# COVID-19 and how to establish a sustainable and climate resilient vaccine cold chain


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# Abbreviations

| | |
|---|---|
| ATEX | Appareils destinés à être utilisés en ATmosphères EXplosives (French for Equipment intended for use in Explosive Atmospheres). |
| BMU | German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (by their German acronym) |
| CFCs | Chlorofluorocarbons |
| $CO_2$ | Carbon Dioxide |
| CSC | Centre for Sustainable Cooling |
| COP | Coefficient of Performance |
| COVID-19 | Coronavirus disease 2019 (COVID-19) is a contagious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). |
| C4 | Project 'Cool Contributions fighting Climate Change' (BMU financed) |
| DEKRA | Deutscher Kraftfahrzeug-Überwachungs-Verein (German Motor Vehicle Inspection Association) is a European vehicle inspection company, that also certifies cold chains. |
| DHL | Dalsey Hillblom Lynn, is a German logistic company providing international shipping and courier services). |
| DNA | Deoxyribonucleic acid |
| DQS | DQS Holding GmbH is German multinational company and one of the leading certification bodies for management systems worldwide that also certifies cold chains. |
| EC | European Commission |
| EER | Energy Efficiency Ratio |
| eNDC | enhanced National Determined Contributions |
| EoL | End of Life |
| EU | European Union |
| FedEx | FedEx Express, is an American multinational delivery services company. |
| F-gases | Fluorinated-greenhouse gases |
| Gavi | International organization, vaccine Alliance, public–private global health partnership |
| GCI | Project 'Green Cooling Initiative' (BMU financed) |
| GDP | Good Distribution Practices |
| GHG | Green House Gases |
| GIZ | Deutsche Gesellschaft für internationale Zusammenarbeit GmbH |
| GPP | Green Public Procurement |
| GWP | Global Warming Potential |
| HCFCs | Hydrochlorofluorocarbons |
| HCs | Hydrocarbons |
| HFCs | Hydrofluorocarbons |
| HFOs | Hydrofluoroolefins |
| HPMP | HCFC Phase-out Management Plan |
| IATA | International Air Transport Association |
| IEC | International Electrotechnical Commission |
| IKI | International Climate Initiative (of BMU) |
| IPCC | Intergovernmental Panel on Climate Change |
| IRR | Financial: Internal Rate of Return |
| ISO | International Organization for Standardization |
| K-CEP | Kigali - Cooling Efficiency Program |
| LN2 | Liquid Nitrogen |

| | |
|---|---|
| MEPS | Minimum Energy Performance Standards |
| mRNA | Messenger Ribonucleic Acid |
| NDC | National Determined Contributions |
| $NH_3$ | Ammonia |
| NPV | Financial: Net Present Value |
| ODP | Ozone Depletion Potential |
| ODS | Ozone Depleting Substance |
| PATH | An international, non-profit global health organization |
| PQS | Performance, Quality and Safety |
| PU | Polyurethane |
| QR | Quick Response |
| RAC | Refrigeration and Air Conditioning |
| SARS-CoV-2 | Severe acute respiratory syndrome coronavirus 2 |
| SDD | Solar Direct Drive |
| SDG | Sustainable Development Goals |
| SGS | SGS is a Swiss multinational company, which provides inspection, verification, testing and certifi cation services, also for cold chains. |
| SOP | Standard Operational Procedures |
| TCR | Temperature Control Regulations |
| TFAs | Trifluoroacetic Acids |
| TÜV | Technischer Überwachungsverein (TÜV); (Technical Inspection Association) are internationally active, independent service companies from Germany and Austria that test, inspect and certify technical systems, facilities and objects of all kinds. They are also certifying cold chains. |
| UL | Underwriter Laboratories is a US certification company that certify products incl. RAC equipment regarding safety standards. |
| ULT | Ultra-Low Temperature |
| UNICEF | United Nations International Children's Emergency Fund |
| UPS | United Parcel Service, is an American multinational package delivery and supply chain management company. |
| USA | United States of America |
| VIP | Vacuum Insulation Panels |
| WHO | World Health Organization |
| WRTM | Wireless Remote Temperature Monitoring |

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We thank the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) for their support.
Moreover, we are grateful for the collaboration and support of all the people, institutions and companies that assisted in the data collection and advice of this study.

## Projects background

GIZ Proklima is a global programme that has been sustainably transforming the cooling sector in emerging and developing countries since 1995. GIZ Proklima implements projects under the Montreal Protocol and under the Paris Agreement.
The Green Cooling Initiative (GCI) is a global initiative and network, funded by the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). The GCI aims to promote sustainable cooling globally. It was formed through a union of various projects and prestigious partners. The GCI has many network members from the private and public sector and operates the internet platform www.green-cooling-initiative.org.

Cool Contributions fighting Climate Change (C4) is a global project, funded by the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). C4 aims to further pursue the international control of F-gases and improve the framework conditions for the use of energy-efficient Refrigeration and Air Conditioning (RAC) equipment and environmentally friendly natural refrigerants and blowing agents.

## Important notice

This publication provides examples of products based on climate-friendly internet research. We are product neutral and do not want to support a specific company. We kindly want to emphasize that these product lists are not complete, meaning that there are many more products available that have similar technical specifications and use ultra-low Global Warming Potential (GWP) refrigerants and blowing agents. Some products do only use ultra-low GWP refrigerants but contain high GWP Hydrochlorofluorocarbon (HCFC) blowing agents, which have been used for the insulation material. Many times, we did not find or receive information on the blowing agents. Consequently, we did not include these products, because they probably cannot be fully labelled as green products. Again, our research might be lacking and there are probably similar products available. Consequently, the product lists shall only be used as green product examples and we strongly recommend to anybody who wants to procure green products to do their own research according to their specific technology requirements and geographic location.

# Introduction

Cooling or freezing equipment for vaccines and the vaccine cold chain itself are quite complex in developed and especially in developing countries. The pandemic COVID-19 (SARS-CoV-2) represents a unique challenge globally, not only economically, but also logistically. Distributing the vaccine to preferably 70 percent of the global population within a short time frame of around 2-3 years is seen by many as the largest refrigeration project ever in history.

With the successes of Moderna's mRNA-1273 vaccine, University of Oxford, and AstraZeneca's AZD1222 vaccines and other vaccines to follow to near future, it seems that a large part of the global vaccine cold chain requires temperatures that are in the temperature range of current conventional vaccines. However, the BioNTech-Pfizer BNT162 vaccine requires temperatures of -70°C. Many countries already purchased millions of doses of it, meaning they will also need to have the required cold chain in place.

Although many countries do have an existing cold chain for conventional vaccines, even these cold chains are not prepared to vaccinate up to 70 percent of the total population mostly twice within a few weeks (apart from Johnson & Johnson) and maybe even a third time after within a longer time frame. Consequently, most countries require quick improvements of their cold chains for vaccines and therefore will need to purchase thousands of new facilities and equipment soon.

Nevertheless, most conventional vaccine cooling and freezing technologies use high Global Warming Potential (GWP) Hydrochlorofluorocarbon (HCFC)/ Hydrofluorocarbon (HFC) refrigerants. Moreover, this equipment has often a relatively low energy efficiency. In contrast, climate-friendly and energy-efficient vaccine cooling and freezing technologies which use ultra-low GWP climate-friendly refrigerants and blowing agents are available.

Green Cooling and Freezing technologies are defined in this publication as the following:

- They use ultra-low GWP (<10) refrigerants, preferably natural refrigerants such as hydrocarbons (HCs).
- They contain insulation materials that are produced with ultra-low GWP (<12) and zero Ozone Depletion Potential (ODP) blowing agents, preferably natural refrigerants.
- They have a high Energy Efficiency Ratio (EER) or low energy consumption per 24hours/ annually and use preferably inverter technology.
- Additionally, they can be powered or backed up by renewable energy sources such as solar energy.

Some people argue that what is now urgently required is to improve the cold chain and that there is no time and no priority to consider climate and environmental aspects. However, this publication is arguing to use this moment to establish a smart, sustainable, green and climate-friendly system for the future, which is aligned and consistent with multilateral agreements. The procurement of thousands of cold chain equipment can also be seen as a chance for green recovery and climate resilience.

Consequently, this publication aims to provide guidance regarding the procurement of climate-friendly and energy-efficient vaccine cooling and freezing technology solutions.

Additionally, this publication focuses on aspects related to standards, training, certification, digitalisation, recycling or destruction of obsolete equipment, cost saving, sustainability, and climate change mitigation potential.

# 1 Background information

## 1.1 Climate change goals

In 2015, 196 countries agreed to the Paris Agreement with the objective to reduce global warming to 1.5°C to 2°C above pre-industrial levels. The national commitments have been formulated in the Nationally Determined Contributions (NDCs), which are currently enhanced (eNDCs). In many NDCs aspects of energy efficiency and HCFC/HFC refrigerants and blowing agents are mentioned.[1]

In 1987 under the Montreal Protocol an international agreement was concluded to protect the stratospheric ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS). First, CFCs have been phased out in the year 2010. HCFCs are currently phased out until 2030. In 2016, under the Kigali Amendment the international community agreed to phase down HFCs globally latest until 2045/2047 to 20/15 percent of the baseline[2]. However, many developed countries agreed to reduce the HFC consumption much faster. For example, in the European Union (EU) F-gas legislation aims to reduce the HFCs consumption by 79 percent until 2030[3].

The global cold chain is responsible for around one percent of global GHG emissions (indirect and direct)[4]. Consequently, this publication argues for cold chains that have no harmful impact for ozone layer as well as are climate-friendly and energy-efficient.

In addition to the climate change goals, the Sustainable Development Goals (SDGs)[5] need to be considered in the context of cold chains. "Immunization is one of the best buys in global health and has a crucial role in achieving 14 of the 17 SDGs". [6]

## 1.2 Direct emissions

Direct emissions mainly result due to refrigerant leakages and account for around 30 percent of the global cold chain related emissions or 0.3 percent of global Green House Gas (GHG) emissions.[7]

Most conventional vaccine cooling and freezing technologies nowadays use HFC refrigerants. However, there is a lot of equipment installed in many developing countries which still contains HCFC and even CFC refrigerants or blowing agents.

Many manufacturers of vaccine refrigeration and freezing technologies state that their product does not contain CFC or HCFC refrigerants. At the same time, however, they often do not clarify that the product contains high GWP HFC refrigerants (e.g. R-404A, GWP 3922) and that the insulation materials (blowing agents) of cold rooms still contain HCFCs (e.g. R-141b GWP 782, ODP 0.11). A GWP of 3922 means that one kg of R-404A refrigerant accounts to the equivalent of 3.9 tons of $CO_2$. HCFCs such as R-141b also have a negative impact on the ozone layer (measured in ODP) in addition to the negative climate impact.

GWP levels and ODP of refrigerants for vaccine refrigeration and freezer technologies as well as insulation foam are shown in Table 1. For comparison also climate-friendly ultra-low GWP refrigerants are shown.

1 UNFCCC (no date) NDCs.
2 Montreal Protocol (2016) *Kigali Amendment*
3 European Environment Agency (2014) Regulation (EU) No 517/2014
4 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*
5 UN (No date) *The 17 Goals | Sustainable Development.*
6 Gavi (no date) *Sustainable Development Goals.*
7 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*

Table 1: Overview ODP and GWP of HCFC, HFC, HFO and ultra-low GWP refrigerants[8]

| Refrigerant | Type | GWP kg CO2eq./kg refrigerant | ODP |
|---|---|---|---|
| C5H10 | HC | 11 | 0 |
| LN2 | LN2 | 0 | 0 |
| R-11 | CFC | 4660 | 1 |
| R-12 | CFC | 10200 | 0.82 |
| R-22 | HCFC | 1760 | 0.005 |
| R-23 | HFC | 12400 | 0 |
| R-134A | HFC | 1300 | 0 |
| R-141b | HCFC | 782 | 0.110 |
| R-170 | HC | 6 | 0 |
| R-152a | HFC | 138 | 0 |
| R-290 | HC | 3 | 0 |
| R-245fa | HFC | 858 | 0 |
| R-365mfc | HFC | 804 | 0 |
| R-404A | HFC | 3922 | 0 |
| R-407A | HFC | 2107 | 0 |
| R-449A | HFO | 1397 | 0 |
| R-452A | HFO | 2141 | 0 |
| R-507A | HFC | 3985 | 0 |
| R-600a | HC | 3 | 0 |
| R-601 | HC | 4 + -2 | 0 |
| R-601a | HC | 4 + -2 | 0 |
| R-744 | $CO_2$ | 1 | 0 |
| R-717 | $NH_3$ | 0 | 0 |
| R-729 | AIR | 0 | 0 |
| R-1150 | HC | 4 | 0 |
| R-1233zde | HFO | 1 | 0 |
| R-1270 | HC | 2 | 0 |
| R-1336mzz(Z) | HFO[9] | 2 | 0 |
| R-1336mzz(E) | HFO | 7 | 0 |

8 IPCC (2013) *Anthropogenic and Natural Radiative Forcing.*
9 IPCC (2005) *Special Report on Safeguarding the Ozone and the Global Climate System.*

The World Health Organization (WHO) Performance, Quality and Safety (PQS) equipment catalogue still contains many units that still use HFC refrigerants with a GWP up to 3,922 and maybe even insulation materials that have been produced with HCFC high GWP blowing agents. The PQS does not provide information on the blowing agents used in the equipment.[10]

For example, if one vaccine cold or freezer room for vaccines contains a refrigeration unit with 1 kg of the refrigerant HFC R-404A, the climate impact (if released to the atmosphere) of the cold room amounts to almost 4 tons of $CO_2$ equivalent for the initial refrigerant charge. It must be mentioned that refrigerant leakages are quite common and occur frequently during operation, especially in developing countries. Most refrigerant is released to the environment at the end of life of the equipment. Moreover, assuming an average 10 percent annual leakage rate and a 15 years total lifespan, on average a total of 240 percent of leakages occur. This results in direct emissions results in direct emissions of almost 11 tons of $CO_2$ equivalent over the life span of the equipment, or 53,000 km driving with an average car.[11] In contrast one equipment using the climate-friendly and ultra low GWP refrigerant e.g. R-290 emits only around 3 kg over the lifetime. This calculation does not include indirect emissions due to energy use.

## 1.3 Indirect emissions

Indirect emissions, due to energy consumption produced by fossil fuels, account for around 70 percent of the global cold chain related emissions or 0.7 percent of global GHG emissions.[12]
A lot of the vaccine cold chain equipment is outdated or malfunctioning[13] and consumes far too much energy compared to the state-of-the-art equipment.

Currently installed conventional vaccine cooling and freezing technologies use HCFC (or even CFC), but mainly HFC and sometimes HFO refrigerants, which have often a relatively low energy efficiency compared to HC refrigerants. This is either due to the age of equipment (HCFC and CFC units) or due to the thermionic properties of the refrigerants (CFC or HFC[14] or HFO[15]).

Besides this, even new vaccine refrigeration or freezing units have low energy performance because energy efficiency is often not the priority. For example, the WHO PQS equipment catalogue does not consider energy efficiency ratios (EER) nor annual energy consumption. Only the indicator kWh/24h is considered, but not for cold or freezer rooms.[16] Energy performance testing and certification, energy rating (EER), Minimum Energy Performance Standards (MEPS) or energy labelling is lacking for vaccine laboratory equipment.

Additionally, a lot of equipment is powered or uses back-up power generated by diesel generators, which could be replaced by solar systems[17].

Consequently, there is a huge energy, GHG emission mitigation and cost saving potential regarding energy efficiency improvements of vaccine cold chain equipment.

10 However, the PQS generally mentions that cyclopentane is used in European countries R141b in the USA, because *"the use of R141b was banned in Europe as of 1st January 2004 and it will eventually be phased out worldwide in 2030".*
11 Diesel 3.17 kg/l. Petrol 2.78 kg/l. Average: 2.975 kg/l. Average use per 100 km = 7 liters.
12 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*
13 PATH et al. (2015) *Next-generation immunization supply chains are needed to improve health outcomes.*
14 HC 21 (no datet) H*ydrocarbons FAQ.*
15 Raveendran, Saji & Sekhar, Joseph. (2019). *Energy and exergy analysis on hydrofluoroolefin/ hydrofluorocarbon (HFO/HFC) refrigerant mixtures in low and medium temperature small-scale refrigeration systems.*
16 WHO (2020) *PQS devices catalogue.*
17 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*

# 2. The vaccine cold chain

The cold chain for vaccines involves many steps as shown in Figure 1 below. This publication will focus on the following 3 stationary parts of the cold chain:

- Central storage
- District/regional storage
- Hospitals/clinics/health centers/ pharmacies

Transport between the 3 parts will not be addressed.

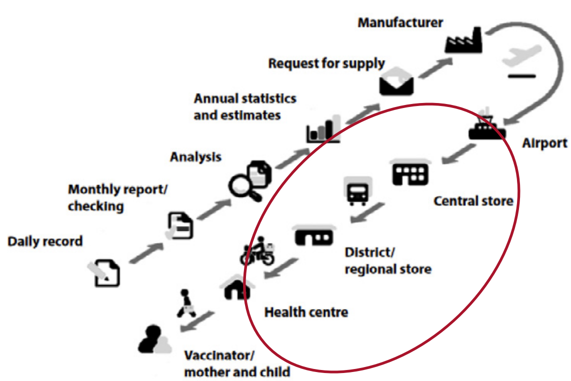



Figure 1: The vaccine cold chain [18]

## 2.1 Current existing vaccine cold chain

According to a study, for the year 2014 comprising 57 Gavi-eligible low and lower-middle-income countries[19], 20 percent of health facilities were unequipped with cold chain equipment, 14 percent had non-functional equipment and 41 percent had poor-performing equipment. This sums up to 75 percent of the health facilities having none or non-functional or poor-performing equipment. 23 percent had outdated but adequate equipment and only 2 percent had optimal equipment in place (see Figure 2).[20]

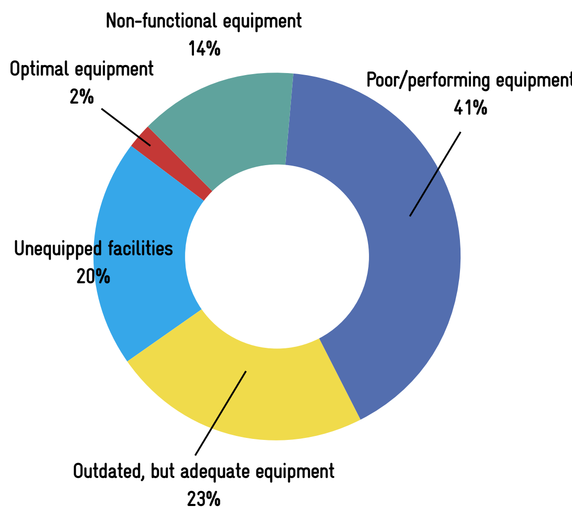



Figure 2: Status of cold chain equipment in 57 low- and lower-middle-income countries [21]

The majority of the new vaccine generations are freeze sensitive and therefore well-functioning cold chain equipment is essential. However, that status on cold chain equipment stated above highlights that 55 percent of the cold chain equipment is lacking regarding freeze sensitivity. For example, according to a study by the WHO in India for the year 2012, 76 percent of freeze-sensitive vaccines had been exposed to freezing.[22]

18 WHO and PATH (2015) *Module 2: The vaccine cold chain.*

19 Gavi (2020), Countries are classified as Gavi-eligible "if their average Gross National Income (GNI) per capita has been less than or equal to US$ 1,630 over the past three years (according to World Bank data published in July each year (Gavi 2020a)." In the year 2020 there were 57 Gavi eligible countries that were able to apply for new vaccine support.

20 PATH et al. (2015) *Next-generation immunization supply chains are needed to improve health outcomes.*

21 Adapted from Ibid.

22 Murhekar, M. V et al. (2013) *Frequent exposure to suboptimal temperatures in vaccine cold-chain system.*

The age of equipment can also be measured in terms of the used refrigerant. According to data (2009-2017) from 81 countries across all 6 WHO regions, between 12-16 percent of cold chain equipment still contains CFC refrigerants (see Figure 3)[23] even though a global ban on the use of CFCs has been in place since 2010.[24]

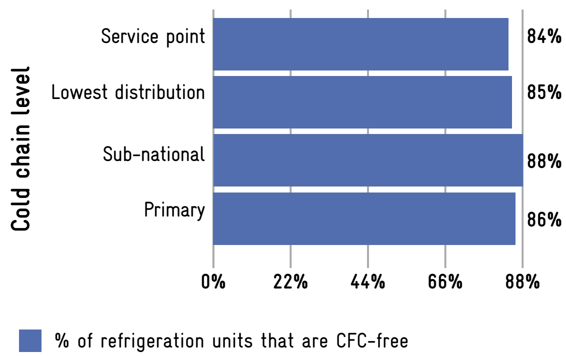



Figure 3: Percentage of CFC-free equipment across cold-chain levels[25]

According to the WHO Performance, Quality and Safety (PQS) catalogue for prequalified devices and equipment, the product list includes currently only 5 different cold/freezer rooms of which 4 contain equipment with R-404A and only one provider offers equipment with R-134a, R-407A and R-452A refrigerants. When it comes to the insulation foam materials the PQS provides information on the blowing agents. But energy consumption or energy efficiency ratings are not mentioned at all.[26]

When it comes to refrigerators and freezers for vaccines the PQS indicates 88 units including 44 solar units. Of these 88 units already 69 units contain the ultra-low GWP refrigerant R-600a or R-290. Regarding the insulation foam and its blowing agent no information is provided.[27] The energy consumption is mentioned in kWh/24h. However, no annual energy consumption nor energy efficiency rating (EER) is specified.[28]

23 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*
24 Montreal Protocol (2016). *Kigali Amendment.*
25 Adapted from Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*
26 WHO (2020) *PQS devices catalogue.*
27 The PQS generally mentions that cyclopentane is used in European countries and R141b in the USA, because *"the use of R141b was banned in Europe as of 1st January 2004 and it will eventually be phased out worldwide in 2030".*
28 WHO (2020) *PQS devices catalogue. Product List E003.*

Table 2: Selected vaccine candidates and their temperature requirements
(Vaccines that are on 3rd phase as of 26 January 2021)

<table>
<tr><th></th><th>Vaccine/ Producer[29 30]</th><th>Storage</th><th>End storage</th><th>Out of storage (Room temp)</th></tr>
<tr><td rowspan="10">+8°C<br>+46°F<br>to<br>+2°C<br>+36°F</td><td>Oxford/AstraZeneca[31 32]</td><td rowspan="2">Up to 6 months</td><td rowspan="2">Up to 6 months</td><td>–</td></tr>
<tr><td>CanSino Biologics/Beijing Institute of Biotechnology[33]</td><td>Up to one week</td></tr>
<tr><td>Sputnik V/Gamaleya Research Institute[34]</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Johnson & Johnson/ Janssen[35]</td><td>Up to 3 months</td><td>Up to 3 months</td><td>–</td></tr>
<tr><td>Sinovac[36]</td><td>Up to 3 years</td><td>Up to 3 years</td><td>–</td></tr>
<tr><td>Bharat Biotech[37]</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Beijing Institute of Biological Products/Sinopharm[38]</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>CureVac[39]</td><td>Up to 3 months</td><td>Up to 3 months</td><td>Up to 24 hours</td></tr>
<tr><td>Wuhan Institute of Biological Products/ Sinopharm[40]</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Novavax[41]</td><td>Up to 6 months</td><td>Up to 6 months</td><td>–</td></tr>
<tr><td>-15°C<br>+5°F<br>to<br>-25°C<br>-13°F</td><td>Moderna/NIAID[42]</td><td>-20°C Up to 6 months</td><td>+2 to +8°C (+36 to +46F) up to 30 days</td><td>Up to 6-12 hours 2° to 25°C (36° to 77°F)</td></tr>
<tr><td>-70°C<br>-94°F</td><td>BioNTech/ Pfizer[43]</td><td>Up to 6 months[44]</td><td>+2 to +8 C (+36 to +46F) up to 5 days</td><td>Up to 2 hours 8° to 25°C (46° to 77°F)</td></tr>
</table>

29 Fischetti, M. (2020) *The COVID Cold Chain.*
30 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*
31 Daley, B. (2020)
32 AstraZeneca (2020)
33 Mak, E. (2020)
34 Sputnik V (2020)
35 Levine, H. (2021)
36 Kim, M. and Liu, R. (2020)
37 Ella, R. et al. (2021)
38 Sinopharm (2020)
39 CureVac (2020)
40 40 Sinopharm (2020)
41 Novavax Inc (2020)
42 Moderna Inc (2020), "Unpunctured vials may be stored between 8° to 25°C (46° to 77°F) for up to 12 hours. Do not refreeze. After the first dose has been withdrawn, the vial should be held between 2° to 25°C (36° to 77°F). Discard vial after 6 hours. Do not refreeze."
43 Ontario Ministry of Health (2021) *COVID-19: Vaccine Storage and Handling Guidance*
44 "*Once opened, and if being used as temporary storage by a vaccination centre, it can be used for 30 days by re-icing every five days*", Ibid.

## 2.2 Temperature requirements on the cold chain

According to a white paper of DHL (2020) only 25 countries (approximately 2.5 billion people) do have a cold chain in place which could comply with the temperature requirement of -70°C (see Figure 4).[45] This means that with the currently existing cold chains the BioNTech-Pfizer vaccine cannot be stored and distributed accordingly in most countries. Moreover, there is indication that even developed countries[46] do not have sufficient infrastructure in place to cope with the required storage capacity because this type of equipment is less available than equipment for conventional temperate ranges.

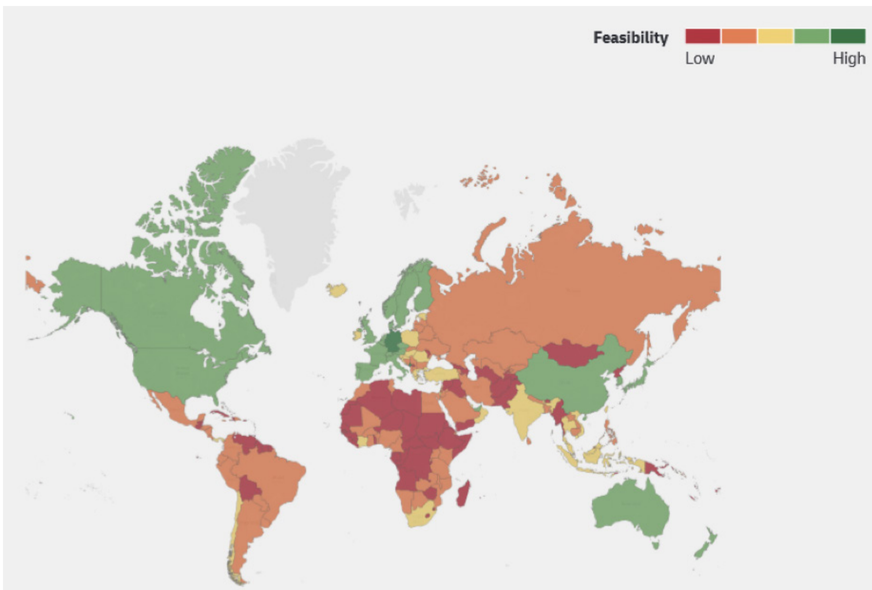



Figure 4: Existing cold chains of -70C temperature requirements[47]

## Temperate ranges -20°C

Most countries do also have an existing vaccine cold chain for the temperate range of up to -20°C. However, these types of equipment are less available than for the temperate ranges of +2°C to +8°C. WHO Effective Vaccine Management (EVM) data from 81 countries (see Figure 5) collected between 2009 and 2017 indicates that cold chain storage equipment for -20°C is not available at service point and district level. Even at sub-national level only 85 percent do have vaccine storage capacities for -20°C.[48]

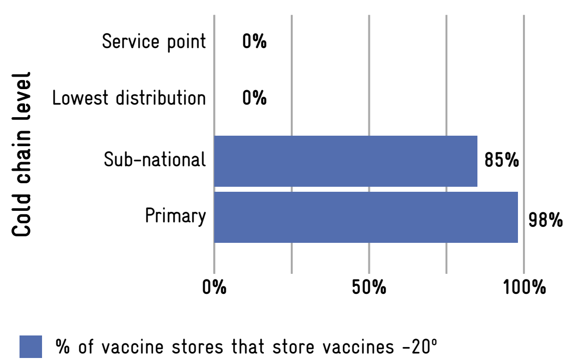



Figure 5: Percentage of vaccine stores keeping vaccines at -20°C[49]

45 DHL (2020) *DHL White Paper.*
46 WHO and PATH (2015) *Module 2: The vaccine cold chain.*
47 DHL (2020) *DHL White Paper.*
48 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*
49 Adapted from Ibid.

### Temperate ranges +2°C to +8°C

Most countries have an existing vaccine cold chain for the temperate range of +2°C to +8°C. According to the WHO, however, there are also many countries that are even lacking vaccine storage capacities within this temperate range.[50] The previously mentioned DHL (2020) white paper estimates that around 60 countries with a total population of around 5 billion have such cold chains in place (see Figure 6).[51] But, in many other countries the existing technologies do not function because they are outdated. Furthermore, their cold chains are not set up to provide vaccine cooling or freezing capacities for large quantities that are required for the expected supply and demand of the vaccination of up to 70 percent of the population within a short time frame. Consequently, many countries need to further invest in their cold chains soon, resulting in thousands of new purchases worldwide.

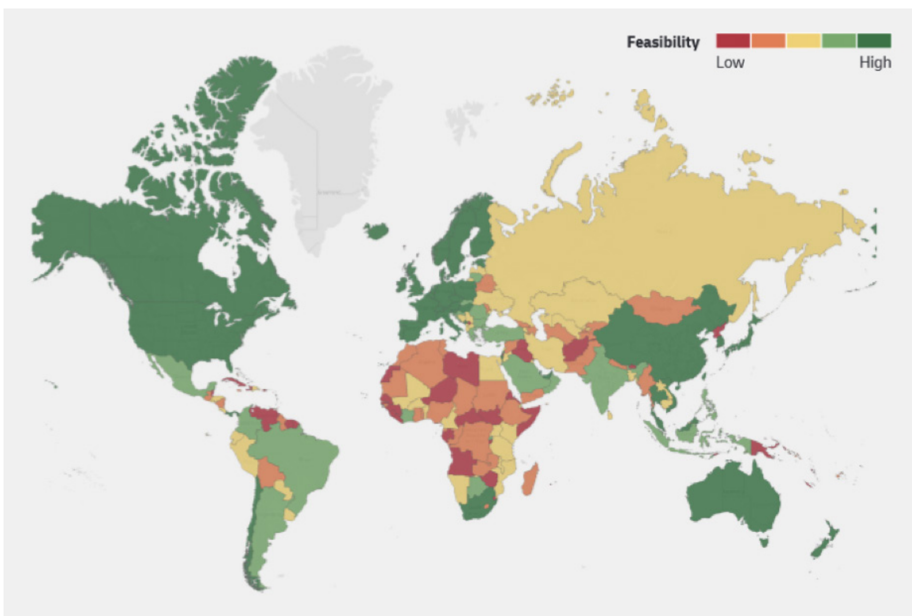



Figure 6: Existing cold chains of conventional temperature requirements[52]

[50] WHO and PATH (2015) *Module 2: The vaccine cold chain.*
[51] DHL (2020) *DHL White Paper.*
[52] Ibid.

# 3 Climate-friendly technologies

Climate-friendly technologies use refrigerants which have an ultra-low GWP (<10), such as natural refrigerants. Furthermore, climate-friendly technologies also use insulation foam for example for cold/freezer rooms that are produced out of ultra-low GWP (<12) blowing agents such as hydrocarbons (e.g. pentane, isopentane, cyclopentane), water-blown or liquid $CO_2$ (see Table 3). Due to the thermodynamics of natural refrigerants, mainly HCs, the energy efficiency of climate-friendly technologies is relatively superior compared to most conventional technologies. Consequently, these technologies are not only climate-friendly but also have lower energy consumption. This leads to a lower carbon footprint because most countries have a carbon intensive power generation, which results in additional $CO_2$ emissions per kWh of energy used (grid emission factor).

This publication mainly focuses on refrigerants and blowing agents, but also lookes at energy consumption and efficiency if information was available. Generally, it can be said that the thermodynamics (a higher Coefficient of Performance (COP), and a low condensing temperature) of natural refrigerants, such as HCs, are excellent. Therefore, equipment with HCs is relatively more energy-efficient, compared to most conventional equipment.[53] Besides this, if available, inverter technologies should also be considered for the procurement of equipment. Energy consumption (preferable annually) and energy efficiency ratios/ ratings (EERs) shall be assessed and considered.

Although the investment costs of climate-friendly and energy-efficient technologies might be a bit higher in the beginning of the investment life cycle, these costs are usually harmonizing over a short time frame due to the higher energy efficiency and thus lower energy costs. Moreover, environmental costs of the released $CO_2$ emissions of refrigerants (direct emissions) or the energy consumption (indirect emissions) due to the fossil fuels energy generation must be considered in the life cycle costs as well.

The following climate-friendly and energy-efficient technology solutions are currently available for various required cold chain temperatures.

## 3.1 National, district or regional level

At a national, district or regional level the following stationary cold/freezer rooms for vaccine cooling/ freezing options exist:

- Insulated cold/freezer rooms with mono blocks
- Site-built insulated cold/freezer rooms with a separate condensing and evaporator refrigeration/freezer unit
- Mobile cold/freezer container.

### 3.1.1 Stationary cold/freezer rooms

Cold rooms or freezer rooms (also referred to as walk-in cold rooms or freezer rooms) are usually used for national or regional storage. For standard vaccine temperature requirements (+2 to +8 or -20°C) usually standard insulated cold/freezer rooms with a mono-block refrigeration/freezer unit (see Figure 7) are used. Alternatively, site-built insulated cold/freezer rooms with a separate condensing and evaporator refrigeration/freezer unit, also referred to as split units, can be built (see Figure 8).

53 Raveendran, Saji & Sekhar, Joseph. (2019). *Energy and exergy analysis on hydrofluoroolefin/ hydrofluorocarbon (HFO/HFC) refrigerant mixtures in low and medium temperature small-scale refrigeration systems.*


Picture 1: Cold room. © Aleksandr Ivasenko/shutterstock.com

There are many climate-friendly on site built insulated cold/freezer rooms with a separate condensing and evaporation units (split system) available. However, they require more tailor-made technical knowledge and expertise on the ground to ensure proper and safe operation. Therefore, this publication will only focus on cold/freezer rooms with mono-block units since they offer all requirements regarding temperatures and are less complicated regarding the technical conditions and safety aspects and qualifications of technicians.

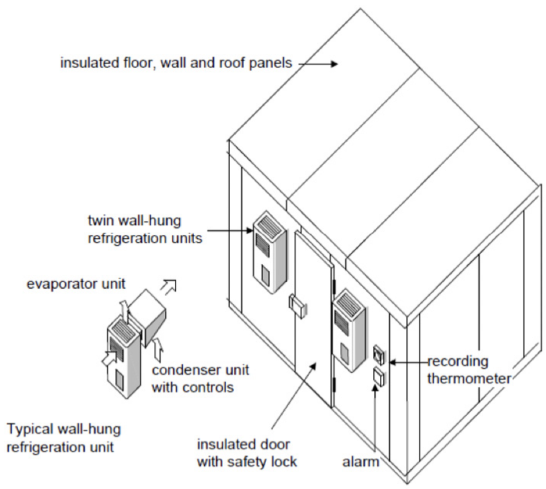



Figure 7: Standard insulated cold/freezer room with mono-block unit[54]

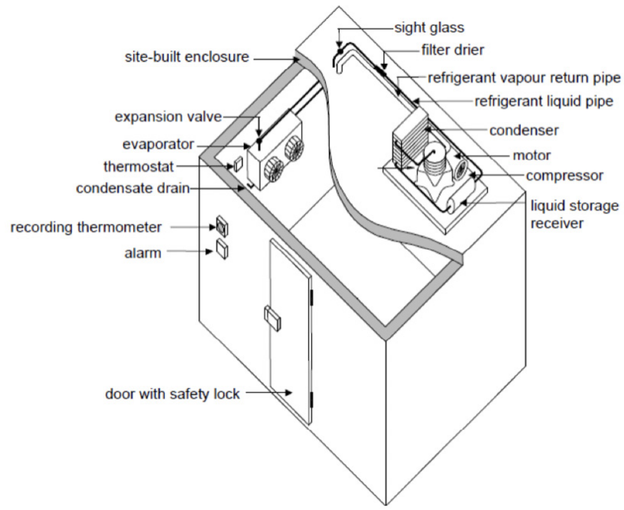



Figure 8: Site-built insulated cold/freezer rooms with a separate condensing and evaporator refrigeration/freezer unit[55]

Standard insulated cold/freezer rooms with a mono-block refrigeration/freezer unit (see Figure 7) have the advantage that they can be easily set up because they use a mono-block refrigeration/freezer unit. The installation is quite simple. Moreover, most standard insulated cold/freezer rooms with mono-block units are also cheaper than tailor made cold rooms. While standard insulated cold/freezer rooms with mono-blocks have their limitations when it comes to size and capacity of vaccines, they are large enough for most regional storage centers (depending on population to be vaccinated, continued supply of vaccines and required storage capacities). Even for national storage they are suitable because several cold/freezer rooms can be set up next to each other, permitting different cold/freezer rooms for different temperatures. Having several standard storage rooms has a further advantage. advantage that If one refrigeration/freezer unti breaks down, not all freezer unit breaks down, not all vaccines might need to be used within a short time frame. To ensure 24/7 power supply it is recommended that a back-up power supply is installed.

The PQS catalogue includes currently only 5 different cold/freezer rooms of which 4 contain equipment with R-404A and only one provider offers equipment with R-134a, R-407A, R-452A.[56]

Mono-block condensing units exist from various manufacturers (see Table 3) also with climate-friendly ultra-low GWP refrigerants such as R-290, R-170 or R-744 ($CO_2$) or R-729 (AIR). They have a high energy efficiency performance and therefore require less energy. The maximum ambient temperature is up to 43/45°C, meaning this type of equipment can be used globally. In contrast conventional mono-block refrigeration/freezer units use HCFC or HFC refrigerants.

The cooling capacity of the systems is likely to increase in the near future due to the increased maximum allowed charge from 150g to 500g of flammable refrigerants per refrigerant circuit (regulated in the updated IEC 60335-2-89:2019 standard).[57] This will also increase the size of the cold room per system. However, as mentioned before, for vaccine storage it would be beneficial to install two smaller refrigeration systems instead of one larger system. If one system fails there is still a functioning system left.

54 WHO and PATH (2015) *Module 2: The vaccine cold chain.*
55 Ibid.
56 WHO (2020) *PQS devices catalogue. Product List E003: Refrigerators and freezers.*
57 IEC (2019) IEC 60335-2-89:2019.

Table 3: Examples of climate friendly mono-blocks with ultra-low GWP refrigerants for cold/freezer rooms

| Manufacturer | Ref. | Temp. range °C | Cooling cap. in kw (50Hz)[58] | Size in $m^3$ [59] | Energy consumption in kW |
|---|---|---|---|---|---|
| Frigadon[60] | R-290 | +4 to +2<br>+4 to +2<br>-20 to -22 | 0.6 – 2.4<br>0.6 – 14.8<br>0.8 – 13.3 | 3 – 105 (+4°C)<br>5 – 430 (+4°C)<br>12 – 534 (-20°C) | 0.85 – 2.15<br>0.3 – 12<br>2.1 – 18.6 |
| Intarcon[61] | R-290 | +10 to 0<br>+10 to -5<br>+10 to -5<br>-15 to -25<br>-15 to -25<br>-20 to -35 | 0.7 – 2.1 (+5°C)<br>0.8 – 2.8 (+5°C)<br>6.5 – 51.5 (+5°C)<br>0.4 – 1.1 (-20°C)<br>0.4 – 1.2 (-20°C)<br>5 – 29.7 (-20°C) | 7 – 43 (+5°C)<br>6 – 28 (+5°C)<br>No information<br>2 – 8 (-20°C)<br>2 – 14 (-20°C)<br>No information | 0.4 – 1.31<br>0.30 – 1.34<br>2.5 – 17.8<br>0.26 – 0.96<br>0.38 – 0.97<br>3.5 – 20.1 |
| Intarcon[62] | R-170 | -60 to -80 | 0.4 – 0.65 (-80°C) | 3 (-80°C) | 0.65 |
| Mirai[63] | R-729 (AIR) | -40 to -110<br>-60 to -110 | 6.5 – 16.0<br>5.4 | No information provided | 10.5 – 23<br>10 |
| Rivacold[64] | R-290 | +5 to -5<br>-15 to -25 | 1.2 – 3.1 (+5°C)<br>1.0 – 4.4 (+5°C)<br>0.8 – 2.8 (-20°C)<br>0.6 – 2.5 (-20°C) | 10 – 38 (+5°C)<br>12.6 – 81.6 (+5°C)<br>5.2 – 20.3 (-20°C)<br>8.2 – 55.5 | No information provided |
| Techno-B[65] | R-290 | +5 to -5<br>-15 to -25 | 1.1 – 3.7 (+5°C)<br>0.8 – 2.1 (-20°C) | 10 – 42 (+5°C)<br>15 – 25 (-20°C) | 0.68 – 2.05<br>0.82 – 2.1 |
| Technoblock[66] | R-290 | +10 to -5<br>-15 to -2 | 0.9 – 4.6 (+5°C)<br>1.2 – 2.5 (-20°C) | 13 – 92(+5°C)<br>4.3 – 28 (-20°C) | No information provided |
| Zanotti (Daikin)[67] | R-744 ($CO_2$) | +10 to -5<br>-16 to -25 | 1.7 – 12.8<br>0.8 – 4.8 | 40 – 200<br>17 – 72 | No information provided |
| Zanotti (Daikin)[68] | R-290 | +10 to -5<br>+10 to -5<br>-15 to -25<br>-15 to -25 | 1.4 – 2.4<br>1.4 – 6.3<br>0.8<br>0.8 – 2.4 | 10 – 25 (+5°C)<br>9.1 – 81 (+5°C)<br>3.4 -4.4 (-20°C)<br>2.7 – 22 (-20°C) | 0.94 – 1.61<br>0.94 – 4.66<br>1.26<br>1.26 |

58 For the 60Hz units the cooling capacity in kw is usually a little bit higher.
59 Average ambient temperature used 32-35 °C. Depending on ambient temperature and on the thickness of the insulation panels. However, the cold/freezer room size can be easily doubled or tripled if a 2nd or 3rd unit is installed.
60 Frigadon (no date) *Cooling Units.*
61 INTARCON (2020) *intartop R-290.*
INTARCON (2020) *intarblock R-290.*
INTARCON (2020) *Superblock R-290.*
62 INTARCON (2021) *CRYOblock system vaccine preservation at-80 °C.*
63 MIRAI (no date) *MIRAI Cold Products.*
64 Rivacold CI (no date) *Product catalogues.*
Rivacold CI (no date) *Ceiling mounted blocksystems.*
Rivacold CI (no date) *Wall mounted blocksystems.*
65 TECHNO-B (no date) *R290 Commercial Straddle-Type Monoblock Units. Reggio Emilia.*
66 Technoblock (no date) *SV Pro range, propane refrigerant r290 unit for cold room.*
67 ZANOTTI (no date) *$CO_2$ Monoblock units*
68 DAIKIN (2018) *Refrigeration Product catalogue 2018; for Zanotti ceiling and wall mounted R-290 units and Zanotti Monoblock R-290 wall and ceiling mounted catalog*

### 3.1.2 Mobile cold/freezer rooms

If time and infrastructure is limited, a quick national/central or district/regional storage solution could be also an insulated reefer container. The advantage is that the container can be immediately used and can also be transported to other places. Moreover, the reefer container could be even be shipped to the final destination, pre-loaded with vaccines.


Picture 2: Insulated reefer container. © Serjio74/Shutterstock.com

In the following some examples of current available reefer containers for vaccines are discussed:

The modified HFC "SuperFreezer" reefer container of ThermoKing can provide temperatures of -70°C. Therefore, it could even be suitable for transporting and storing the BioNTech-Pfizer vaccine. Unfortunately it uses the HFCs R-134a and R-23,[69] latter one has a GWP of 12,400, meaning 1 kg refrigerant has a $CO_2$ equivalent of around 12.5 tons. Each reefer unit is charged with 3.2 kg of R-23, which is equivalent to 39.68 tons of $CO_2$, and leakages can occur frequently during handling and transport. Additionally, the unit also contains R-134a,[70] with a charge of approximately 3 kg. This is equivalent to 3.9 tons of $CO_2$.

In contrast Carrier offers a $CO_2$ NaturalLine container model with a GWP of 1, which can provide temperature of minus -40°C.[71] This is unfortunately not low enough for the BioNTech-Pfizer vaccine, but sufficient for the Moderna vaccine, which requires -20°C and for all other vaccines currently under development requiring +2°C to +8°C. However, energy efficiency aspects need to be considered depending on the ambient temperature.

MECOTEC developed a mobile hybrid 20" container solution that use cryogenics (LN2) as a refrigerant (GWP of 0) that can provide temperatures up to -80°C with a capacity of up to 1 million vaccine doses.[72] LR Kältetechnik also developed a LN2 ULT mobile 20" and 40" container solutions.[73]

Furthermore, reefer containers with R-290 have already been designed[74] and it would require a second refrigeration circuit with R-170, like many ULT freezers already use, to achieve such ultra-low temperatures of -70°C.

## 3.2 Health center level

At hospital, health center, clinic, or pharmacy level the following vaccine cooling/freezing options exist:

- Vaccine laboratory refrigerators for +8/+2°C.
- Vaccine laboratory freezer for -20°C.
- Solar Direct Drive (SDD) Vaccine laboratory refrigerators/freezers.
- Ultra-Low Temperature (ULT) freezers.

### 3.2.1 Refrigerators (+8/+2°C) and freezers (-20°C)

Most hospitals, health centers, clinics or pharmacies do have laboratory or conventional refrigerators/ freezers to store vaccines or medicine for standard refrigeration temperatures of +2°C to +8°C or even freezing temperatures of -20°C.


Picture 3: +8/+2°C pharmacy refrigerator.
© Narah/shutterstock.com

69 Avery, P. (2020) *Thermo King ready for -70 degrees Celsius.*
70 MAERSK (2013) *Super Freezer Refurbishment Guide.*
71 Carrier (2020) *Cold Storage Solutions for COVID-19 Vaccine Distribution.*
Carrier (2020) *Precise Cooling and Monitoring for COVID-19 Vaccines.* [Infographic]
72 MECOTEC (2020) *First Mobile Hybrid Container Solution for COVID-19-Vaccines.*
73 L&R Kältetechnik (2020) *Mobiles Pharmalager für COVID-19 Impfstoffe.*
74 König, H., Bararu, M. and Holtappels, K. (2016) *Practical tests with R290 used in reefer container refrigeration leakage testing.*

Currently many of these old units are based on HFCF refrigerants and some old devices in developing countries even CFCs. Moreover, there are still a lot of new laboratory refrigerators and freezers that contain HFC refrigerants with GWP levels. Some of them have a GWP of 3922 (e.g. R-404A). Besides this, many old refrigerators and freezers contain insulation foam that is produced with blowing agents such as HCFCs (e.g. R-141b) with a GWP of 782 (ODP 0.11) and some old appliances still contain the blowing agent CFC R-11 (GWP 4660, ODP 1).


Picture 4: -20°C hospital freezer.
© ajisai13/shutterstock.com

However, climate-friendly and energy-efficient technologies are available. The PQS of the WHO indicates 88 vaccine refrigerators and freezers, with 42 units with AC power supply included. Out of these 42 units, 28 units are based on the ultra-low GWP refrigerant R-600a, 1 unit contains R-290 and 13 units contain R134a.[75] Examples of climate-friendly and energy-efficient vaccine refrigerators for the temperature range of +2°C to +8°C are shown in Table 4 and examples of laboratory freezers for the temperature range of -20°C are listed in Table 5.

Considering the currently installed equipment especially in developing countries and considering the additional demand of global vaccine storage capacities especially for -20°C freezing temperatures for the Moderna vaccine, in many countries there will be additional demand for vaccine freezers or refrigerators. Therefore, it is recommended to purchase only climate-friendly and energy-efficient equipment.

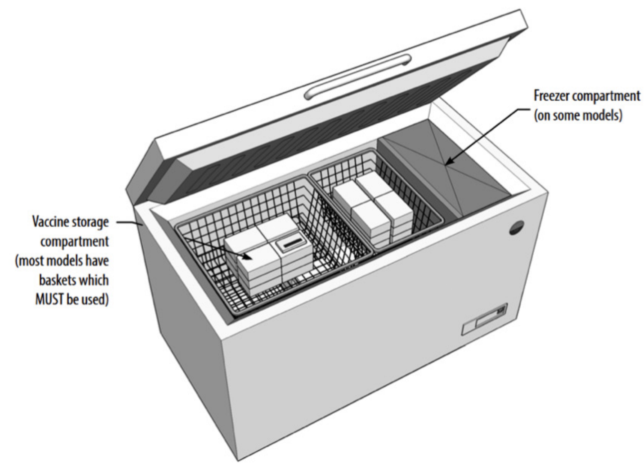



Figure 9: Commonly used vaccine refrigerator/freezer (top opening ice-lined mains electric or solar direct drive)[76]

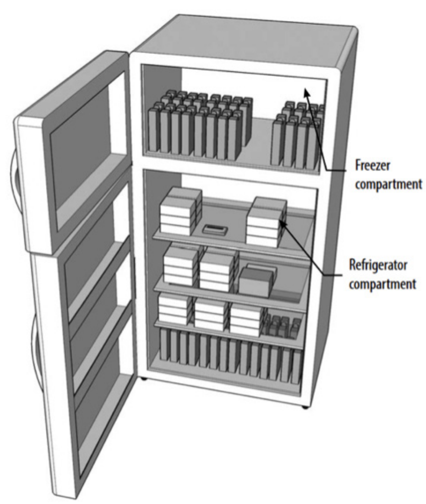



Figure 10: Commonly used vaccine refrigerator/freezer (front opening mains electric model)[77]

75 WHO (2020) *PQS devices catalogue. Product List E003: Refrigerators and freezers.*
76 WHO and PATH (2015) *Module 2: The vaccine cold chain.*
77 Ibid.

Table 4: Examples of climate-friendly laboratory refrigeration/freezer units

| Manufacturer and Model | Refrigerator temp. range In °C | Freezer temp. range in °C | Capacity in litres[78] | Refrigerant | Blowing agent | Energy consumption |
|---|---|---|---|---|---|---|
| Liebherr MKUv/MKv[79] LKPv[80] | +8 to +2<br>-2 to +16 | N.A.<br>N.A. | 142- 361<br>597 – 1361 | R-600a<br>R-290 | HC<br>HC | 0.7 – 1.11 kWh/24h<br>1.36 – 2.24 kWh/24h |
| PHCBI (Panasonic) MPR[81] | +14 to +2 | N.A. | 165-345 | HC | PU | No information provided |
| PHCBI (Panasonic) MPR[82] | +14 to +2 | -20 to -30 | Refrigerator:326<br>Freezer: 136 | HC | PU | No information provided |
| Qingdao Haier Biomedical HYC/HYCD[83] | +8 to +2 | -20 to -40 | 62- 361 | HC | R-1233zde | No information provided |
| Vestfrost AKS/G[84] VLS & MK[85] | +8 to +2 | N.A. | 48-360 | R-600a | PU (Cyclo-pentane) | 0.4 – 3.58 kWh/24h[86] |
| Vestfrost VLS 064 RF AC[87] | +8 to +2 | -7 to -10 | Refr.: 52.5<br>Freezer: 5.1 | R-600a | PU (Cyclo-pentane) | 0.63 kWh/24h |
| Godrej GVR[88] | +8 to +2 | +8 to +2 | 57.7 – 278 | R-600a | PU | 0.56 – 2.04 |

78 Depending on ambient temperature
79 Liebherr (no date) *Kühlgeräte für Medikamente.*
80 80 BPV (no date) *Kühlschränke.*
81 81 PHCbi (2020) *MPR Pharmaceutical Refrigerators with Natural Refrigerants.*
82 PHCbi (2019) *MPR Natural Refrigerant Pharmaceutical Refrigerators with Freezer.*
83 Haier Biomedical (no date) *-25°C Biomedical Freezer.*
84 Vestfrost (no date) *+2/+8°C Refrigerators.*
85 Vestfrost (no date) *Icelined Refrigerators.*
86 Depending if the device has a glass or solid door, and if it´s in stable or cool down phase.
87 Vestfrost (no date) *Combined ILR/Icepack Freezer.*
88 Godrej & Boyce (no date) *Vaccine Refrigerators.*

Table 5: Examples of climate-friendly laboratory vaccine freezers (-20 °C)

| Manufacturer and Model | Refrigerator temp. range In °C | Freezer temp. range in °C | Capacity in litres | Refrigerant | Insulation foam material (blowing agent) | Energy consumption |
|---|---|---|---|---|---|---|
| B medical systems U Range[89] | N.A. | -20 to -86 | 206 – 863 | R-290 & R-170 | PU | 11 – 12.4 kWh/24h |
| CryometrixT[90] | +20 to 0 | 0 to -90 | 950 | LN2 | No information provided | No information provided |
| Liebherr LCv/LGT/ LGPv[91] | N.A. | -9/-10 to -26/-30/-45 | 105 – 1361 | R-600a or R-290 | HC | 1.8 – 7.2 kWh/24h |
| PHCBI (Panasonic) MPR[92] | +14 to +2 | -20 to -30 | Refrigerator:326 Freezer: 136 | HC | PU | No information provided |
| Qingdao Haier Biomedical DW[93] | N.A. | -10 to -25 | 92 – 262 | HC | R-1233zde | 0.65 – 0.95 kWh/24h |
| Vestfrost MF[94] | N.A. | -18 to -28 | 95 – 271 | R-600a | PU (Cyclopentane) | 2.24 – 4.23 kWh/24h |
| Vestfrost VT / VTS[95] | N.A. | -10 to -25<br>-15 to -30 | 74<br>256 | R-600a<br>R-290 | PU (Cyclopentane) | 0.52 kWh/24h<br>1.9 kWh/24h |

89 B Medical Systems (2020) *Ultra-Low Freezers.*
90 Cryometrix (no date) *T-90 Storage Freezer.*
91 BVP (no date) *Gefrierschränke /-truhen.*
92 PHCbi (2019) *MPR Natural Refrigerant Pharmaceutical Refrigerators with Freezer.*
93 Haier Biomedical (no date) *-25°C Biomedical Freezer.*
94 Vestfrost (no date) *Vaccine/Icepack Freezers.*
95 Vestfrost (no date) *-25°C Freezer.*

### 3.2.2 Solar Direct Drive (SDD) refrigerators / freezers

Solar Direct Drive (SDD) vaccine refrigerators/ freezers need to comply with strong WHO temperature criteria. They need to sustain the temperatures between +2°C to +8°C for up to 72 hours without external power supply. Some SDD vaccine refrigerators/ freezers also contain a freezer for ice packs for field vaccinations. Currently the PQS of the WHO includes 46 solar units, of which 41 contain the ultra-low GWP refrigerant R-600a and 1 R-290. 4 units contain R-134a and one unit does not contain any refrigerant.[96] Some manufactures use PU foam that has been produced e.g. with HC Cyclopentane an ultra-low natural blowing agent. Other units within the PQS devices catalogue are based on HFC refrigerants with a GWP up to 1,300 and maybe even contain insulation materials that have been produced with HCFC high GWP blowing agents. The PQS does not provide information on the blowing agents used in the equipment.[97] It is recommended to procure only units containing ultra-low GWP refrigerants and blowing agents.

Picture 5: Solar-powered example freezer.
© Creative Lab/shutterstock.com

96 WHO (2020) *PQS devices catalogue. Product List E003: Refrigerators and freezers.*
97 However, the PQS generally mentions that cyclopentane is used in European countries and R141b in the USA, because *"the use of R141b was banned in Europe as of 1st January 2004 and it will eventually be phased out worldwide in 2030".*

### 3.2.3 Ultra-low temperature (ULT) freezers (-70°C)

ULT freezers, also referred to as Ultra-Deep Temperature freezers, can usually be found in many biobanks, clinics, and laboratories globally. The temperatures allow medium to long-term storage of a wide spectrum of biological samples such RNA or DNA, etc.

For the European market, manufacturers of ULT freezers must comply with the European Regulation UE 517/2014, to ensure their use even after 2030. Therefore, only ultra-low GWP refrigerants are permitted such as R170 (Ethane), R290 (Propane), or Liquid Nitrogen (LN2) etc. Table 6 provides some examples.[98] Regarding ultra-low freezer devices, the PQS of the WHO does not contain this type of equipment so far.[99]

Table 6 Examples of climate-friendly vaccine Ultra-Low Temperature Freezers (-70°C)

| Manufacturer and Model | Model | Temp. range in °C | Capacity in litres | Refrigerant | Insulation foam | Energy consumption |
|---|---|---|---|---|---|---|
| Arctiko[100] | ULUF | -40 to -88 | 7 - 50 | Nature R | PU | 4 – 7 kWh/24h |
| B medical systems | U Range[101] | -20 to -86 | 206-863 | R-290 & R-170 | PU | 11-12.4 kWh/24h |
| Binder | UF V[102] | -40 to -90 | 477 | R-290 & R-170 | CFC-free | 1.4 – 1.6 kW |
| Cryometrix | T[103] | +20 to -90 | 950 | LN2 | No information provided | No information provided |
| Eppendorf | CryoCube / UTL[104] | -50 to -86 | 110-740 | R-290 & R-170 | PU | 6.3 – 13.6 kWh/24h |
| Liebherr[105] | SUFsg | -40 to -86 | 491 - 728 | R-290 | HC | 7.9 – 8.1 kWh/24h |
| NuAire | Blizzard[106] | -40 to -86 | 828 | R-290 & R-170 | CFC free PU | No information provided |
| PHCBI (Panasonic) | VIP ECO[107] | -40/-50 to -86 | 528 - 845 | R-290 & R-170 | PU | No information provided |
| Qingdao Haier Biomedical | DW[108] | -40 to -86 | 579 - 959 | R-290 & R-170 | R-1233zde | 7.5 – 12 kWh/24h |
| Vestfrost | VT[109] | -60 to -86 | 74 - 383 | R-1150, R-600a, R-50 | PU (Cyclopentane) | 5.3 – 10.3 kWh/24h |

98 FDM Environment Makers (2019) *How does an Ultrafreezer work?*
99 WHO (2020) *PQS devices catalogue. Product List E003: Refrigerators and freezers.*
100 Arctiko (2020) *Corona Impfstoff Kühlgeräte fürTransport und Lagerung.*
101 B Medical Systems (2020) *Ultra-Low Freezers.*
102 BINDER (no date) *UF V 500-liter ultra low. temperature freezer with climate-neutral refrigerants.*
103 Cryometrix (no date) *T-90 Storage Freezer.*
104 Eppendorf (no date) *Products/Freezers.*
105 Liebherr (no date) *Ultratiefkühlschränke.*
106 NuAire (2017) *Blizzard Laboratory Ultralow Temperature Freezer.*
107 PHCbi (2021) *VIP ECO Ultra Low Freezers (-86°C).*
108 Haier Biomedical (no date b) *Ultra Low Energy Series.*
109 Vestfrost (no date) *-86°C ULT Freezer.*

Picture 6: Ultra-low freezer. © BlurryMe/shutterstock.com

To ensure a constant freezing cycle many manufactures offer accessories such as a $CO_2$ and/or LN2 emergency systems, which are also independently supplied with power via a probe and a battery.[110] Liquid-$CO_2$ can ensure that the temperature stays between -50°C and -70°C and LN2 even ensures temperatures up to -85°C.[111] In addition, freezers often contain a digital weekly temperature recorder, which is for example mandatory for freezers with temperatures between -45°C and -86°C for the storage of blood plasma, according to international standards.[112]

110 110 FDM Environment Makers (2019) *How does an Ultrafreezer work?*
111 Eppendorf (no date) *Products/Freezers/Devices.*
112 FDM Environment Makers (2019) *How does an Ultrafreezer work?*

### 3.3 Dry ice

Dry ice is solid $CO_2$ with a temperature of -78.5°C (-109.3°F).[113] Currently, dry ice is frequently used for transport of vaccines that require ultra-low temperatures. According to Pfizer the BioNTech-Pfizer vaccine can be transported and stored for up to 10 days without opening in special transport boxes (temperature-controlled thermal shippers) that are filled with dry ice. After 10 days, Pfizer thermal shippers can be refilled with dry ice to extend the storage by additional 5 days each time for up to 30 days of transportations in total. After 30 days the vials can be stored under conventional 2°C to 8°C storage conditions for additional 5 days. In that way, the vaccines can be stored for a total of up to 35 days. However, once the vials are stored under 2°C to 8°C temperature conditions, re-freezing or storage under frozen conditions is not possible anymore.[114]

Therefore, dry ice is a solution when the time during shipment and the actual vaccination is below 35 days. However, there is also a risk that the vaccines will be exposed to higher temperatures during the 35 days and may become unusable. Furthermore, many countries do not have enough dry ice production capacities. For example, there are only two dry ice production facilities in Bangladesh,[115] for a population of 165 million.[116] Furthermore, many countries do only have dry ice production in the capital. Probably for most countries dry ice offers a quick solution to get the vaccines to the required vaccine centers. However, for larger countries, as well as many developing countries, this is very likely to bring logistical challenges.

Besides this, dry ice is currently only a solution for vaccines that can be stored below -40°C, such as the vaccine from BioNTech-Pfizer.

Dry ice is no solution for Moderna because their vaccines cannot be stored on dry ice or below -40°C (-40°F).[117] Dry ice is also not a suitable solution for all other vaccines that require only conventional 2°C to 8°C storage conditions.

Picture 7: Dry ice production. © CornelPutan/shutterstock.com

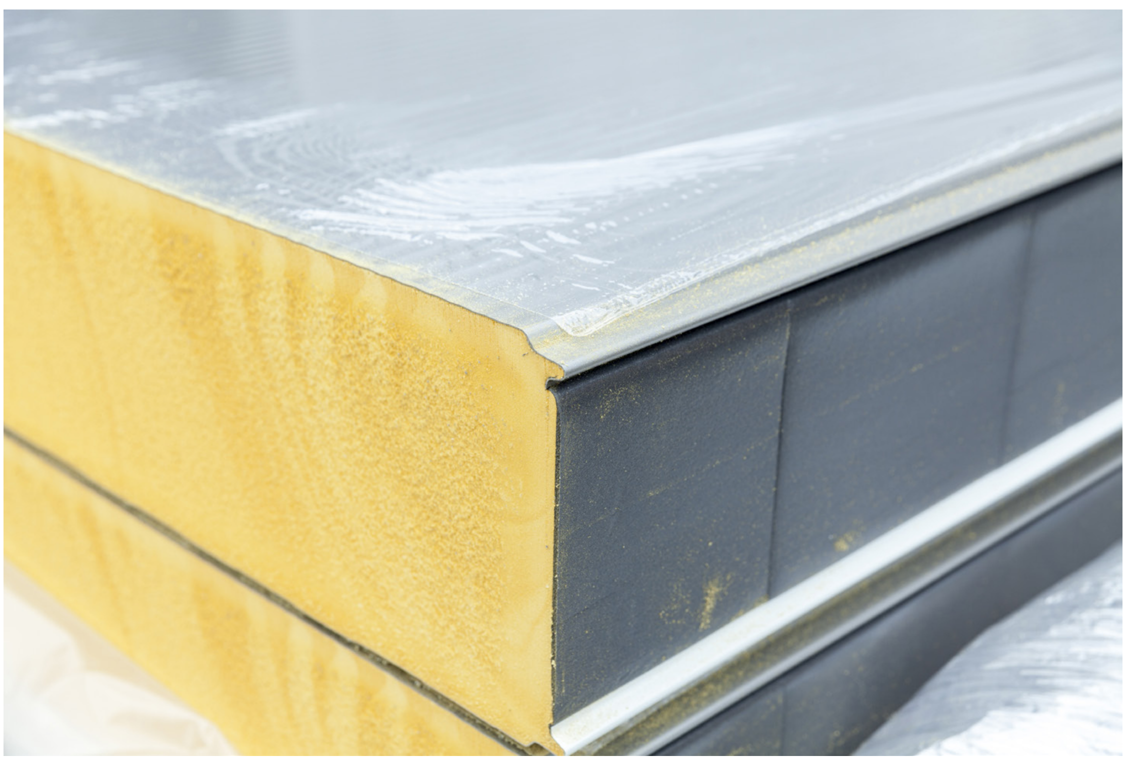
113 Britannica (2011) *Dry ice.*
114 Pfizer (2020) *COVID-19 Vaccine U.S. Distribution Fact Sheet.*
115 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*
116 Worldometer (2021) *Bangladesh Population.*
117 Moderna Inc (2020) *Storage & Handling.*

## 3.4 Insulation foam

In addition to the refrigeration/freezer unit and the used refrigerant, the insulation foam of cold/freezer rooms and refrigerators/freezers is produced with blowing agents that still can contain HCFCs such as R-141b (GWP 782; ODP 0.11), which are harmful for the ozone layer and climate and therefore are phased out until 2030 globally.[118] However, in many developing countries insulation foam containing the blowing agent R-141b is still produced and sold and therefore even some new cold rooms can contain R-141b. Besides this, R-141b is probably still used in the USA for some appliances and insulation material of cold rooms.

For example, the insulation foam of one standard small cold/freezer room (14 $m^3$) that includes 6.3 kg of the blowing agent R-141b has an equivalent to around 4.9 tons of $CO_2$ as well as 0.001 kg ODP.

On average the insulation material of one standard vaccine refrigerator or freezer (300 liters) contains 0.25 - 0.36 kg of R-141b (depending on the thickness of the material), which is equivalent to around 196 – 294 kg of $CO_2$ and has also a marginal ODP. A refrigerator or freezer that contains 0.28 - 0.42 kg of the blowing agent CFC-11 has an equivalent of 1.3 - 1.95 tons of $CO_2$ and the ODP is 9 times higher than of R-141b.



Picture 8: Insulation panels. © DJ Srki/shutterstock.com

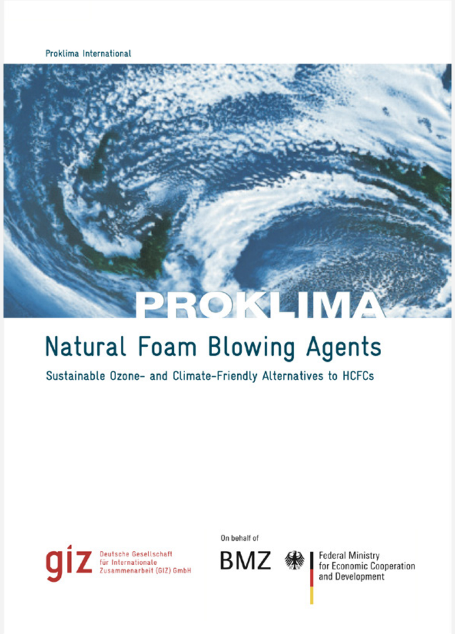
118 UNEP (2019) *HCFC Phase-out management plans and HCFC production phase-out management plans.*

There are climate-friendly alternatives wich use ultra-low to zero GWP blowing agents such as hydrocarbons (e.g. pentane, isopentane, cyclopentane), water-blown or liquid $CO_2$. Their environmental impact is very low to almost zero.[119] Many foam producers have already converted or will convert in the future. Consequently, this paper argues that the technical specifications regarding the foam shall be clearly defined (GWP <12) to avoid the procurement of insulation material that still contains the HCFC blowing agent R-141b.

Apart from replacing HCFC blowing agents with hydrocarbons, water-blown or liquid $CO_2$ blowing agents, R-141b is replaced with hydrofluoroolefin (HFO) blowing agents, which have an ultra-low GWP and therefore have a very low climate impact. However, some studies argue that the degradation products of HFOs, namely trifluoroacetic acids (TFAs) will have a negative effect on the environment, organism, ground water and human health.[120] Others argue they have a neglectable impact.[121] Because it is unknown what environmental impact TFAs will have in 100 years, blowing agents based on natural refrigerants like hydrocarbons (HC) are more likely to have no negative impact at all. Consequently, this publication recommends purchasing foams that contain insulation material blown with natural blowing agents.

Most countries do not have destruction facilities for foam and therefore at the end of life (EoL) these emissions are released to the atmosphere. Additionally, there is the negative impact of the blowing agent to the ozone layer.

Further reading[122]




**119** GIZ Proklima (2012) *Natural Foam Blowing Agents.*
**120** UBA (2020) *Persistente Abbauprodukte halogenierter Kälte- und Treibmittel in der Umwelt*
**121** E.g. Fleet, D et al. (2017) *Study on environmental and health effects of HFO refrigerants.*
**122** GIZ Proklima (2012) *Natural Foam Blowing Agents.*

# 4 Standards, trainings, and certification

## 4.1 Safety standards

By introducing climate-friendly ultra-low GWP refrigerants safety standards need to be considered. Some refrigerants are flammable, such as HCs, others operate under high pressure such as $CO_2$. Consequently, international safety standards such as the IEC 60335-2-89:2019[123] permit only up to 500g of HCs in one refrigeration cycle. However, all vaccine refrigerator or freezers units usually contain a maximum of approx. 150g HCs and therefore cause no risks during operation. It must be mentioned that around 70 percent of all domestic refrigerators worldwide, as well as many commercial refrigerators, already use HCs. Thus, it can be concluded that vaccine refrigerators and freezers based on flammable refrigerants such as HC can be operated safely, since they are also hermetically sealed and contain a maximum of 150g – 500g of flammable refrigerants per refrigeration circuit.

Depending on the refrigerant charge, location and room size of the installation, product safety certification according to standard IEC 61010-2-011 and 012[124] or ATEX[125] or IECEx of UL[126] is required.

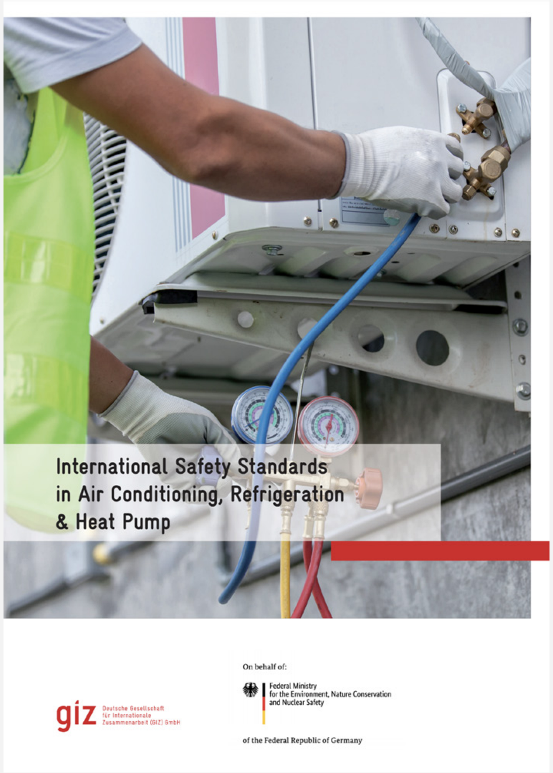
Moreover, the following vaccine refrigeration and lab equipment standards shall be considered:

•IEC 61010-2-011:2019[127]: Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use.
•WHO Performance, Quality and Safety (PQS).[128]

When it comes to repair of vaccine refrigerators and freezers that contain flammable refrigerants international best practice and safety standards such as the EN-378[129] or the ISO-5149[130], ISO-22712[131] and ISO-13585[132] need to be applied. These safety standards also need to be applied to mono-blocks, which usually contain around 150g of HCs. Mono-blocks with larger quantities of flammable refrigerants need to be handled with extra care, but it is recommended to use mono-blocks with a lower refrigerant charge which are usually sufficient. Site-built insulated cold/freezer rooms that use flammable refrigerants are only recommended to be used if qualified and certified refrigeration and air-conditioning (RAC) technicians are available and the above-mentioned international safety standards are followed. When it comes to reefer containers that contain flammable refrigerants, the ISO-20854[133] standard needs to be applied. In general, those international standards should be adopted to national standards in the respective language.

123 IEC (2019) IEC 60335-2-89:2019
124 IEC (2019) IEC 61010-2-011:2019
IEC (2019) IEC 61010-2-012:2019
125 EU (2016) ATEX Directive 2014/34/EU.
126 UL (no date) *IECEx Hazardous Areas Certification for Access to International Markets.*
127 IEC (2019) IEC 61010-2-011:2019
128 WHO (2020) *PQS devices catalogue.*
129 European Standards (2019) EN 378-1,2,3,4
130 ISO (2014) ISO 5149-4:2014
131 ISO (Under development) ISO/FDIS 22712
132 ISO (2012) ISO 13585:2012
133 ISO (2019) ISO 20854:2019

Further reading[134]




134 GIZ Proklima (2018) *International Safety Standards in Air Conditioning, Refrigeration & Heat Pump.*

## 4.2 Energy efficiency standards

The energy efficiency of most domestic or commercial refrigerators and freezers is tested in internationally accredited laboratories according to international standards. Many countries follow the IEC 62552-3:2015 standard on *"Household refrigerating appliances - Characteristics and test methods Part 3: Energy consumption and volume"*, which specifies the characteristics of household and similar refrigerating appliances[135] such as commercial refrigerators/ freezers. Most countries do also have national or regional mandatory or voluntary Minimum Energy Performance Standards (MEPS) and energy labelling legislation or policies.[136] Surprisingly, during the research of this publication (might be limited[137]), no information on energy performance testing, MEPS and energy labels for laboratory refrigerators or freezers was found. Moreover, a lot of the laboratory equipment does not even show the 24 hour or annual energy consumption. Consequently, it is recommended the energy performance of laboratory vaccine refrigerators or freezers and to include them within the national or regional MEPS and labelling schemes. Furthermore, procurement officers should consider energy efficiency during the procurement processes to safe energy and costs and to reduce $CO_2$ emissions.

Besides this, many countries or regions do have eco-labels for domestic or commercial refrigerators/ freezers, which consider a high energy efficiency and usually ultra-low GWP refrigerants and blowing agents.[138] Therefore, it is recommended that laboratory refrigerators and freezers that comply with these strong requirements shall also receive an eco-label certification to help the buyers to purchase climate-friendly and energy-efficient equipment.

## 4.3 Qualification of temperature-controlled storage areas

The WHO "Model guidance for the storage and transport of time and temperature-sensitive pharmaceutical products" defines the qualification of temperature-controlled storage areas.[139]
They include:

- "ultra-low freezers, freezers, freezer rooms, refrigerators, cold rooms and controlled-ambient stores".
- "refrigerated and temperature-controlled trucks, refrigerated and temperature-controlled ocean containers."
- "insulated containers used to maintain product temperature during road and air transport."

The qualification exercise (see Picture 9) consists of the following sequential phases:


Picture 9: The four sequential phases of qualification exercises[140]
© connect2cleanrooms

However, this exceeds the scope of this publication and therefore this topic will not be discussed in further detail.

135 ISO (2019) ISO 20854:2019
136 UN Environment (2019) *Energy-efficient and Climate-Friendly Refrigerators.*
137 137 It could be that some of the equipment is energy labeled after import as a national/regional requirement.
138 EC Environment (2019) *Co-operation with international Eco-labels.*
139 WHO (2015) *Supplement 7 Qualification of temperature-controlled storage areas.*
140 Cleanrooms (no date) *DQ IQ OQ PQ Cleanroom Qualifications.*

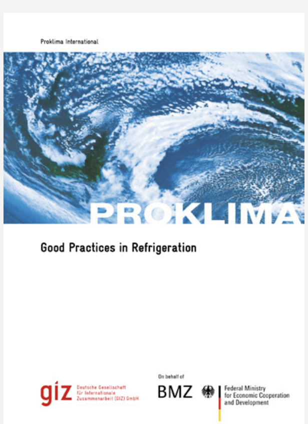
## 4.4 Training and certification of RAC technicians

As stated above, only qualified, and certified RAC technicians shall perform (installation, maintenance)[141] and repair refrigerator or freezer units that contain ultra-low refrigerants, according to international best practice standards. In many developing countries RAC technicians require training and certification.

As stated previously, in many countries domestic and commercial refrigerators and freezers using hydrocarbons are available and RAC technicians know how to service and repair them. Under the national HCFC Phase-out Management Plans (HPMPs) of the Montreal Protocol, many trainers and technicians have already received trainings on flammable refrigerants. Nevertheless, additional trainings and certification according to international best practice and standards are highly recommended. Besides this, national registries of certified technicians should be in place.

Picture 10: Technicians training in São Paulo, Brazil. © GIZ Proklima/ Jefferson Costa.

Further reading[142]






141 Installation and maintenance is here only referred to refrigeration or freezer units for cold rooms (e.g monoblocks) or specific equipment.
142 GIZ Proklima (2012) *Guidelines for the safe use of hydrocarbon refrigerants*
GIZ Proklima (2012) *Good Practices in Refrigeration*
GIZ Proklima and Green Cooling Initiative (2020), *Fit for Green Cooling*

### 4.5 Standards, training and certification of distributors and operators

Distribution, handling, and storage of vaccines requires trained personnel and certified companies and according to international standards on proper safe storage and handling of COVID-19 vaccines. The WHO Standard Operational Procedures (SOP)[143] and Good Distribution Practices (GDP)[144] certification requires distributors and operators to meet stringent WHO criteria for safety and security. The EU's GDP regulations[145], the United States Pharmacopeia Standard[146] or, when it comes to air cargo the IATA Temperature Control Regulations (TCR)[147] or Guidance for Vaccine and Pharmaceutical Logistics and Distribution[148] are some related standards. Furthermore, there are various guidelines, as well as many training providers related to distribution, safe storage and handling of vaccines.[149] Certification of companies and personnel that are part of the entire cold chain from the sender to the receiver in the areas of personnel, technical aspects, processes, etc., is done for example by TÜV[150], SGS[151], DQS[152] DEKRA[153], etc. However, this topic exceeds the scope of this publication.

All operators of cold chain equipment should receive trainings on the handling of the specific equipment, which can also be offered online by the manufacturers. Each equipment needs to be delivered with an operational, maintenance and troubleshooting manual, preferably in the main language that is spoken in the respective country of destination.

Frequently required operational spare parts should be ordered and delivered with the equipment. See also 4.1 on maintenance spare parts.  Furthermore, maintenance as well as 24/7 service with proper reaction times need to be contracted with the manufactures.

Picture 11: Operator training. © GIZ Proklima

143 WHO (2013) *EVM Model Standard Operating Procedures.*
144 WHO (2010) *Annex 5 WHO Technical Report Series, No. 957.*
145 European Commission (no date) *Good Manufacturing and Distribution Practices.*
146 USP (no date) *USP Reference Standards.*
147 IATA (2021) *CEIV Pharma.*
IATA (2021) *Temperature Control Regulations (TCR).*
148 IATA (2021) *Guidance for Vaccine and Pharmaceutical Logistics and Distribution.*
149 Examples of safe vaccine storage, handling guidelines and trainings:
WHO (2002) *Guideline for establishing or improving primary and intermediate vaccine stores.*
WHO (2013) *EVM Model Standard Operating Procedures.*
PAHO (no date) *Vaccine Storage and Handling.*
150 TÜV SÜD (no date) *SS 620 Good Distribution Practice for Medical Devices.*
151 SGS (no date) *Good distribution practices (GDP).*
152 DQS GmbH (no date) *GDP: Good Distribution Practice.*
153 DEKRA (no date) *Good Distribution Practice GDP.*

# 5 Other relevant aspects

## 5.1 Availability of spare parts

Most vaccine refrigerators and freezers are usually functioning without any problems for many years and especially some of the laboratory equipment also has long periods of warrantee. However, to ensure sustainability, frequently required spare parts should be ordered at the same time when the procurement of the equipment is done. Furthermore, it should be tried to establish a supply chain of spare parts. Therefore, if possible, it is recommended to procure similar equipment for the same country. Moreover, lists of spare parts, maintenance and repair manuals and support contact details of the manufacturer or the next spare part representative should be always provided at the same time the equipment is delivered.

## 5.2 Temperature monitoring devices

Vaccines must be stored under strict temperature requirements, which in reality are often not met. Vaccines can be easily damaged if there is a deviation outside the required temperature ranges. Many vaccines are freeze sensitive and critical temperature variations usually occur at storage level. Consequently, it is crucial to maintain stable temperature requirements. Monitoring devices are therefore essential.[154]

Pre-qualified temperature monitoring devices can be found in the PQS of the WHO. There are temperature monitoring solutions for: Cold/freezer rooms; refrigerators/freezers and cold boxes/vaccine carriers.[155]

## 5.3 Voltage regulators and stabilizers

Voltage fluctuations are common in developing countries. Voltage regulators are rather small and can be used for plug-in refrigerators and freezers. Voltage stabilizers are usually larger and can be used for cold/freezer rooms.

According to WHO it is recommended to connect cold chain equipment to a voltage regulator or stabilizer, if voltage fluctuations are above or below 7 percent of the nominal voltage.[156]

## 5.4 Securing transport and storage

In contrast to common vaccines, securing the SARS-CoV-2 vaccines' transport and storage is becoming essential for various reasons. Due to the current low supply and high demand of SARS-CoV-2 vaccines, transport and storage must be protected heavily in many ways. Apart from secured transport, storage rooms and equipment must be secured accordingly by police, security guards, fences, looked storage rooms, against theft[157] but also against destruction by vaccine opponents. Furthermore, newer smart cold chain equipment is connected to the internet (see 5.5 Establishing a smart digital cold chain) and therefore it is recommended that these smart digital solutions are protected accordingly from hacking.[158]

154 NextLeaf Analytics (no date) *Coldtrace | Alerts & Analytics for a Smarter Vaccine Cold Chain.*
155 WHO (2020) *PQS devices catalogue. Product List E006: Temperature monitoring devices.*
156 UNICEF (no date) *Cold chain frequently asked questions.*
157 Silverman, E. (2020) *From shipping to security, a Covid-19 vaccine supply chain takes shape.*
158 Satter, R. (2020) *IBM warns hackers targeting COVID vaccine 'cold chain' supply process.*
Silverman, E. (2020) *From shipping to security, a Covid-19 vaccine supply chain takes shape.*

## 5.5 Establishing a smart digital cold chain

Digitalization offers smart solutions to track the global vaccine cold chain. For example, there are some manufacturers of refrigerator/freezer equipment that already offer equipment with a QR code that can be used with an app to track temperatures[159], locations, performance, and other parameters. However, it is recommended that these smart digital solutions are protected well from hacking.[160] Moreover, most of these apps are only complying with their specific manufacturer requirements and cannot be accessed by or share data with third parties. However, to monitor the performance of the global vaccine cold chain, access to data to build and use effective digital data solutions, e.g. block-chains, would be essential. Wireless Remote Temperature Monitoring (WRTM) devices and apps such as the low-cost system of Coldtrace (WHO PQS approved) are further examples.[161]

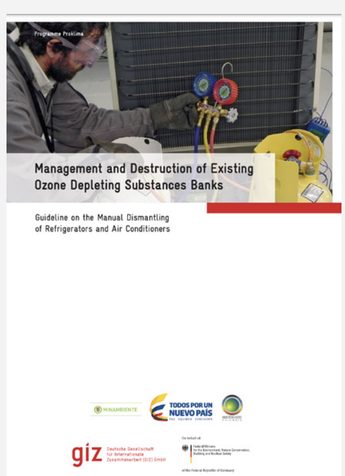
159 e.g. Vestfrost.
160 Satter, R. (2020) *IBM warns hackers targeting COVID vaccine 'cold chain' supply process.*
161 NextLeaf Analytics (no date) *Coldtrace | Alerts & Analytics for a Smarter Vaccine Cold Chain.*

# 6 Management, recycling, or destruction of obsolete vaccine cold chain equipment

As stated previously, there are many old vaccine and conventional refrigerators, freezers, cold and freezing units which do not meet the WHO requirements or which are broken. To minimize the harm to the environment, ozone layer and climate it is strongly recommended to decommission these appliances and installations according to international standards, to recover and collect the refrigerants as well as to destroy the insulation materials containing CFC and HCFC blowing agents. Apart from the refrigerants and the insulation materials (blowing agents), e-waste should be at least tried to be recycled according to international best practices.

Picture 12: Old refrigerators. © GIZ Proklima.

Further reading[162]




162 GIZ Proklima (2017) *Management and Destruction of Existing Ozone Depleting Substances Banks.*

# 7 Emissions of the global cold chain

According to a recent publication of the University of Birmingham and the Centre for Sustainable Cooling (CSC) which was financed by Kigali-Cooling Efficiency Program (K-CEP), approximately 1 percent of global GHG emissions are due to the cold chain. In developing countries, this number can go up to 3-3.5 percent of GHG emissions. Furthermore, the entire health care sector is estimated to be responsible for up to 5 percent of the global GHG emissions. The indirect emissions (due to fossil fuels) are responsible for around 70 percent of the total emissions and the direct emissions (leakage of refrigerants) are responsible for around 30 percent of the total emissions of the cold chain.[163]

If global cold chain technologies would use ultra-low GWP refrigerants and insulation foam that has been produced with ultra-low GWP blowing agents, the mitigation potential regarding direct emissions would be up to 0.3 percent of global GHG emissions. Furthermore, if global cold chain technologies would be highly efficient, indirect emissions could be probably reduced by up to 50 percent which would result in a mitigation potential of up to 0.35 percent of global emissions. Concerning the indirect emissions of the vaccine cold chain, apart from energy efficiency aspects, current off-grid diesel generators (and back-up power supply) can be replaced by solar systems.

Combining the global mitigation potential of indirect and direct GHG emissions up to 0.65 percent of global GHG emissions of the worldwide cold chains could be reduced. Note that these numbers do not even consider an increase of renewable grid energy to power the equipment, which would further reduce the indirect GHG emissions.

Unfortunately, it exceeds the scope and research to break down the specific mitigation potential for the vaccine cold chain. However, in the previous chapters this publication provides some examples and comparisons between conventional equipment useing HCFC or HFC refrigerants and blowing agents and Green Cooling and Freezing technologies based on ultra-low GWP.

163 Peters, T. (2020) Understanding the cold-chain challenge for Covid-19 vaccination.

# 8 Cost saving aspects

As stated previously, climate-friendly and energy-efficient vaccine cold chain technologies usually come at a slightly higher cost. However, due to the higher energy efficiency the elevated initial investment costs are usually recovered within a few years, due to lower energy consumption resulting in reduced energy bills. Besides this, Green equipment that uses ultra-low GWP refrigerants and insulation material that contains ultra-low GWP blowing agents is becoming more and more available in recent years and therefore the costs have already decreased significantly. The costs of Green laboratory refrigerators and freezers are already comparable with equipment that uses high GWP HFC refrigerants or HCFC/blowing agents. Additional demand for Green equipment will further reduce the costs due to increased economies of scale. For direct solar driven vaccine refrigerators and freezers or ultra-low freezers this trend has already occurred.[164] The Financial Internal Rate of Return (IRR) or Net Present Value (NPV) of Green technologies versus conventional ones can be assessed individually. However, the environmental costs of the released $CO_2$ emissions of refrigerants (direct emissions) or the energy consumption (indirect emissions) due to the fossil fuels energy generation must be considered in the life-cycle-costs as well.

164 See chapter on solar freezers and also on ultra-low freezers.

# 9 Up-scaling and sustainability strategies

There are various ways how to support the establishment of a climate-friendly and energy-efficient cold chain.

On the one hand, many stakeholders do not have enough information on technology alternatives. On the other hand, efforts towards production, sales and procurement of climate-friendly technologies are not acknowledged so far and regulations and guidelines are lacking. Therefore, there are limited incentives towards more ultra-low GWP solutions. Life-cycle costs regarding energy consumption and climate and environmental costs of GHG emissions are usually not sufficiently considered in guidelines, regulations and during procurement. However, initially higher investment costs of climate-friendly and energy-efficient technologies are usually harmonized over time due to the lower energy costs.

The following specific up-scaling strategies are providing ideas and recommendations for various stakeholders:

• The WHO should consider and recommend climate-friendly ultra-low GWP refrigerants and blowing agents for the insulation materials, as well as energy efficiency such as annual electrical consumption, EER and labelling in their guidelines and PQS.
• Other countries should follow the best practice example of the European Regulation UE 517/2014, to ensure the use of equipment also after 2030.[165]
• Manufactures should consider the design and production of climate-friendly and energy-efficient equipment. Furthermore, they should further improve their supply chains and the availability of spare parts.
• Ensure that spare parts are available on demand within short time frames.
• Conduct energy efficiency testing and certification of cold chain equipment.
• Apply regional or national Minimum Energy Efficiency Standards (MEPS) and energy labelling for cold chain equipment.
• Include cold chain equipment under eco-labelling schemes and certification.
• Green Public Procurement (GPP) guidelines should consider climate-friendly refrigerants and blowing agents as well as energy efficiency. [166]
• Tax incentives for green equipment or tax disincentives for high GWP refrigerants and insulation materials, as well as the respective technologies that use these types of refrigerants and blowing agents could be established.
• International logistic companies such as DHL, FedEx, UPS, airlines, sub- contractors and cargo shipping enterprises should also consider climate-friendly technologies and demand them from their national sub-contractors.
• Procurement guidelines of organisations such as Gavi, UNICEF, PATH, etc. should consider ultra-low GWP refrigerants and blowing agents as well as higher requirements on energy efficiency (e.g. EERs).
• National, district and regional vaccine storage centers as well as hospitals and health care centers should also consider procuring these types of equipment.
•Operators should receive sufficient training on proper operation on the specific equipment.
• Avoid diesel generators and consider renewable energy options for power supply/ power back-up.[167]

165 European Environment Agency (2014) *Regulation (EU) No 517/2014.*
166 GIZ Proklima (2021) *Green Cooling in Public Procurement: Assessing ways to advance procurement of climate-friendly and energy-efficient air conditioners in the public sector.*
167 Peters, T. (2020) *Understanding the cold-chain challenge for Covid-19 vaccination.*

• Install voltage regulators and stabilizers to ensure sustainability. [168]
• National standard bodies should adopt relevant international best practice and safety standards.
• RAC training institutes should include in their curricula ultra-low GWP refrigerants, installation, servicing, repair, de-commissioning, and recovery and establish certification schemes.
• Maintenance plans, policies and budget allocations should be in place to ensure frequent servicing of equipment and therefore increase the life expectancy and sustainability.
• Leakage rates should be reduced especially of cold/freezer rooms but also for other equipment especially at the end of life (EoL).
• Regulations and their application on management, storage, recycling, or destruction of old refrigerants, blowing agents, refrigerant oils, as well as all other materials incl. vaccine waste should be established.
• Digital tools shall be designed and applied to monitor the global cold chain and to inform and exchange on the above.
• Draft information materials and organise virtual events on the above-mentioned recommendations.

168 UNICEF (no date) *Cold chain frequently asked questions.*

# Conclusion

Although many countries do have an existing cold chain for conventional vaccines, according to a study by WHO, 75 percent of the health facilities assessed in 47 developing countries had none or non-functional or poorly performing equipment. Consequently, most countries require quick improvements of their cold chains for vaccines and therefore will need to purchase thousands of new equipment in the near future.

Approximately 1 percent of global GHG emissions are due to the global cold chain. In developing countries, this number can go up to 3-3.5 percent of GHG emissions. Furthermore, the entire health care sector is estimated to be responsible for up to 5 percent of world GHG emissions.

Most conventional vaccine cooling and freezing technologies use HFC refrigerants and some of them still contain insulation foam that is blown with high GWP HCFC blowing agents. Moreover, most conventional cold chain equipment has often a relatively lower energy efficiency. However, climate-friendly and energy-efficient vaccine cooling and freezing technologies which use ultra-low GWP refrigerants are available in the market.

Some people argue that what is now urgently required is to improve the cold chain and that there is no time and no priority to consider climate and environmental aspects now. However, this publication shows, this is the time to establish a smart, sustainable, green and climate-friendly system for the future, which is aligned and consistent with multilateral agreements. The procurement of thousands of cold chain equipment can also be seen as a chance for green recovery and climate resilience.

Consequently, this publication argues that not only the required vaccine temperature and technology requirements shall be considered for the decisions of the procurement, but also the environmental and climate impact as well as energy efficiency.
This publication tries to provide an overview of Green Cooling and Freezing technologies for vaccines at national, district or regional and health center level, for the temperature ranges +2°C to +8°C, -20°C and -70°C. Apart from focusing on refrigerants, blowing agents of the insulation material as well as energy efficiency aspects are discussed.

Although the investment costs of climate-friendly and highly energy-efficient technologies might be higher in the beginning of the investment cycle, these costs are usually harmonizing over a short time frame due to the higher energy efficiency and thus lower energy costs. Furthermore, environmental costs of the released $CO_2$ emissions of refrigerants (direct emissions) or the energy consumption (indirect emissions) due to the fossil fuels energy generation must be considered in the life cycle costs as well.
This publication recommends to procurement officers and decision makers to purchase only vaccine cold chain equipment that:

- uses ultra-low GWP (<10) refrigerants, preferably natural refrigerants such as hydrocarbons (HCs).
- contains insulation material that has been produced with ultra-low GWP blowing agents (<12), preferably natural refrigerants.
- has a high Energy Efficiency Ratio (EER) or a low energy consumption per 24h/annually and uses preferably inverter technology.
- additionally, consider to power or back-up the equipment by renewable energy sources such as solar energy.

To ensure sustainability, proper operation and maintenance by trained and certified laboratory operators and RAC technicians are essential. RAC technicians need to follow international safety standards like IEC 61010-2-011:2019, EN 378-1 to 4, ISO-5149 1 to 4.

The application of energy efficiency standards like IEC 62552-3:2015 is also highly recommendable. During the research information on Energy Efficiency Ratings (EER) were not identified. It is therefore recommended that the energy performance of laboratory vaccine refrigerators or freezers shall also be tested in international accredited laboratories and that laboratory equipment is included under national or regional Minimum Energy Performance Standards (MEPS) and energy labeling schemes. Furthermore, laboratory refrigerators and freezers that comply with strong environmental requirements such as ultra-low GWP and high energy efficiency levels shall also receive an eco-label certification, to help the buyers to purchase climate-friendly and energy-efficient equipment.

Moreover, the WHO should consider and recommend climate-friendly ultra-low GWP refrigerants and blowing agents for the insulation materials, as well as energy efficiency such as annual electrical consumption, EER and labelling in their guidelines and PQS. Additionally, procurement guidelines of organizations such as Gavi, UNICEF, PATH, etc. should consider ultra-low GWP refrigerants and blowing agents as well as higher requirements on energy efficiency (e.g. EERs).

To minimize the harm to the environment, ozone layer and climate, old appliances and installations should be de-commissioned according to international standards. Refrigerants need to be recovered and collected, recycled, or destroyed and insulation materials that contain CFC or HCFC blowing agents destroyed.

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