 2014/68/EU (Pressure Equipment Directive, PED)	Design, manufacture, and conformity assessment of pressure equipment and assemblies above 0.5 bar before placed on the EU market
Directive 89/391/EEC (OSH Framework Directive)	General prevention framework for worker safety and health across all sectors, including employer duties for risk assessment, prevention, training, and worker consultation

Key Safety Standards

Standard	Scope
EN 378	European standard for refrigerating systems – safety and environmental requirements
ISO 817	Refrigerant designation and safety classification
IEC 60335-2-24	Domestic refrigerating appliances
IEC 60335-2-40	Air conditioners and heat pumps
IEC 60335-2-89	Commercial refrigerating appliances

Note: EN 378 is currently under revision with expected improvements for natural refrigerant requirements.

PFAS

In recent years global concerns are rising over per- and polyfluoroalkyl substances (PFAS), including trifluoroacetic acid (TFA), a persistent environmental degradation product of modern hydrofluoroolefin (HFO) and HFC refrigerants. While designed to reduce global warming potential (GWP), HFOs degrade in the atmosphere to form TFA – a short-chain PFAS. TFA accumulates in water and soil and increasingly high concentrations have been found in drinking water, beverages, animals and food crops resulting in serious concerns on impact to human and animal health.

TFA's resistance to degradation and lack of large-scale remediation methods make it a mounting ecological and regulatory challenge. At EU-level a regulatory discussion on PFAS restriction under REACH, the European Union's chemicals regulation is currently underway.

Natural refrigerants are PFAS-free and provide a future-proof solution for sustainable cooling and heating.

Recommendations & Conclusion

Accelerating the uptake of natural refrigerants requires coordinated action across the supply chain. The figure below sets out concrete recommendations for system designers, end-users and operators, and policy makers across RACHP applications.

Across all refrigeration, air conditioning, and heat pump system (RACHP) application categories, commercially proven natural refrigerant options exist today. Natural refrigerants represent the most sustainable and efficient alternative to synthetic refrigerants. The regulatory direction is clear - EU F-Gas phase-out and the Kigali Amendment phase-down schedule eliminate the long-term viability of high-GWP refrigerants worldwide. As natural refrigerants align with global efforts to reduce environmental impact and comply with regulations and standards their use is expected to grow as industries seek to adopt more eco-friendly practices. The question for system designers, operators, and policy makers is no longer whether to transition, but how to do so efficiently.

System Designers

01. Design for natural refrigerants from the start – retrofit is more costly than new design

02. Consider indirect systems — secondary loops reduce refrigerant charge and are well-suited to specific application requirements[1]

03. Size systems appropriately – avoid oversizing; optimize for efficiency

04. Follow applicable standards – EN 378, and product-specific EN standards

05. Integrate safety measures – gas detection, ventilation, and leak minimization

End Users/Operators

01. Prioritize natural refrigerants for new installations – they are future-proof

02. Request lifecycle cost analysis – natural refrigerants often have lower total cost of ownership

03. Ensure proper training for maintenance personnel

04. Establish regular inspection schedules – preventive maintenance reduces risks

05. Plan for end-of-life – natural refrigerants have simpler disposal requirements

Policy Makers

01. Support training programs for technicians handling natural refrigerants

02. Review building codes to enable broader natural refrigerant use

03. Provide incentives for conversion to natural refrigerant systems

04. Update standards to reduce barriers for manufacturers

05. Include RACHP sector in national climate plans (NDCs)

01. Secondary loops are particularly suitable for: applications with high safety demands where refrigerants must remain in the machinery room; installations where long distances are an issue (to manage pressure drop in pipes); multiple-temperature applications; and food applications with food-contact certification requirements.

Further References

Organization	Resources	Website
Fraunhofer Institute	Research on heat pump performance and field studies, design of refrigeration systems, low charge circuits	www.fraunhofer.de
GIZ Green Cooling Initiative	Country cooling data, technical publications, tools, training materials, country reports and inventories, policy documents, webinars	www.green-cooling-initiative.org
IIAR – The International Institute of All-Natural Refrigeration	Standards, Ammonia Refrigeration Global Standards and Regulations, The Natural Refrigeration Review journal, training materials, information papers, videos, tools	www.iiarresources.org
IEA – International Energy Agency	The Future of Cooling (2018), Cooling Emissions and Policy Toolkit (2020)	www.iea.org
IIR – Institut International du Froid	FRIDOC Database covering all refrigeration sectors compiling documents from scientific and technical works from across the globe	www.iifiir.org/en/fridoc
UNEP OzonAction	Training and capacity-building resources on natural refrigerants for Article 5 countries under the Montreal Protocol	www.unep.org/ozonaction
UNEP TEAP	Technology and Economic Assessment Panel reports - authoritative data on refrigerant transitions by sector	www.ozone.unep.org

Further Reading and References
eurammon Resources

Resource	Description
Factsheets	Technical overviews of R729, R717, R744, and Hydrocarbons - eurammon.com/resources
Information Papers	In-depth guidance on natural refrigerants and their applications - Informtion papers | eurammon
Case Studies	Documented real-world applications across industries - Case studies | eurammon
video: “Naturally Cool”	History and use of natural refrigerants -YouTube: naturally cool - History and Development of Natural Refrigerants
Historical use	In early refrigeration systems in the late 19th and early 20th centuries

Further Reading and References:
eurammon Resources

Acknowledgement

This paper is a product of the eurammon Steering Committee. We thank the following experts for their contribution:

Angback, Tommy	Alfa Laval Technologies AB
Bücherl, Markus	Johnson Controls Systems & Service GmbH
Colbourne, Daniel	Re-phridge Ltd
Forsberg, Stina	KRAHN Specialty Fluids AB
Frank, Thomas	Refolution Industriekälte GmbH
Kuijpers, Lambert	A/gent Consultancy b.V
Pruss, Yannick	Refolution Industriekälte GmbH
Rabenstein, Michael	Evapco Europe GmbH
Schadt, Joachim	Secon GmbH
Schultze, Sebastian	GEA Refrigeration Germany GmbH
Van der Hoff, Menno	Triple Aqua Licensing Ltd.

Disclaimer

This guide is intended as general technical orientation for professionals in the RACHP sector. It does not constitute engineering design advice and does not replace project-specific system design, risk assessment, or compliance with applicable standards and national regulations — including EN 378, the IEC 60335 series, the Pressure Equipment Directive 2014/68/EU, the ATEX Directives, and local building, fire and workplace safety codes.

The figures and decision trees in this guide are simplified representations intended to orient the reader. They do not cover every system variant, site constraint or national requirement. Safety classifications, charge limits and regulatory requirements are stated as at September 2026 and are subject to change; EN 378 is currently under revision. All values must be verified against the current editions of the relevant standards and against the specific installation.

Systems using flammable, toxic or high-pressure refrigerants must be designed, installed, commissioned and maintained by suitably qualified personnel.
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Edition:

First edition, October 2026. Regulatory information current as at October 2026.
Suggested citation: eurammon e.V. (2026): Choosing the best Natural Refrigerant for your Application. A eurammon Guide for the Refrigeration, Air Conditioning and Heat Pump Sector. Königstein im Taunus.

Editor: euroammon Secretariat - coordinated by Britta Patzold
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Authorised representatives: Rob Vandenboer, Chair; Michael Freiherr, Vice Chair
VAT identification number (USt-IdNr.): DE325029648