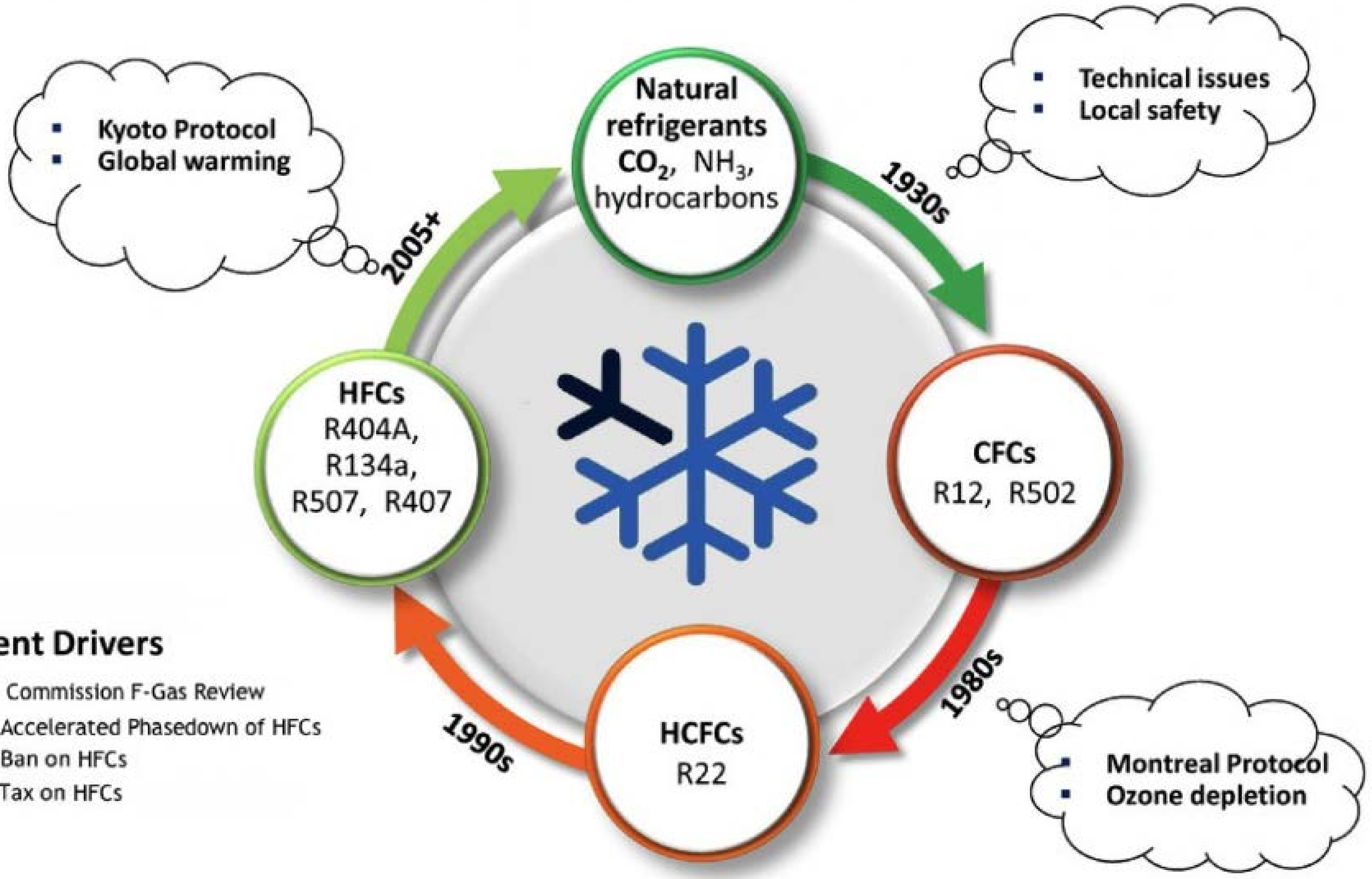
Training Course
Alternatives Refrigerants
Challenges & Perspectives

Dennis Huehren

The Closed Cycle - Driving Natural & Alternative Refrigerant Solutions



Current Drivers

- EU Commission F-Gas Review
  - Accelerated Phasedown of HFCs
  - Ban on HFCs
  - Tax on HFCs

Overview: Modules and Sections

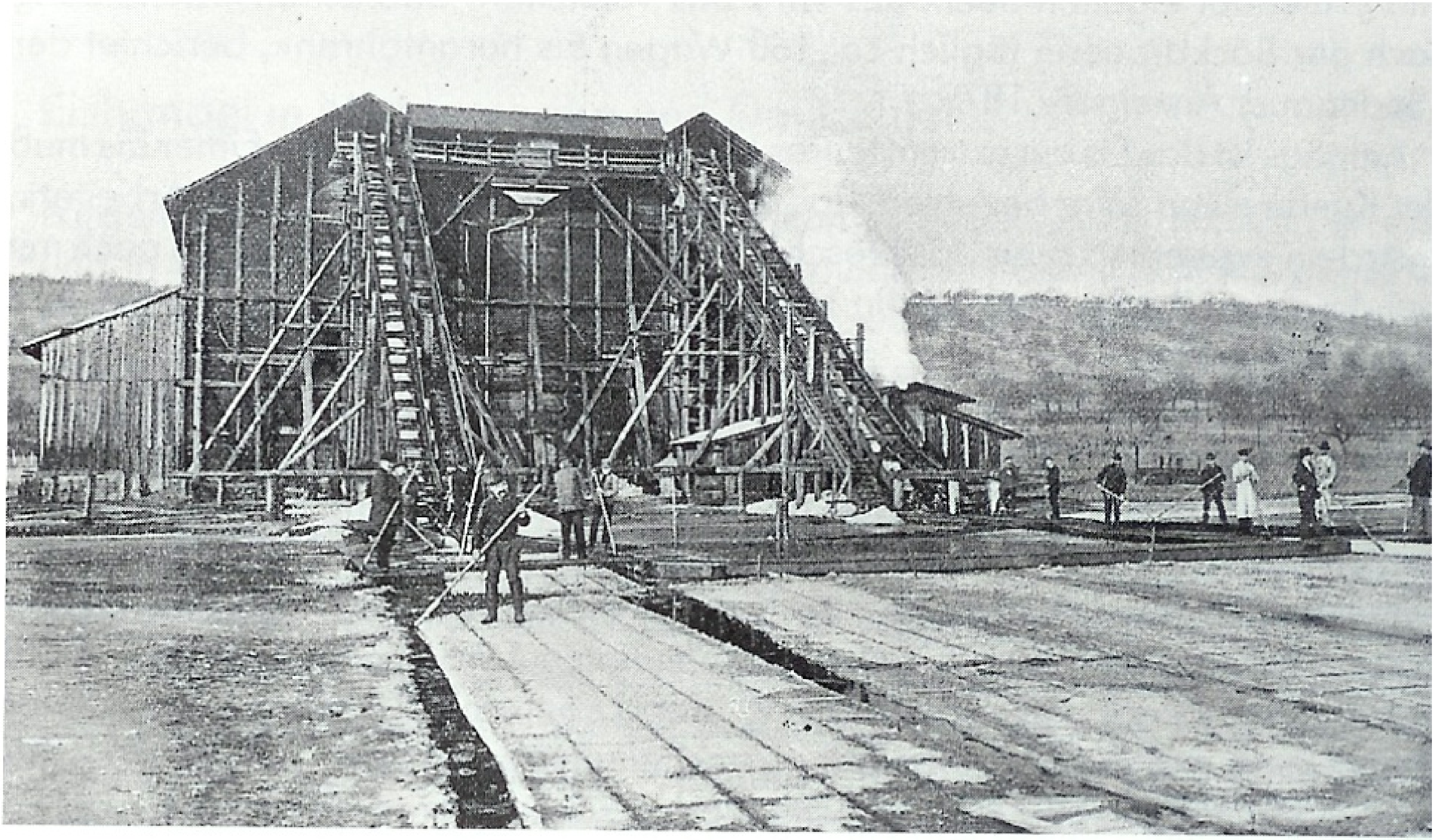
- History of refrigeration
- Status of Refrigeration in the Society
- General Refrigerant Issues
- General Application Considerations for Refrigerants
- Alternative Refrigerants Selection
- European Way in Regulations and Bans
- Global Phase-Down Scenarios
- Energy Efficiency Issues

History of Refrigeration

- Refrigeration relates to the cooling of air or liquids, thus providing lower temperature to preserve food, cool beverages, make ice and for many other .
- Most evidence indicate that the Chinese were the first to store natural ice and snow to cool wine and food.
- Ancient people of India and Egypt cooled liquids in porous earthen jars.
- In 1834, Jacob Perkins, an American, developed a closed refrigeration system (vapour compression circuit) using liquid expansion and then compression to maintain the cooling effect. He used Ether as refrigerant, in a hand- operated compressor, a water-cooled condenser and an evaporator in liquid cooler. Patented 1835 as Ether-ice-machine.
- Unfortunately some machines exploded because of the formation of highly explosive Peroxide (Ether in reaction with Oxygen)

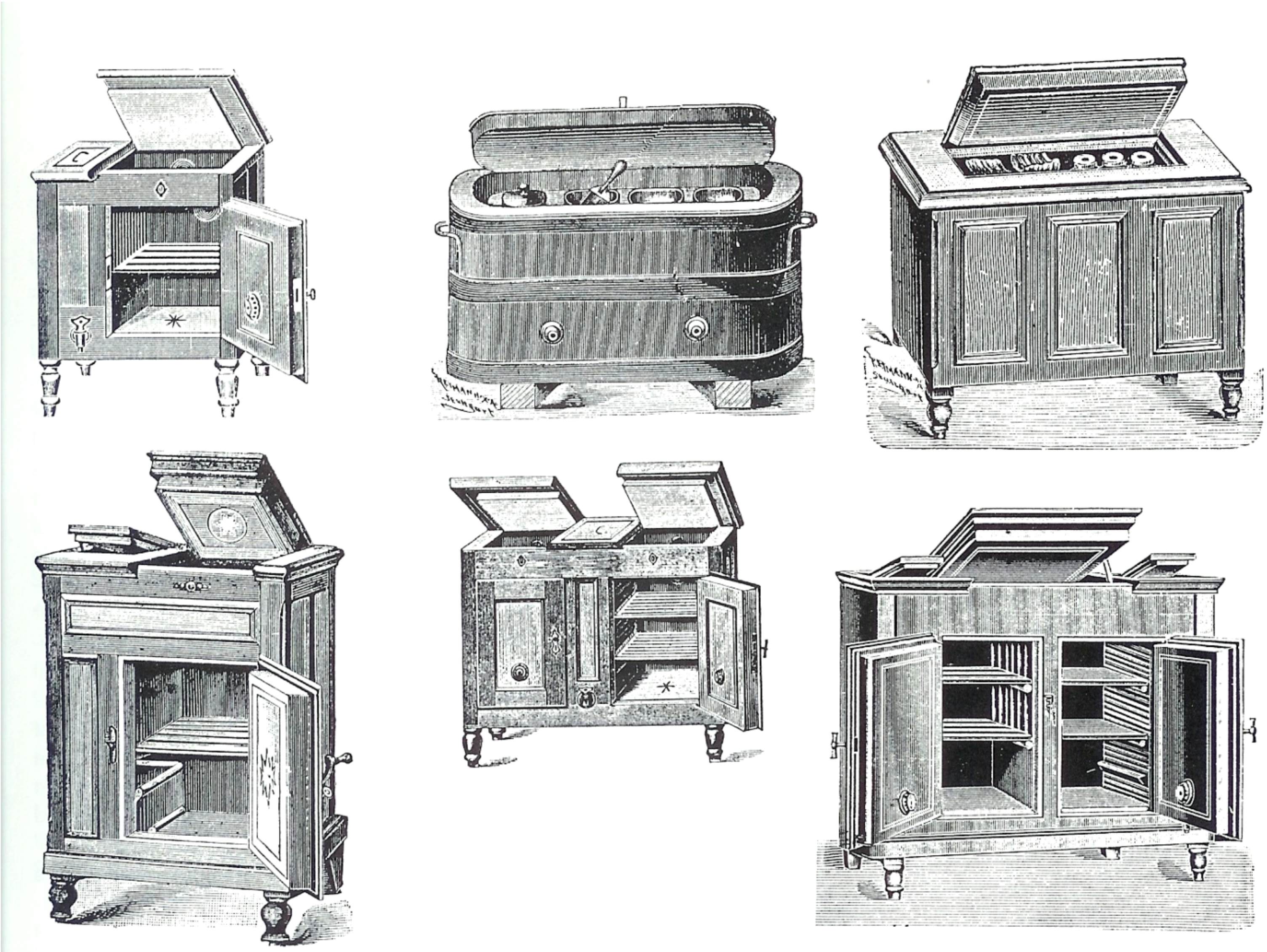
Harvest Ice (ca. 1900)

Harvest Ice and Storage (ca. 1900)



Ice Transport (ca. 1900)

„Refrigerator“ (Ice - Box) ca. 1900



Pictures: Eisfink Co. Germany

Ice and Refrigeration, **1922**

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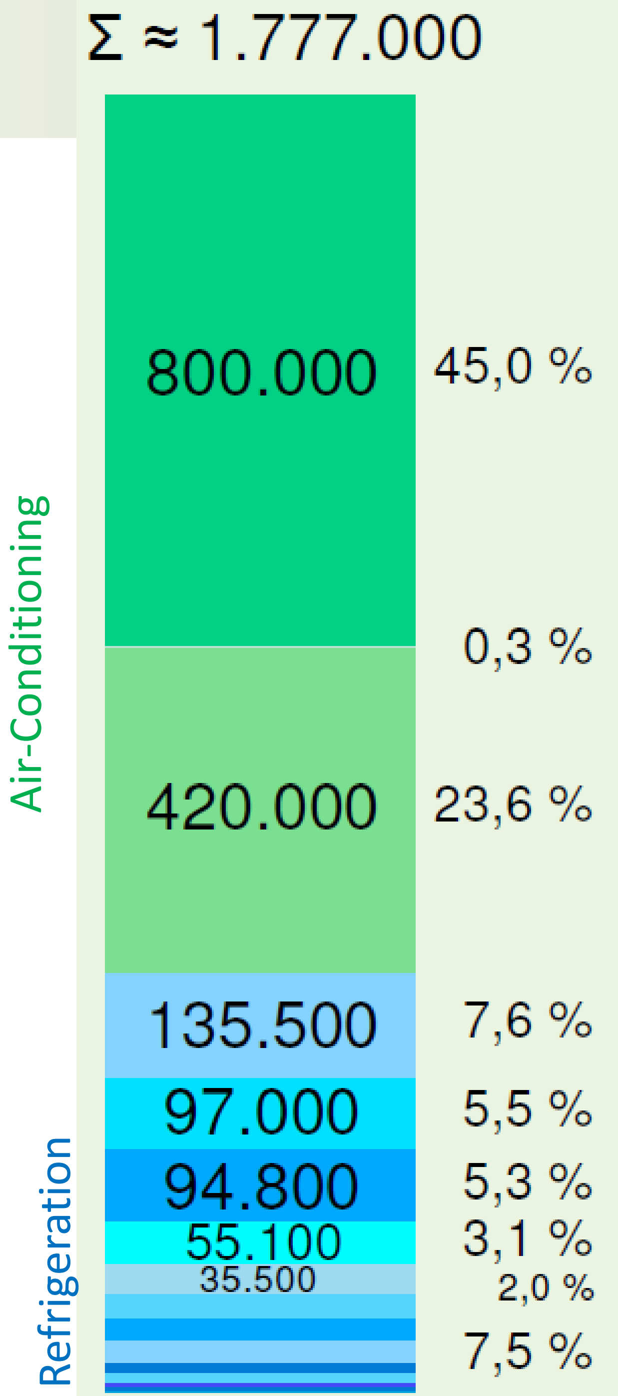
Status of Refrigeration in the Society

Area of Application

- Perishable Food, Cold Chain, AC
- Medical Science, Biology
- Industrial Production Processes → Medicine, Microchips Production, Process Engineering, Production Engineering, Metallurgy

Disciplines:

- Mechanical Engineering
- Supply Engineering
- Process Engineering
- Electrical Engineering
- Substitutes Research (Chemistry)
- Safety Engineering
- Thermodynamics



Estimated RAC Systems in Germany / VDMA

+ 2,07 Mio. Stand Alone Units
+ 1,1 Mio. Mobile AC

> Data Processing Centres

> AHU Centralised Systems

> Catering Industry

> Dairy Farms

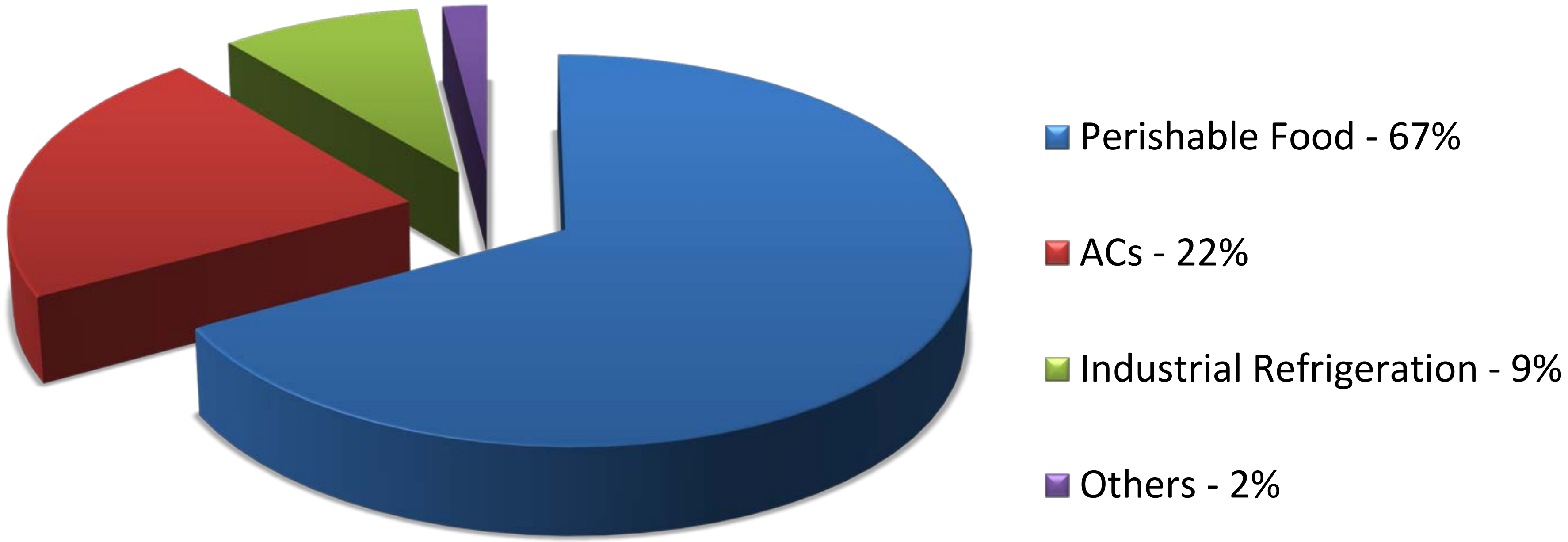
> Hotels & Small Accommodation Business

> Butcher Shops

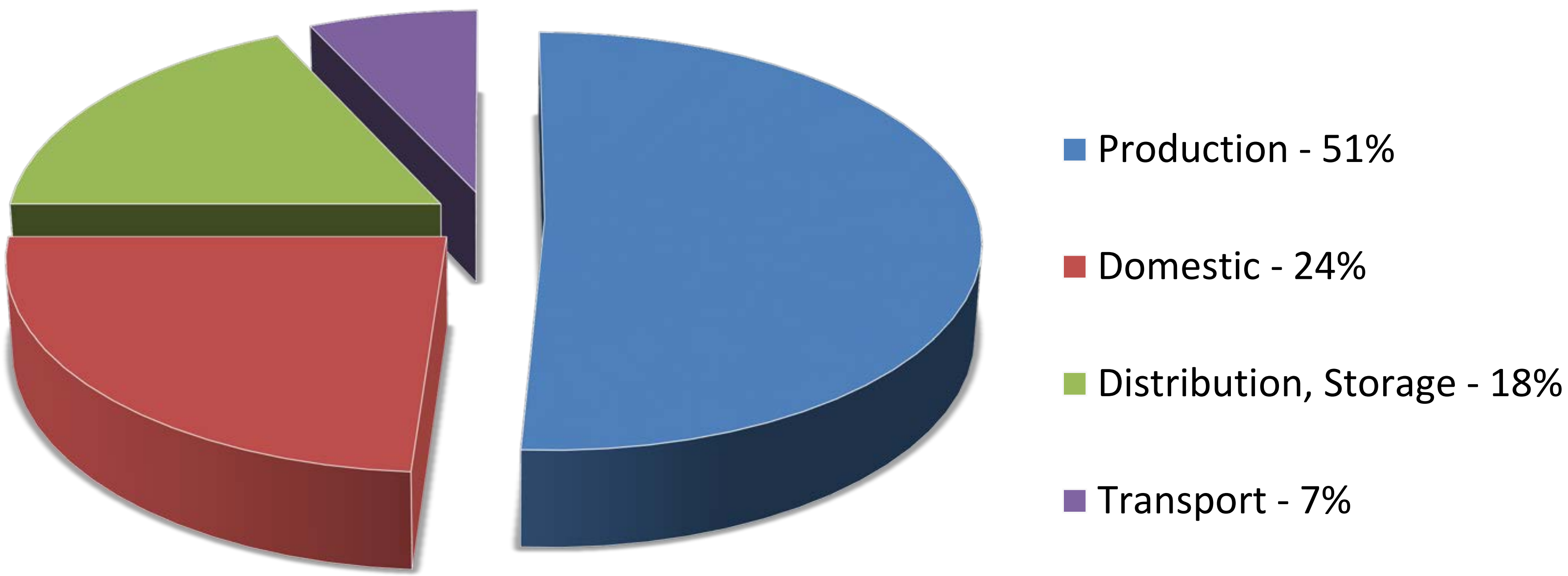
> Supermarket Centralised Systems

> Breweries, Drugstores, Flower shops

Primary Energy Demand / Germany



Cooling Demand Perishable Food / Germany



Application Areas Refrigeration

Temperature Range		Application
In K	In °C	
333,15 to 293,15	60 to 20	Heat Pumps
293,15 to 283,15	20 to 10	Air - Conditioning
273,15 to 223,15	+/-0 to -50	Perishable Food, Ice Cream, Water Ice, Concrete Cooling, Process Eng., Skating Rings, Shaft Construction, Foundation Eng.,
223,15 to 173,15	-50 to -100	Mechanical Engineering, Joining Technologies, Dry-Ice (CO_2 Snow) Production, Metallurgy,
223,15 to 73,15	-50 to -200	Gas Treatment, LPG, Techn. Gases Liquefaction (LPG, Air), Air Separation, Transport and Storage (LPG), O_2 Extraction, Freeze Drying, LN_2 – Quick Freezing
73,15 to 23,15	-200 to -250	Astronautics, Electronics, Laboratory Engineering,
23,15 to 0	-250 to -237,15	Superconductivity, Physical Basic Research

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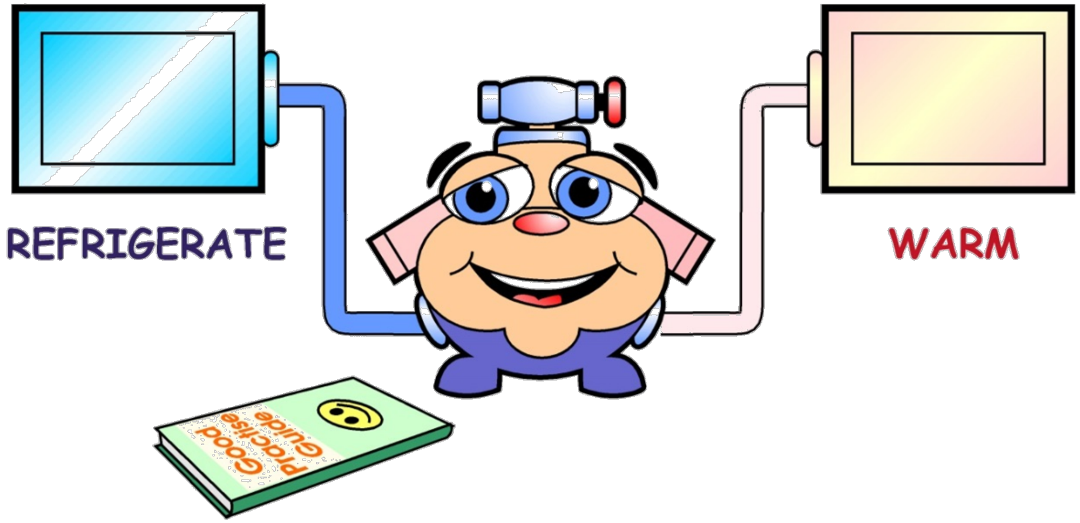
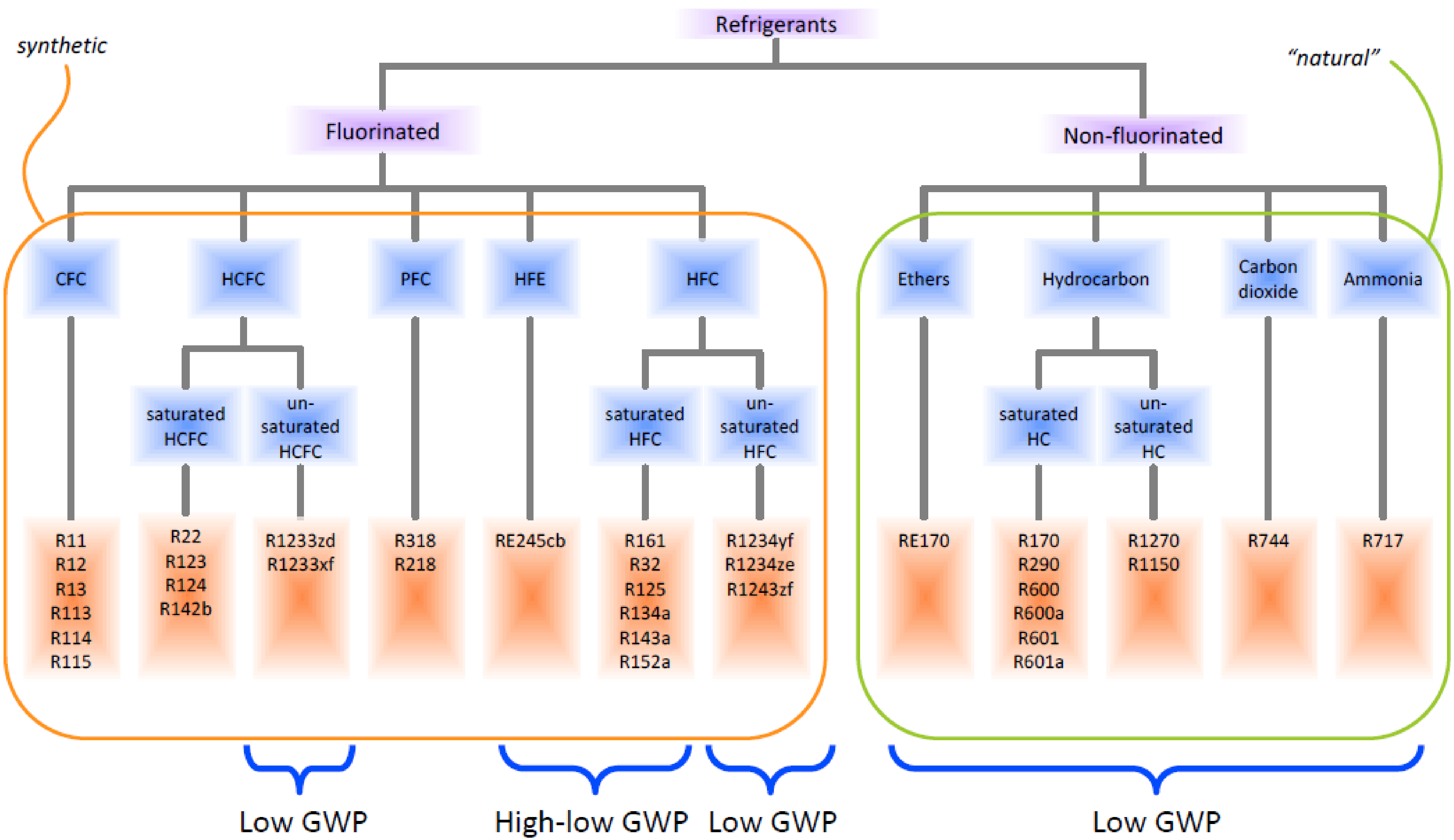
Refrigerant - General

- Substance used in a cooling system, such as an air conditioner or refrigerator, as the heat transfer medium which changes from vapour to liquid and back to vapour (phase changes) in the refrigeration cycle.
- It is important to consider the operating pressures in both the low and high sides of the system.
- Refrigerant should have a condensing pressure that does not exceed the pressure that the system components are designed for, as this can have safety implications



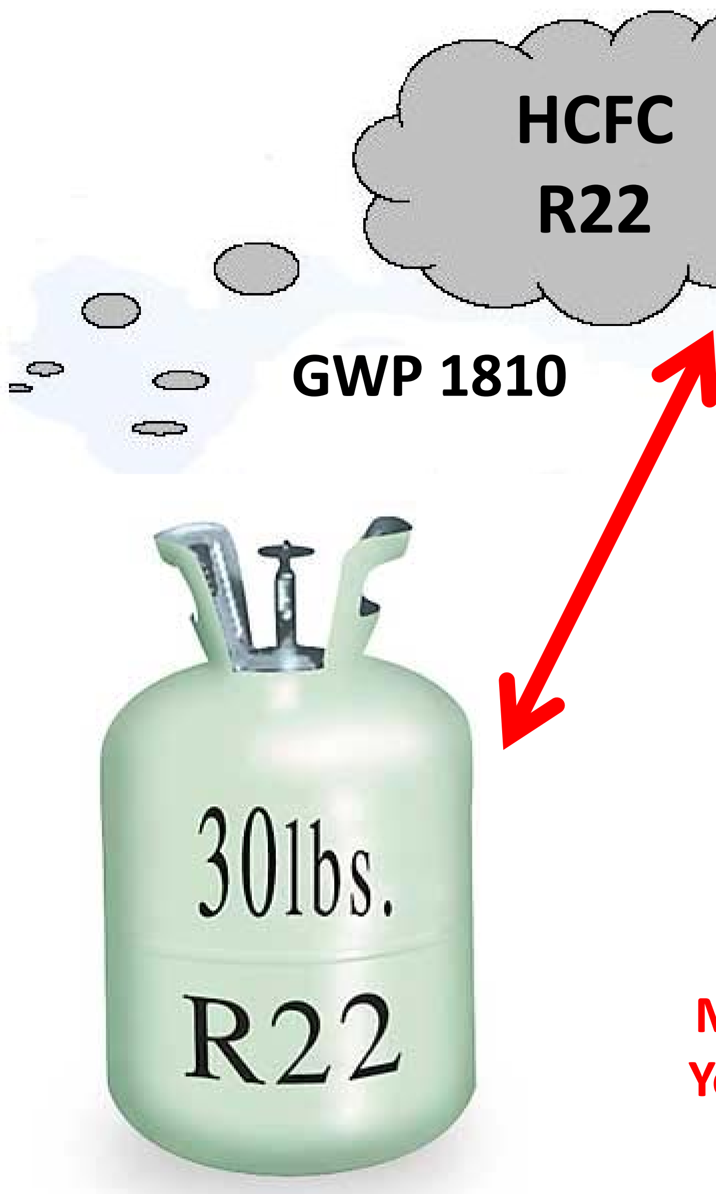
Refrigerant Options

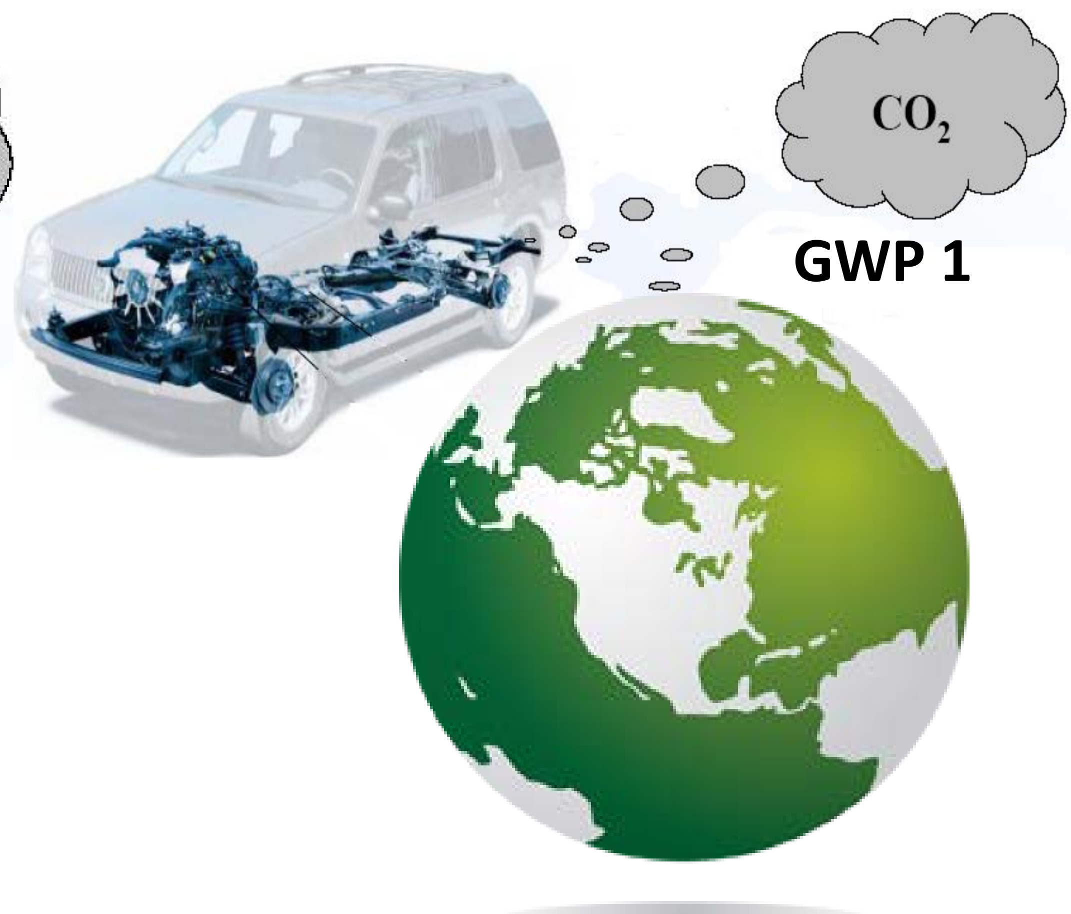


Environmental Characteristics

Refrigerant		Atmospheric Lifetime (Years)	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP) (100 Year)
CFC (no more)	CFC-11 (Baseline ODP)	50	1	4000
	CFC-12	102	1	10900
HCFCs	HCFC-22	13.3	0.055	1820
	HCFC-123	1.4	0.02	93
	HCFC-141b	9.4	0.11	630
HFCs	HFC-134a	14.6	0	1300
	HFC-245fa	7.3	0	820
	R-32	-	0	675
HCs	HC-290 (Propane)	-	0	3
	R-1270 (Propylene)	-	0	<2
HFC Blends	R-404A	-	0	3260
	R-407A	-	0	1770
	R-407C	-	0	1530
	R-410A	-	0	1730
Ammonia	R-717	-	0	<1
CO2	R-744	-	0	1

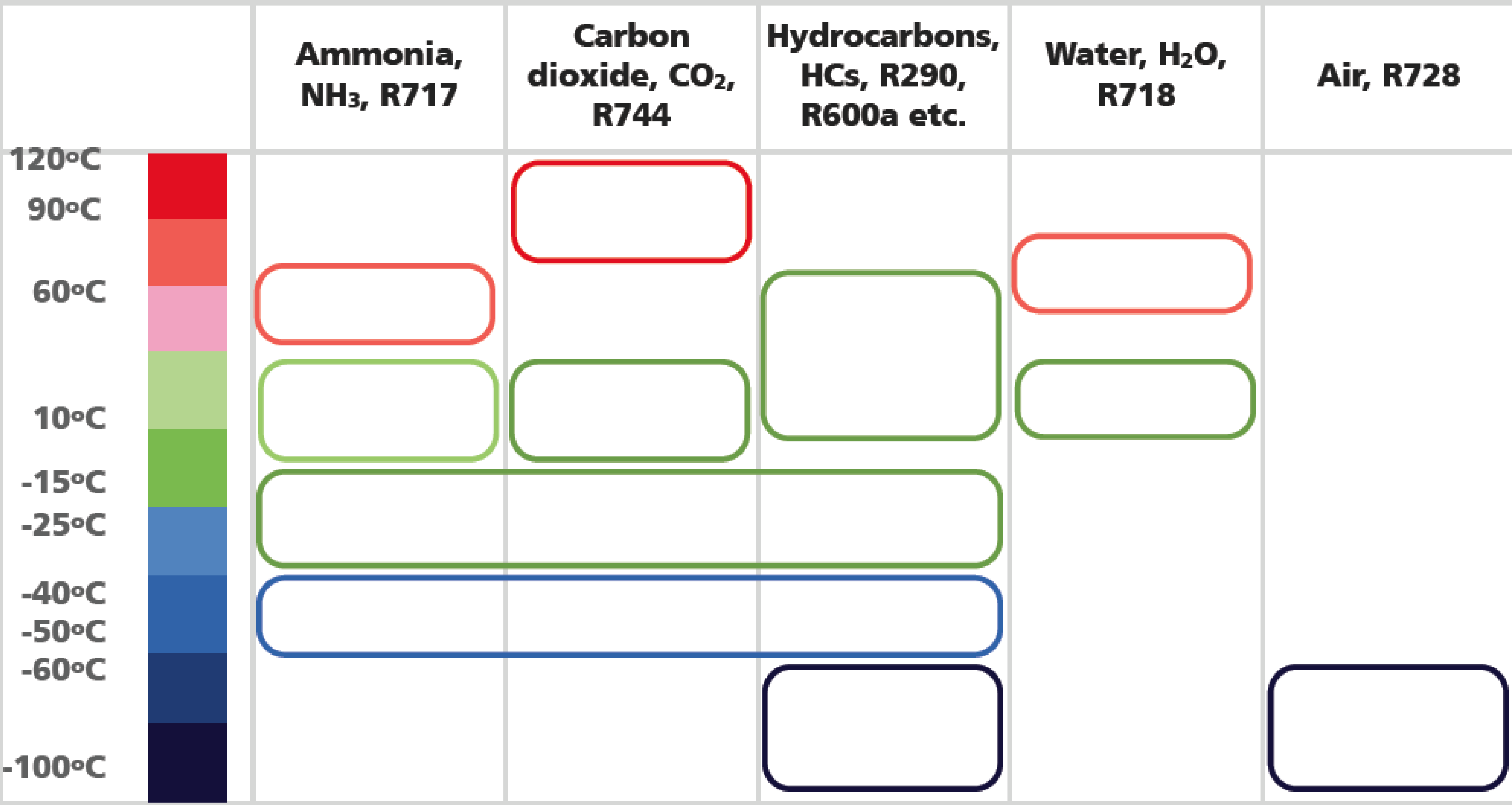
GWP of HCFC R22





4,5 Kg of R22 are equal to 8145 kg of CO2
Medium-class car exposes approx 0.200 Kg/Km CO2
You can drive 40725 Km (1 x round the Earth) for the same CO2 Emission of 4,5 Kg HCFC-R22

Potentials of Natural Refrigerants RACHP Applications



RHPAC = Refrigeration, Heat Pumps, Air- Conditioning

Source: adapted from Mayekawa, 2012

Natural Refrigerants Characteristics

Lower Flammability & Toxic

Very high pressure

Higher Flammability

REFRIGERANT	REFRIGERANT NUMBER	CHEMICAL FORMULA	GWP (100 YEARS)	ODP	NORMAL BOILING POINT (°C)	CRITICAL TEMPERATURE (°C)	CRITICAL PRESSURE (BAR)	SAFETY GROUP	MOLECULAR WEIGHT (G/MOL)
Ammonia	R717	NH_3	0	0	-33.3	132.4	114.2	B2	17.03
Carbon dioxide	R744	CO_2	1	0	-78	31.4	73.8	A1	44.0
Propane	R290	C_3H_8	3.3	0	-42.1	96.7	42.5	A3	44.10
Isobutane	R600a	C_4H_{10}	4	0	-11.8	134.7	36.48	A3	58.12
Propylene	R1270	C_3H_6	1.8	0	-48	91	46.1	A3	42.08
Water	R718	H_2O	0	0	100	373.9	217.7	A1	18.0
Air	R729	-	0	0	-192.97	-	-	-	28.97

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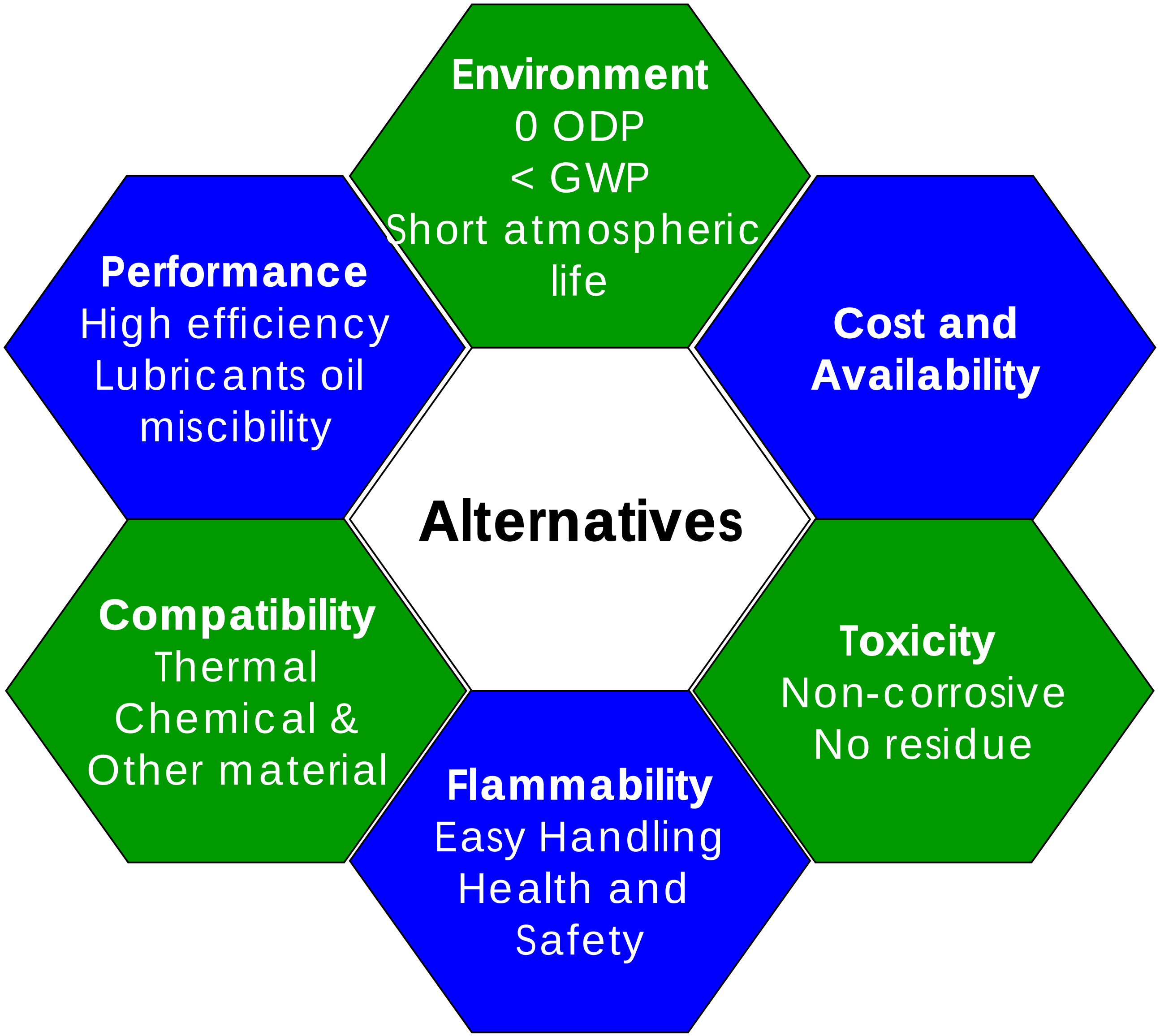
General application consideration for refrigerants



HFCs and HFC Blends

e.g. R-134a, HFC-32, R-404A, R-407C, R-410A, R-507A

☑ Advantages

- Zero ODP
- Non-flammable
- Capacity close to HCFC 22 (R-407C)

☒ Disadvantages

- High GWP
- Oil {polyol ester oil (POE) / poly alkyl glycol oil (PAG)} used is highly hygroscopic
- COP less than HCFC
- Reliability/Compatibility issues with the materials of system construction
- System changes necessary

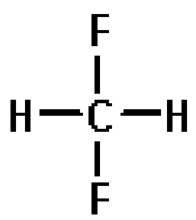
HFC-32 - Characteristics

Single fluid

Boiling point: -51.7°C

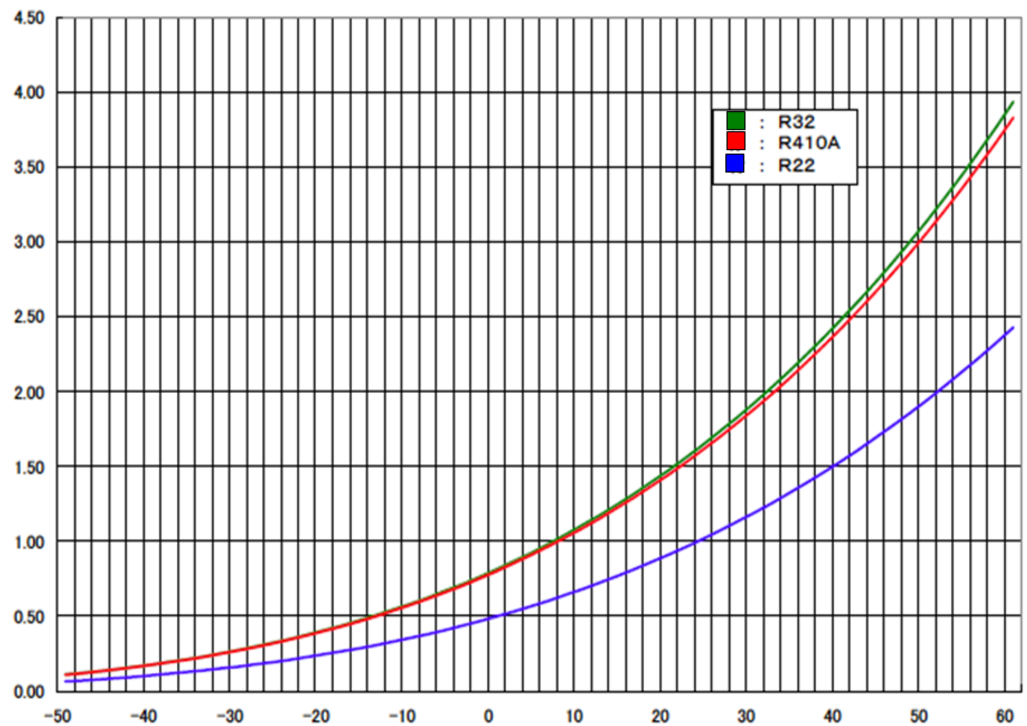
Sensitive to contamination

Non-miscible with Mineral oils



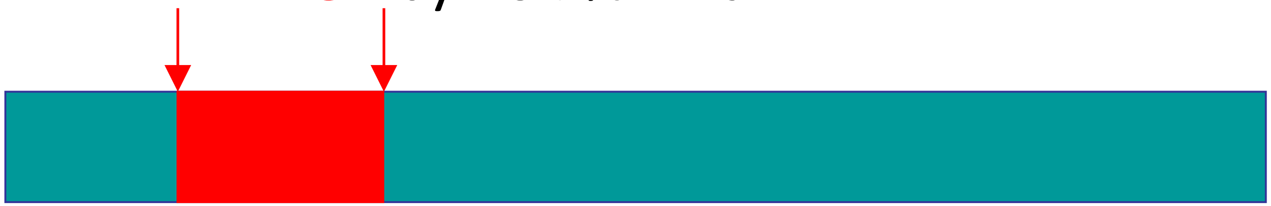
CH_2F_2

Difluoromethane



Flammability range :

14 - 31 by Vol. % in air



0 %

100 %

Unsafe range

HFCs – possibilities

R-407C *as a substitute to* HCFC-22

- Retrofit possible > high GWP

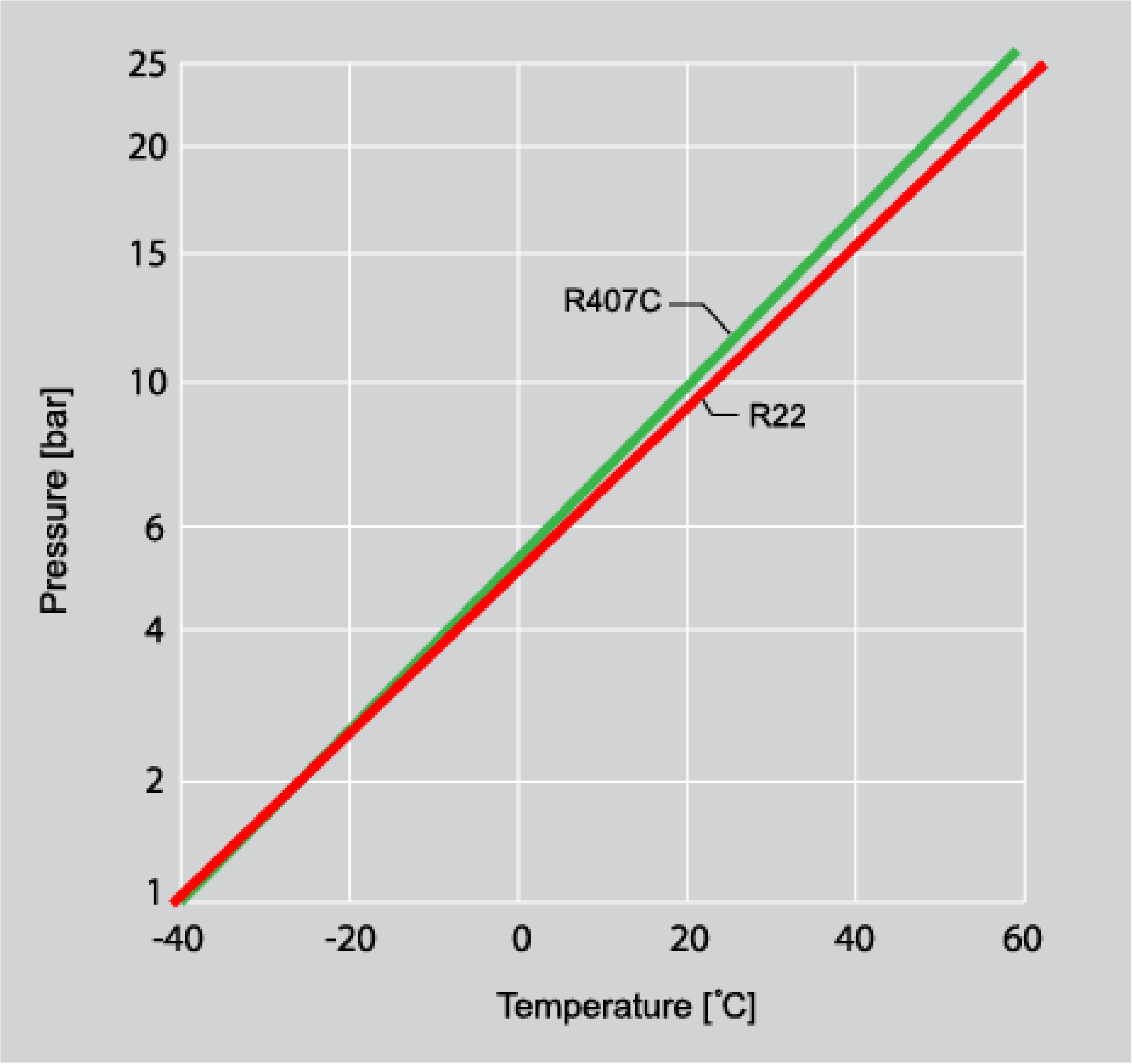
R-410A *as a substitute to* HCFC-22

- For new systems > high GWP
- It has higher pressures
- It is **not recommended** as **retrofitting** refrigerant

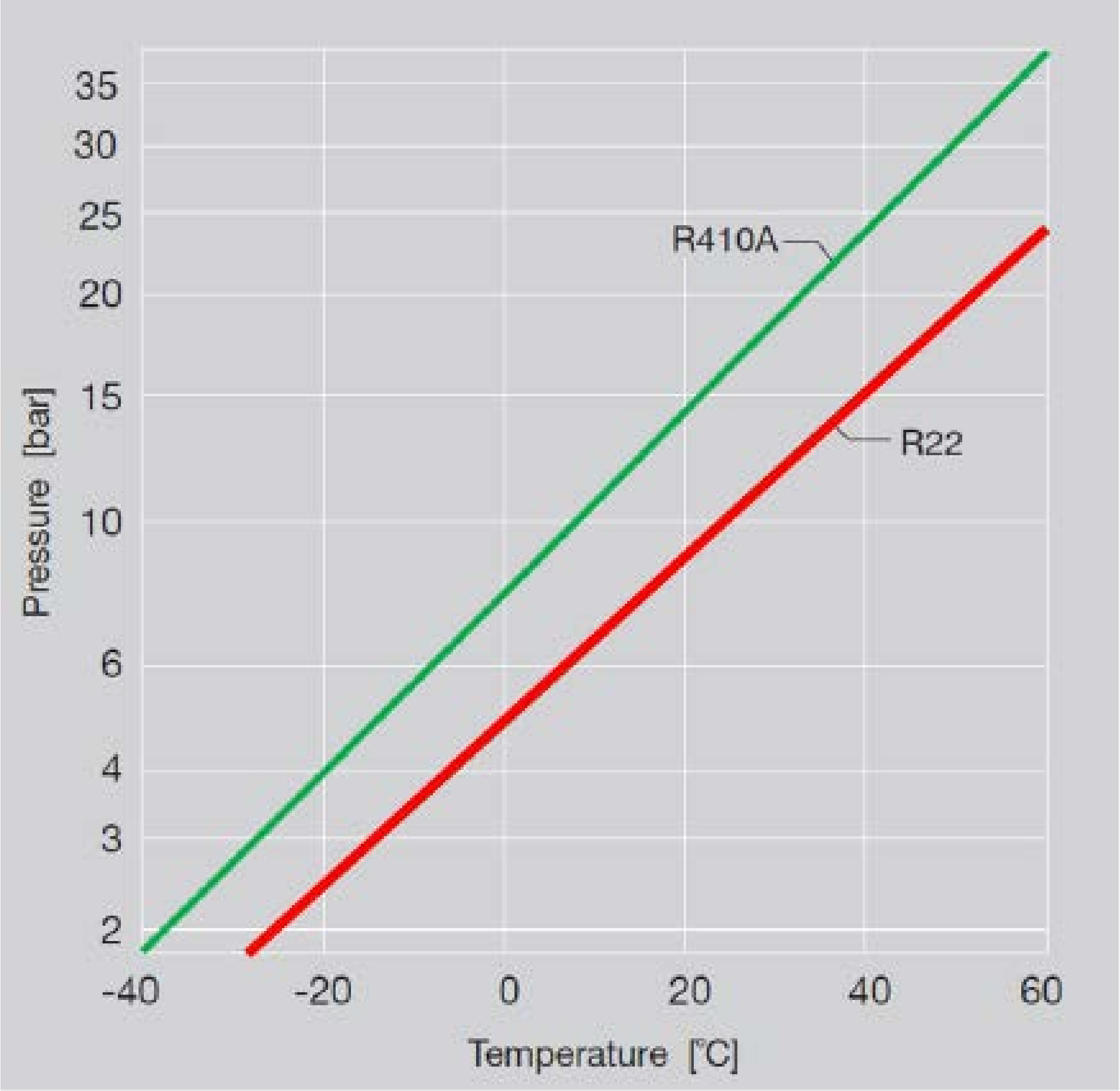
R-507A *as a substitute to* HCFC-22

- HFC blend replacement option for R-22 in commercial refrigeration systems
- It can be used in new and existing systems, and provides very similar performance over the entire operating range.
- High GWP

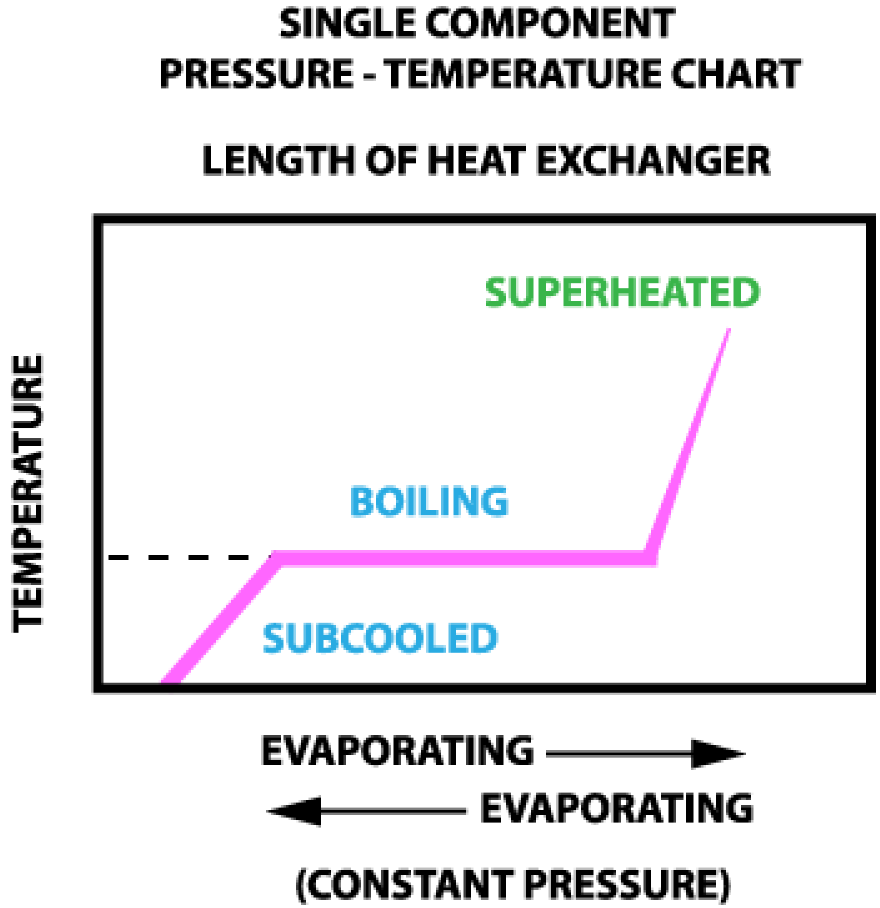
R407C versus R22 Operating Conditions



R410A versus R22 Operating Conditions



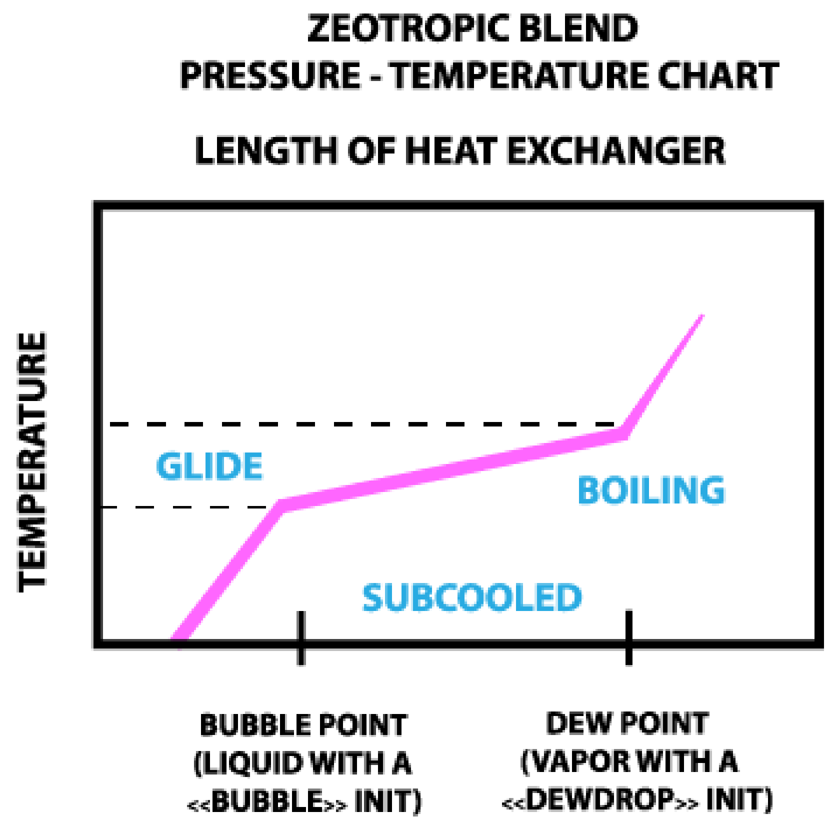
HFC Blend - Azeotropic



Azeotropic Blends

- An Azeotropic blend is a mixture of usually two substances, which behaves as if it were a pure fluid.
- It behaves like a single refrigerant when condensing or evaporating, i.e., the temperature remains constant at a given pressure.

HFC Blend - Zeotropic



Zeotropic blends

- The components within the mixture change their composition in the liquid and vapour phases as the blend boils or condenses.
- A change in the molar composition and/or a change in saturation temperature during boiling or condensation; in this way, it does not behave like a single refrigerant when condensing or evaporating.

Hydrocarbons (HCs)

e.g. HC-290 (C_3H_8 Propane), R1270 (C_3H_6 propylene)

☑ Advantages

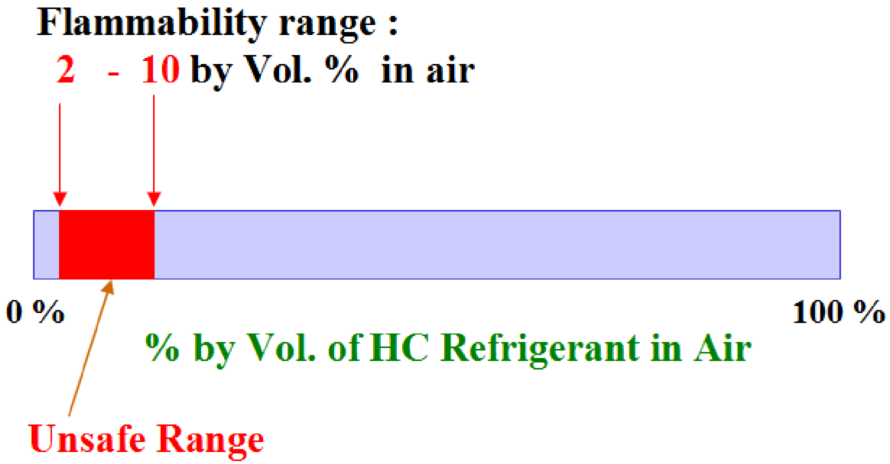
- Zero ODP
- Negligible GWP
- Long term solution
- Work with Mineral Oil and some other commonly used refrigeration oils with appropriate viscosities and application limitations
- Capacity close to HFC/HCFC and better (HC-290 and HC-1270)

☒ Disadvantages

- Flammable
- Changes needed to some electrical components
- Adequate ventilation surrounding the system / equipment essential

Hydrocarbons (HCs) Issues

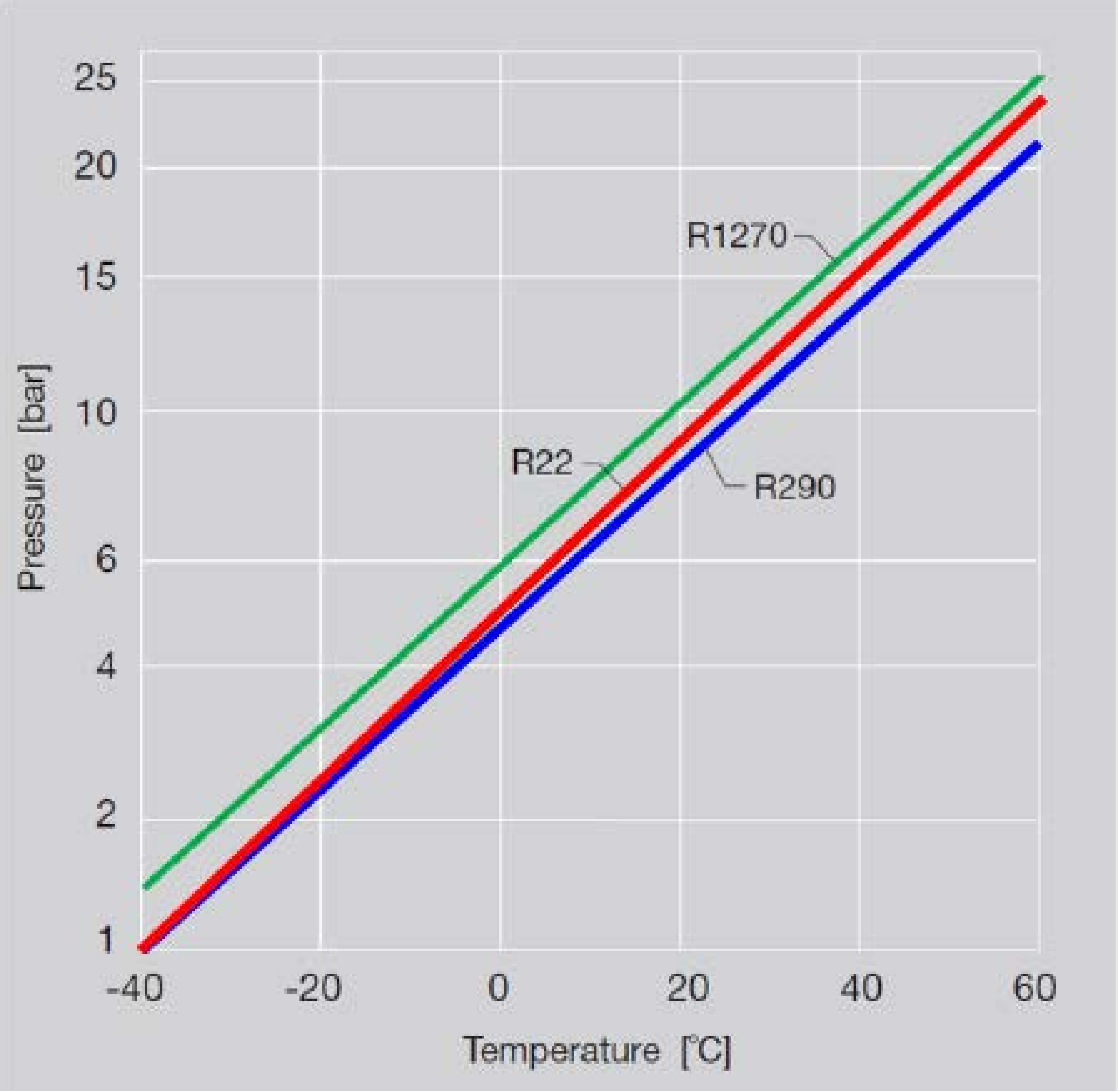
- Electrical devices attached to / close to system must be non-sparking (sealed type) or solid state or installed in separate/ adjacent room
- Provision of adequate ventilation surrounding system/equipment
- HC charge is lower by more than 50% of HCFC by weight
- Safe manufacturing / servicing essential
- Training needed



HC-290 (Propane)

- Single substance
- Boiling Point: -42.2 °C
- Much lower vapour pressures
- Miscible with Mineral Oil and some other commonly used refrigeration oils with appropriate viscosities and application limitations
- Compatible with compressor materials
- Today widely used in air-conditioners, chillers, plug-in appliances and commercial refrigeration

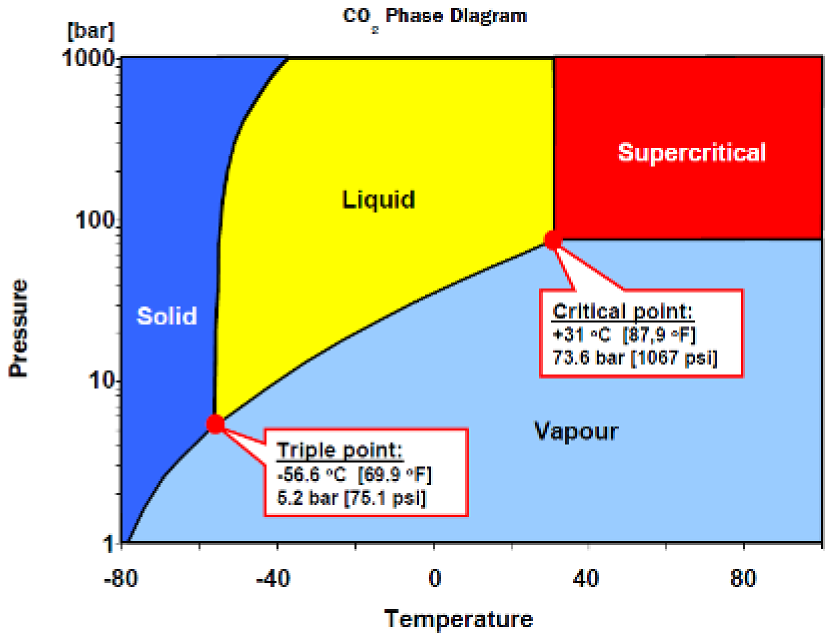
R-290 versus R22 Operating Conditions



HC-290 (Propane) : Characteristics

- Different compressor design
- Quieter
- Different capillary tube
- Lower condensing pressures
- Lower evaporating pressures
- Less friction, reduced maintenance and increased lifetime
- Easy to adapt for technicians and engineers (focus on safety considerations)

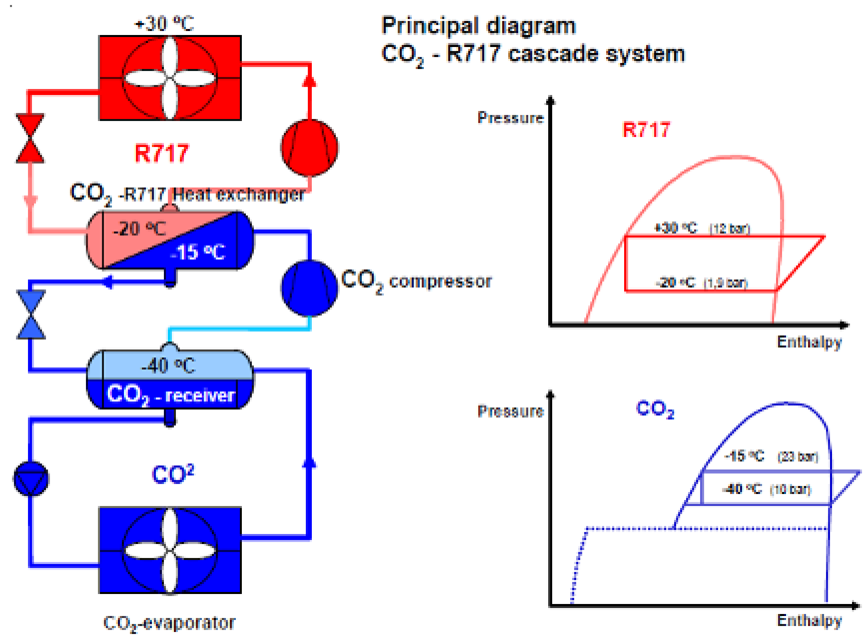
Carbon Dioxide (CO_2) Characteristics



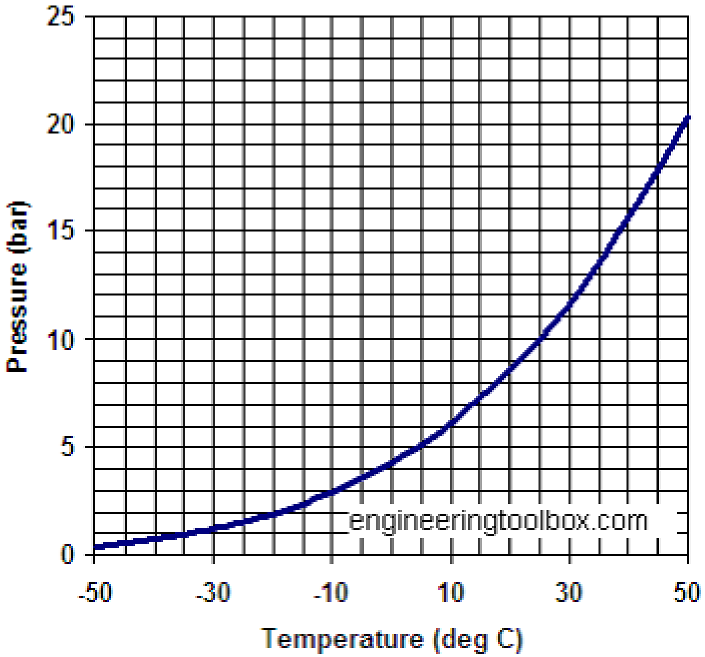
- Carbon Dioxide is a substance that can exist as a gas, liquid or solid (dry ice), and can be used under high pressure as a refrigerant.
- CO_2 has been used as a refrigerant since 1850 and is now regaining popularity due to its low environmental impact.
- Zero ODP and a GWP = 1.
- Excellent thermodynamic properties make it suitable for a range of applications.

Carbon Dioxide is;

- A liquefied gas under pressure
- Non flammable
- In high concentration can be toxic and may cause asphyxiation.
- Heavier than air
- Odourless and colourless
- High operating pressure
- Not possible for retrofit



Ammonia Characteristics

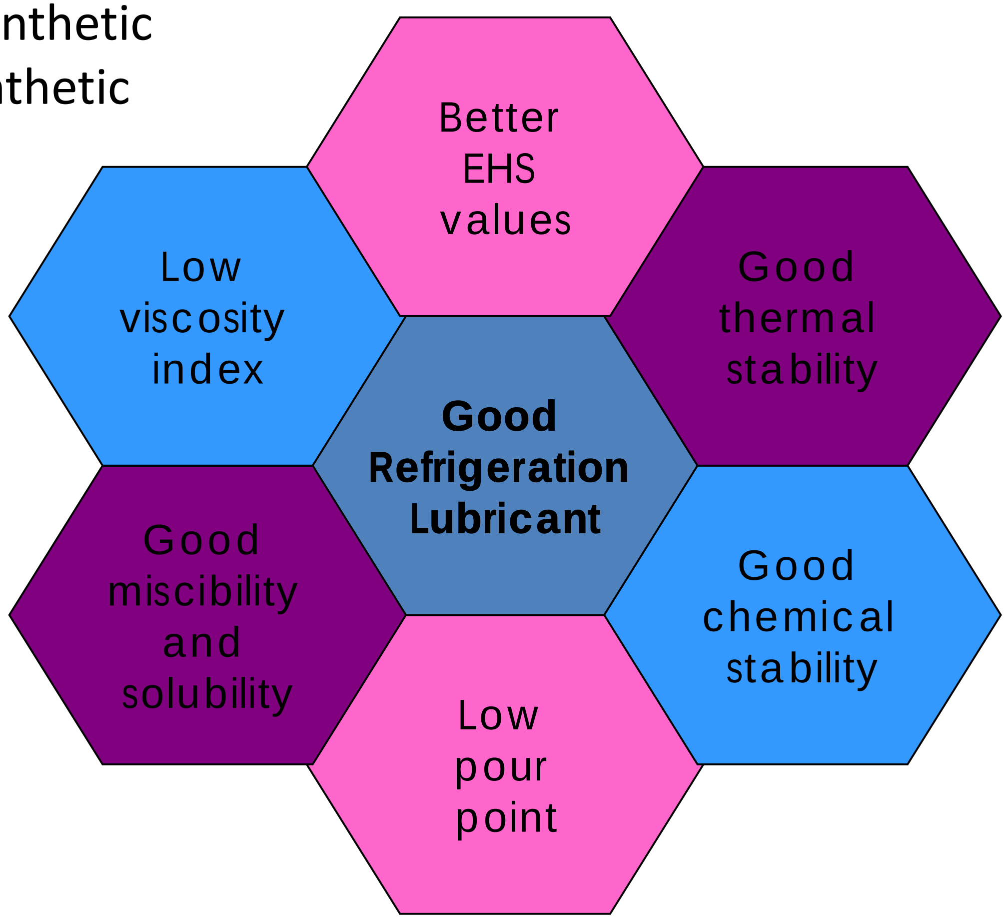


- Environmental friendly
- Boiling point is -28 degree F (-33.33 degree C).
- Highest refrigerating capacity per pound of any refrigerant
- Toxic and flammable within certain conditions
- Corrosive nature of ammonia
- leak testing by using Sulphur sticks. When ammonia reacts with sulfur, a dense smoke is formed.

Refrigeration Oil and Good properties

Five main categories of refrigeration lubricants:

1) mineral oils (MO)… HCFC
2) alkyl benzene oils (AB)…HCFC
3) polyol ester oils (POE)...synthetic
4) poly alpha olefin oils (PAO)…synthetic
5) poly alkyl glycol oils (PAG)…synthetic



Appropriate Lubricant

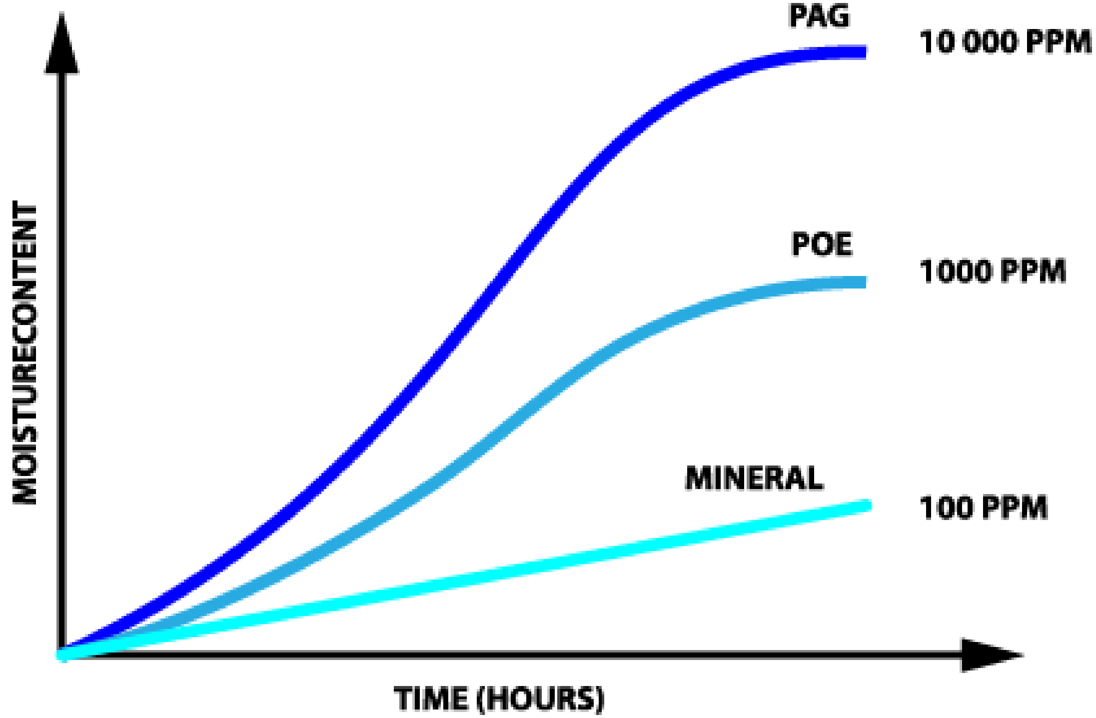
Refrigerant	Appropriate Lubricant				
	Mineral Oil (MO)	Alkyl benzene (AB)	Polyol Ester (POE)	Poly alpha oelfin (PAO)	Poly alkyl glycol (PAG)
CFC-11	✓	×	□	□	×
CFC-12	✓	✓	□	□	×
R-502	✓	✓	□	□	×
HCFC-22	✓	✓	□	□	×
HCFC-123	✓	✓	□	□	×
HFC-134a	×	×	✓	×	□
HFC-404A	×	×	✓	×	□
HFC-407C	×	×	✓	×	□
HFC-410A	×	×	✓	×	□
HFC-507A	×	×	✓	×	□
HC-600a	✓	□	✓	✓	□
HC-290	✓	□	✓	✓	□
R-717 (NH_3)	✓	□	×	✓	□
R-744 (CO_2)	□	□	✓	✓	✓

✓: Good Suitability □: Application with limitations ×: Not Suitable

Poly Alkylene Glycol (PAG) & Polyol Ester Oil (POE) Issues

Highly hygroscopic

- Reliability problems
- Servicing issues



Hygroscopy of POE and mineral lubricants

Issues with Alternative Refrigerants

HFC blends

- POE lubricants are highly hygroscopic
- Better manufacturing & servicing practices needed
- High GWP
- Phase out scenarios worldwide
- Training required

Hydrocarbons

- Require safer design
- Better manufacturing & service practices
- Knowledge of legislation, regulation and standards relating to flammable refrigerants;
- Detailed knowledge of and skill in handling flammable refrigerants including blends, personal protective equipment, refrigerant leakage prevention, handling of cylinders, charging, leak detection, recovery and disposal.
- Training required

Issues with Alternative Refrigerants

CO_2

- High pressure refrigerant
- Better manufacturing & servicing practices
- Require safer design
- Training required

Ammonia

- Require safer design
- High discharge temperature of ammonia gas
- Better manufacturing & service practices
- Training required

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Alternative refrigerants to replace CFCs, HCFCs and high GWP HFCs

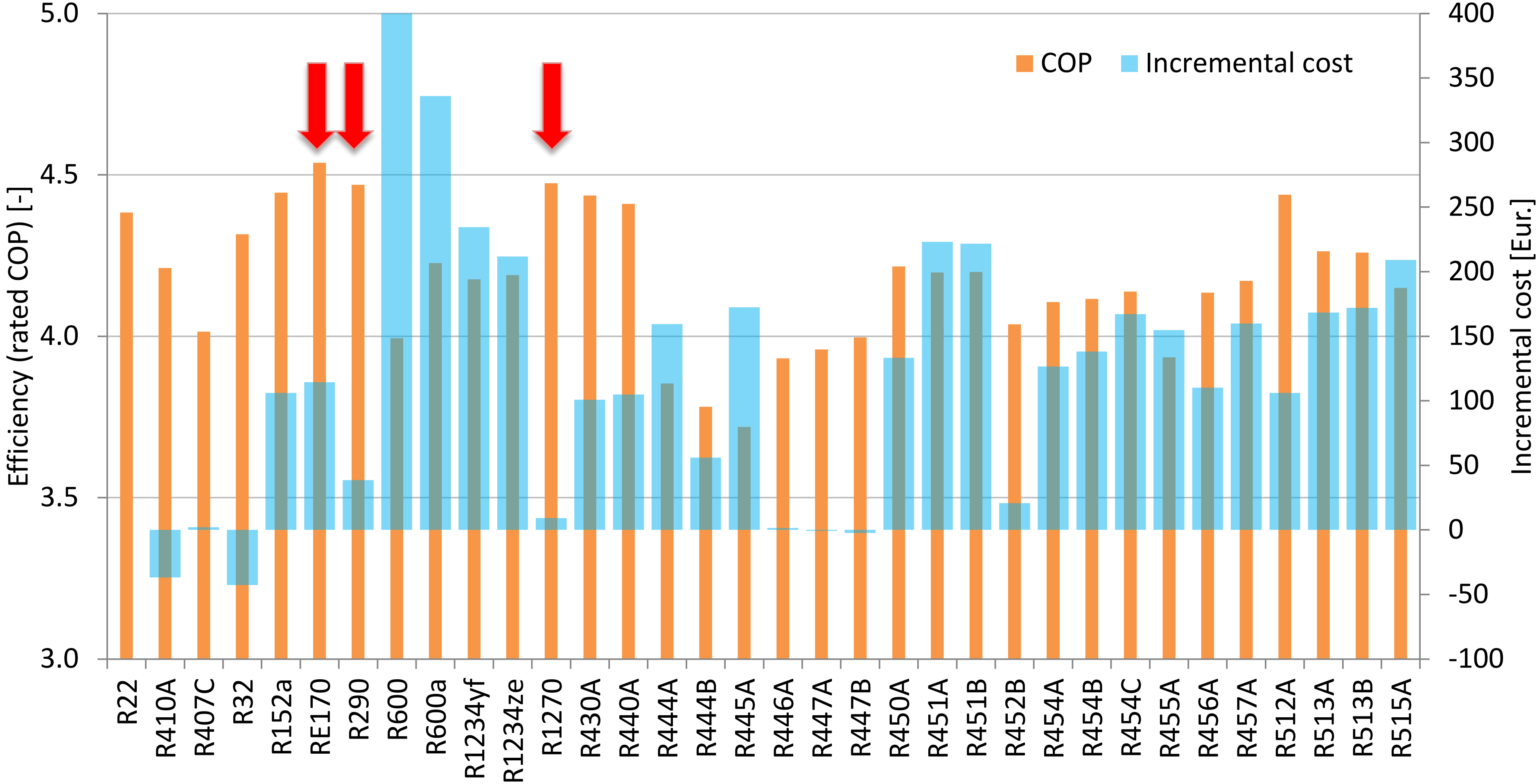
Characteristics of low-GWP refrigerants

	Safety class	ATEL (kg/m3)	LFL (v/v)	Pressure (bar)
HCFC-22	A1	0.3	-	10.4
R-744	A1	0.07	-	64.3
HFC-1234ze	A2(L)	[0.28]	7.5%	5.0
HFC-1234yf	A2(L)	0.47	6.3%	6.8
HFC-152a	A2	0.14	4.8%	6.0
HC-1270	A3	0.10	2.5%	11.5
HC-290	A3	0.09	2.1%	9.5
HFC-161	[A3]*	[?]	4.3%	9.3
R-717	B2(L)	0.00035	13%	10.0

On-going evaluation of various alternatives

Assessment of all new/proposed low- and medium GWP alts

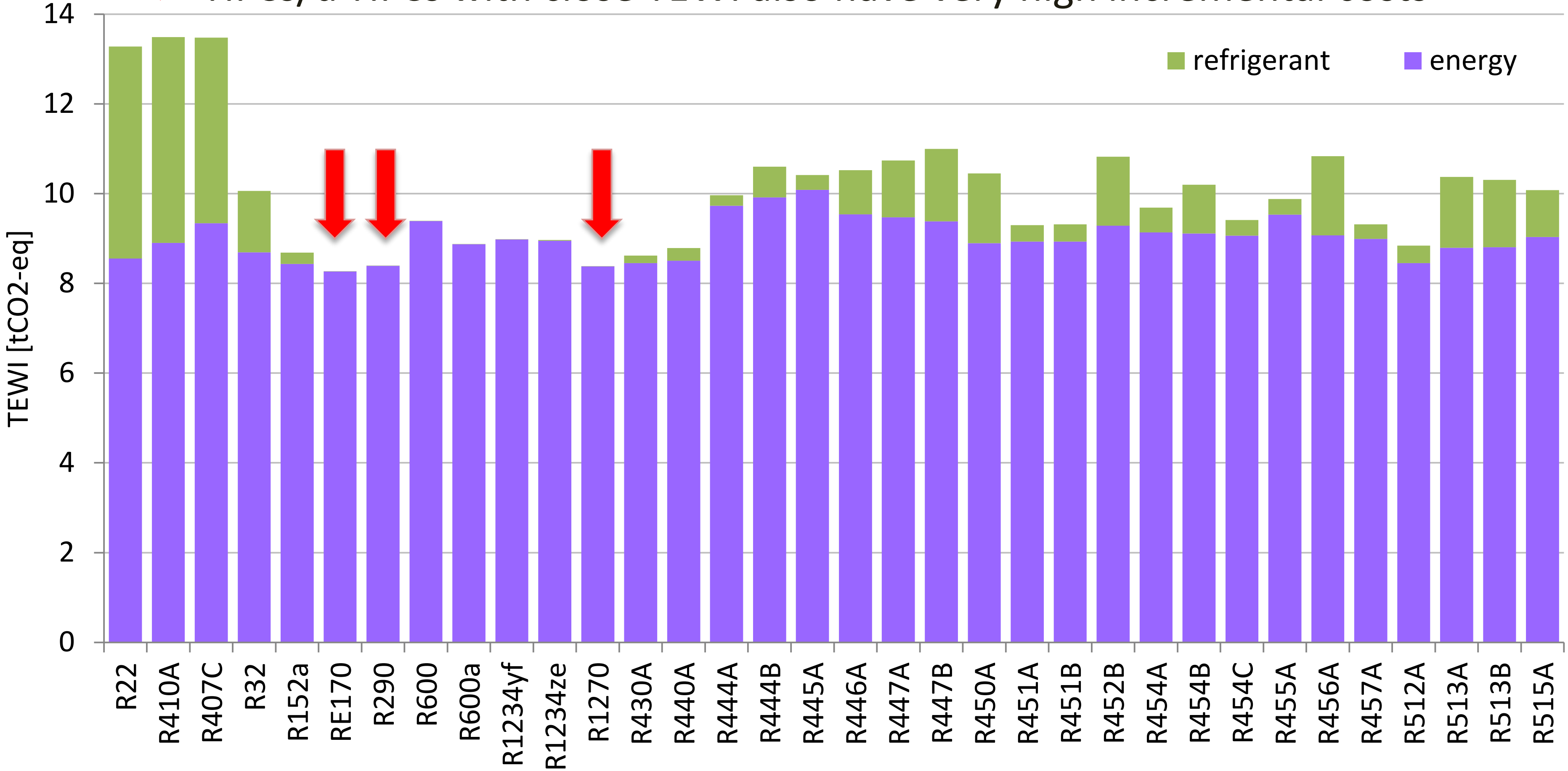
- Of all of them, HCs offer the highest COP for least incremental cost



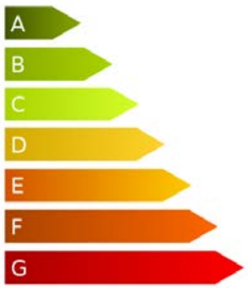
On-going evaluation of various alternatives

Assessment of all new/proposed low- and medium GWP alts

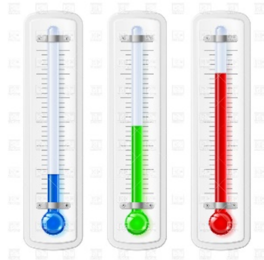
- Also HCs gives lowest TEWI of all alternatives
- HFCs/u-HFCs with close TEWI also have very high incremental costs



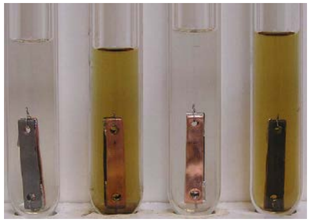
Major considerations for refrigerant selection



Pressure (matching)



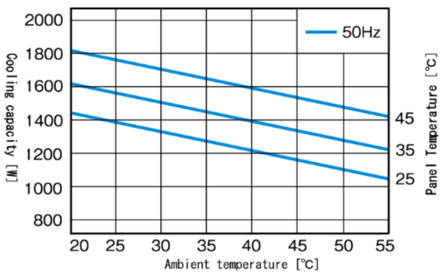
Temperature glide (minimisation)



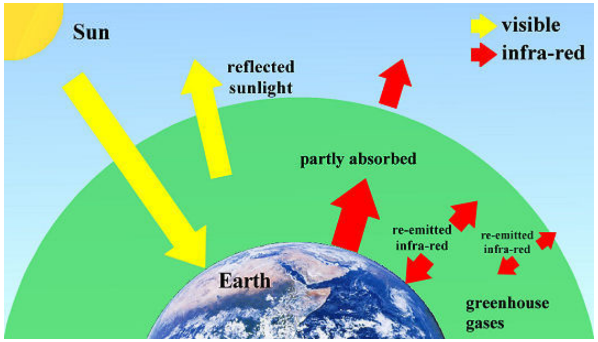
Material compatibility

Efficiency (COP)

Oil solubility/ miscibility



Cooling (heating) capacity



Global Warming Potential

Cost (refrigerant)

Flammability

Toxicity

Cost (system/ equipment)

Aspects affecting refrigerant choice

PRIMARY STAGE SELECTION: FN { PROPERTIES }

Environmental
- ODP
- GWP
- etc

Safety
- flammability
- toxicity
- etc

Chemical
- reactivity
- adsorbtivity
- etc

Thermodynamic
- vapour pressure
- latent heat
- etc

SECONDARY STAGE SELECTION: FN { MARKET }

Availability
- refrigerant
- components
- etc

Costs
- refrigerant
- components
- etc

Know-how
- training
- literature
- etc

Verbal
- reccommendation
- instruction
- etc

Categories of barriers and challenges

Initially identified several categories of barriers

- Technical (refrigeration engineering)
- Technical (safety engineering)
- Supply and availability (equipment, componen fluids)
- Commercial (investment, profit, financial incentives)
- Market (customer, consumer, competing products)
- Information resources (know-how, guidance, technical data)
- Regulatory and quasi-regulatory (legislation, standards)
- Psychological and sociological aspects

General Servicing Issues	NH3 R717	CO_2 R744	HCs R290, R600a …
Weight in relation to air	Lighter	Heavier	Heavier
Refrigerant Purity	99.98 % min Moisture < 200 ppm	99,99 % Moisture < 10 ppm	99.5 % min Moisture < 10 ppm
Gauges & Circuit Equipment	Stainless Steel R717 indication	High Pressure R744 indication	As for HCFC / HFC HC indication
Vacuum Pump	Stainless Steel ATEX, Vent Line	Regular Vent line	Regular ATEX, Vent line
Charging	Scale	Scale Pressure	Sensitive Scale
Tubing	Carbon steel, stainless steel	Copper Stainless steel **HP**	Copper
Leak Finding	Nose, Gas detector, Litmus paper, Sulfur stick, Bubble test, PPE	Gas detector, Bubble test, PPE	Gas detector Bubble test, PPE
Pressure test Leak Test	Nitrogen 4.0	Nitrogen 4.0 Trace Gas (N_2/H_2)	Nitrogen 4.0 Trace Gas (N_2/H_2)
Strength test PS x 1.1	Nitrogen 4.0	Nitrogen 4.0	Nitrogen 4.0

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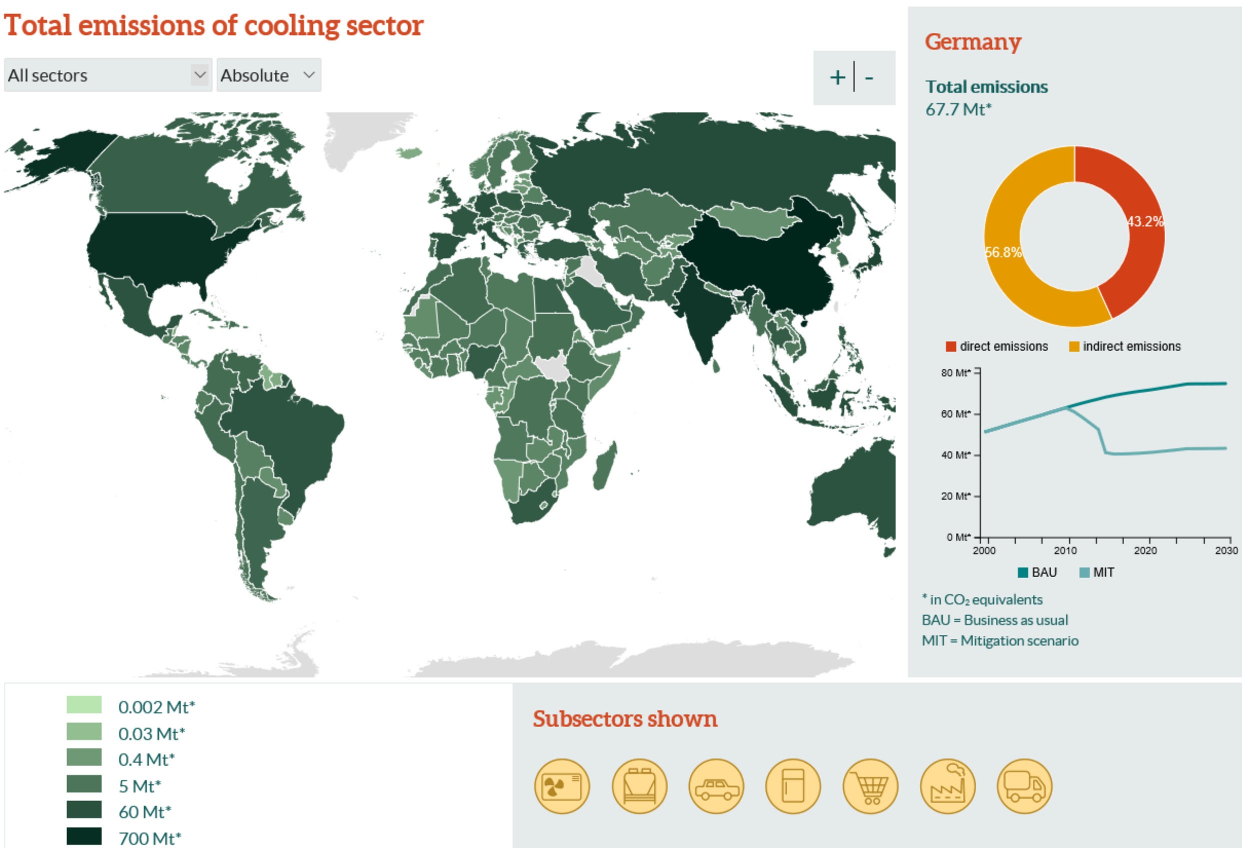
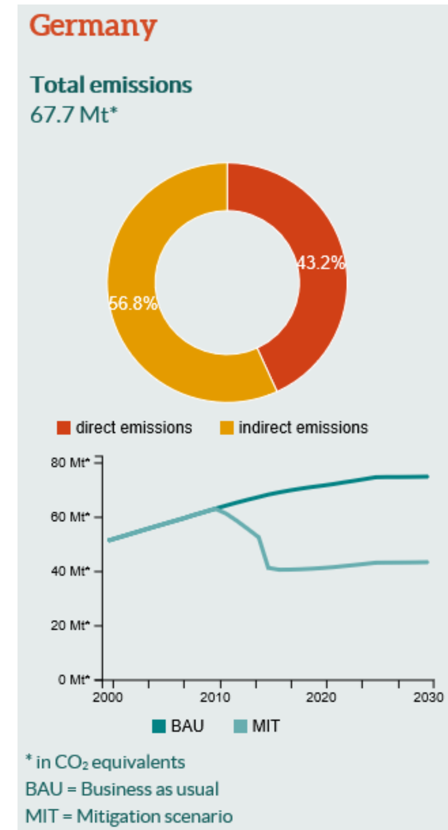
- Global Phase-Down Scenarios
- Energy Efficiency Issues

Green Cooling Initiative: country emissions timeline



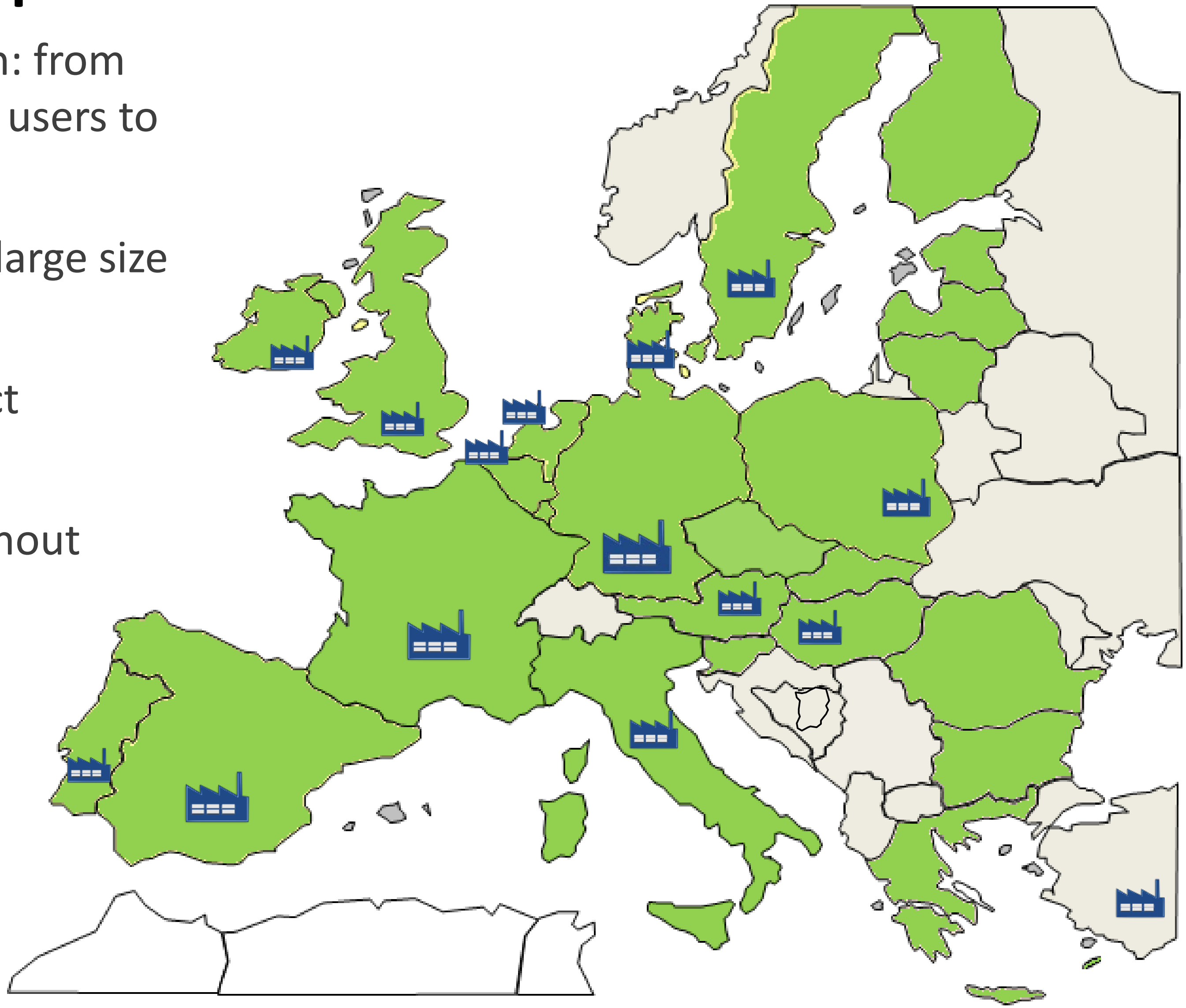


For further information about emissions caused by cooling, reduction potential and green cooling visit: www.green-cooling-initiative.org

European Industries RACHP Priorities

Situation in Europe

- The full value chain: from producers through users to installers
- Small – medium – large size enterprises
- Over 200,000 direct employees
- Production throughout Europe
- Using all types of refrigerants



European Industries RACHP Priorities

Promote Energy Efficiency

- 2030 targets
- Ecodesign & Energy label Directives
- Eco Label Directive
- EPBD - Energy Performance of Buildings Directive
- RES - Renewable Energies Directive
- Energy Efficiency Directive

Promote sustainable management of refrigerants

- Make the new F-Gas rules work
- Support EU Commission and Member States in implementing the new rules
- Support global action to reduce consumption of HFCs

Raise awareness on Market Surveillance

- Importance of properly enforcing and policing legislation

EU Legislation on Refrigerants in the international Context

Montreal Protocol
UNEP

Kyoto Protocol
UNFCCC

EU 2037/2000
Regulation on Ozone-Depleting Substances

EU 814/2006
F-Gas Regulation

EU 1005/2009
Revised Regulation on Ozone-Depleting Substances

EU 517/2014
Revised F-Gas Regulation

EU 20-20-20 Targets
EU 2050 Low Carbon Roadmap

HCFC PHASE- Out in the EU - IMPACT ANALYSIS

The recast of the EU Regulation on ozone depleting substances in 2009 accelerated the **HCFC phase-out** schedule by placing a **complete ban on using HCFCs** (both “virgin” or “recycled”) **by 2015**, enhancing therefore the urgency to replace HCFC equipment/plants.
Some entities seek to leapfrog HFCs, especially in equipment with a long lifetime and vast refrigerant inventories.

Introduced in 2009 as EN 1005/2009
Under revision!
Will be replaced in 2017

Source: Shecco, 2014

F-GAS REGULATION - IMPACT ANALYSIS

The EU Regulation putting rigorous measures on fluorinated gases, including a step-wise phase-down of HFCs, bans on f-gases in new equipment in certain sectors, and strengthened containment and recovery measures.

To prevent hydrofluorocarbon (HFC) emissions from the HVAC&R sector.

First introduced in 2000 as EN 2037/2000 repealed by EN517/2014, taking affect at 01/2015.

Source: Shecco, 2014

Training & Know -How

EU-VO 303/2008

Essential in F-Gas regulation and will be adopted in Ozone Layer Chemicals Order. (DIN EN 13313 also valid)

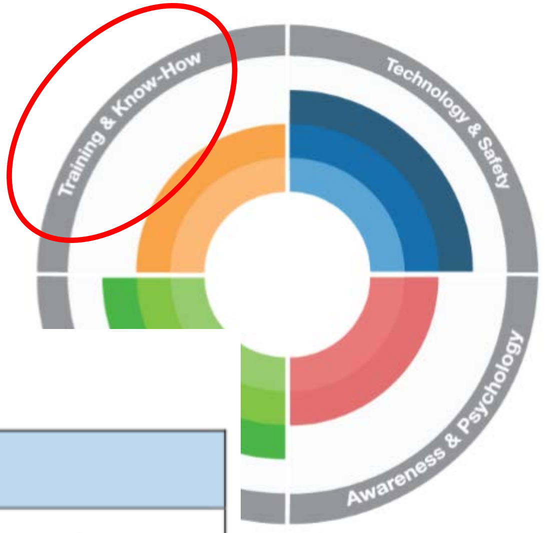


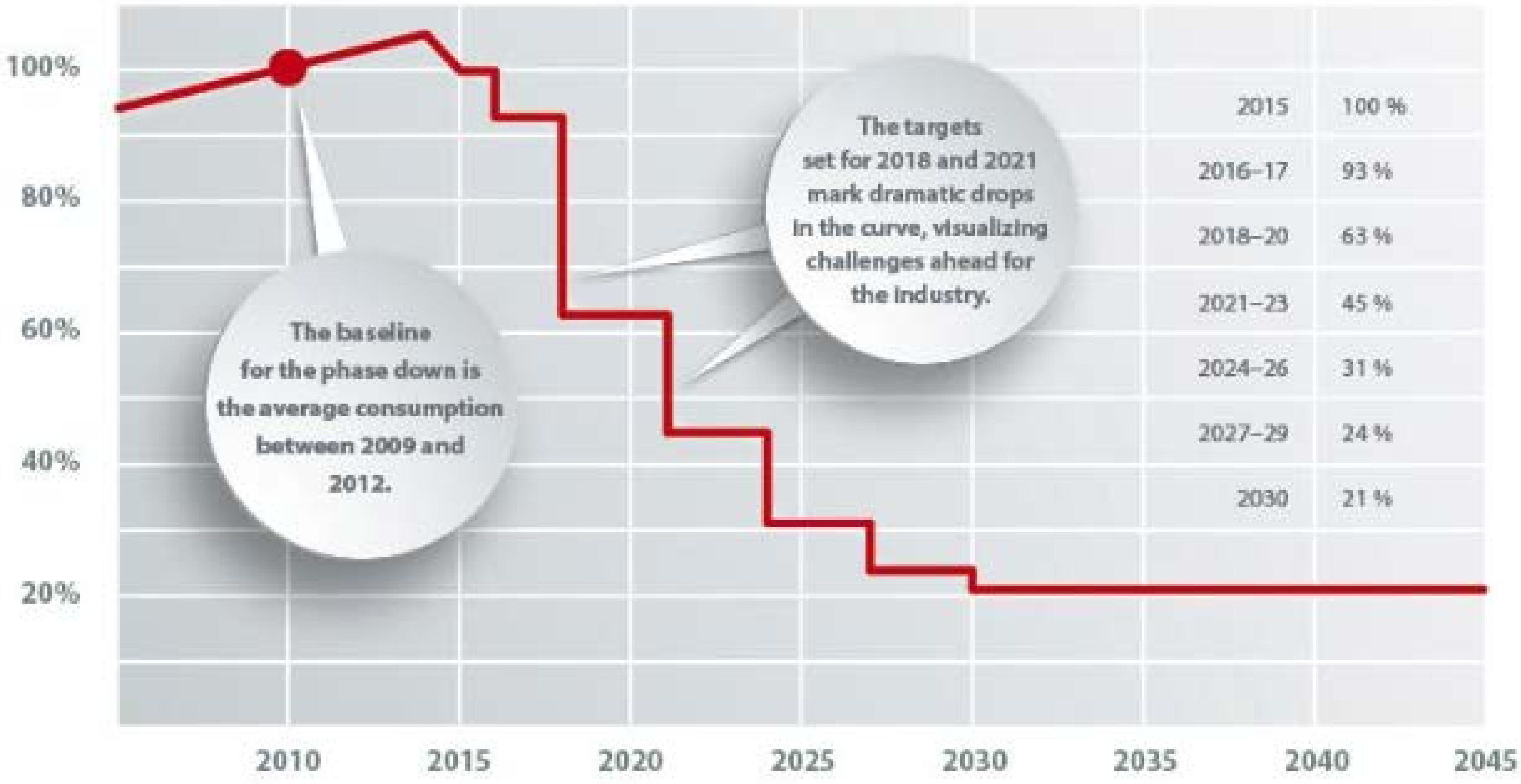
Table 1: Categories of RACHP Personnel Training

Category	Size of system	Activities Allowed
I	Any size	Leakage checking, refrigerant recovery, installation, maintenance and servicing
II	< 3kg* Any size	Refrigerant recovery, installation, maintenance and servicing Leak checking (not entailing breaking into the refrigeration circuit)
III	< 3 kg*	Refrigerant recovery
IV	Any size	Leak checking (not entailing breaking into the refrigeration circuit)

Source: Shecco, 2014

* < 6 kg for systems that are hermetically sealed

EU HFC Phase-Down schedule



Source: Danfoss.com

LEGAL TRENDS IN EUROPE : F- GAS REGULATION

Norway
HFC tax of €42.50 per tCO_2eq

UK
ECA, Enhanced Capital Allowance

Netherlands
Tax incentive for natural refrigerants and energy efficient systems

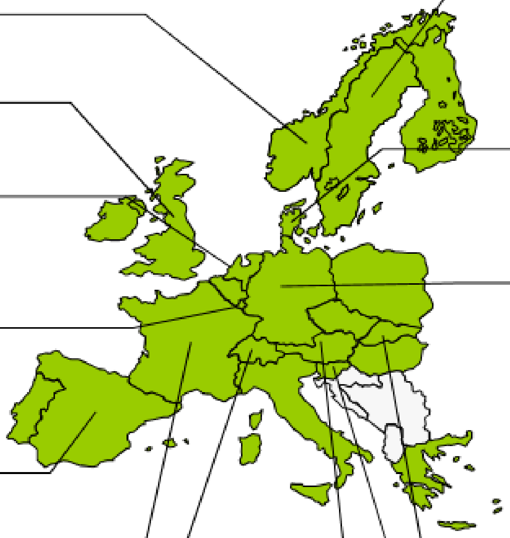
Luxembourg
Max. 30 kg filling charge HFC per system and max. 100 kW cooling capacity

Spain
GWP-based tax being phased in between 2014 and 2016 for GWP>150. €20/tCO_2eq by 2016, with lower levels of 33% and 66% during 2014 and 2015

Does not apply to first refrigerant charge

France
GWP based tax proposal. Decision pending.

Switzerland
HFC bans for commercial stationary applications of:
>40kW for plus cooling; >30kW for minus cooling, or >8kW for minus cooling if it is a combined plus & minus system
HFC bans for industrial applications of:
Cooling capacity >400kW ; 100kW for deep freezing



Sweden
GWP based tax proposal by Swedish Ministry of Finance:
26€/kg for R134a
75€/kg for R404A
Decision pending

Denmark
Tax on GWP e.g. R404A: 50 €/kg
Max. 10 kg filling charge HFC per system

Germany
Investment subsidy for natural refrigerants and energy efficient systems
Max. allowed F-gas leakage rate for start-up's after 30.6.08:

< 10 kg	max. 3 %/a
10kg <m< 100kg	max. 2 %/a
> 100 kg	max. 1 %/a

Slovakia
Specified max HFC leakage rates w/ penalties for non-conformance.

Slovenia
HFC tax of €0.71 per tCO_2eq

Austria
100 kg HFC filling charge and 1,5 kg/kW over 100 kg

Rest EU-27 States
F-gas regulation. Regular leakage tests for refrigeration systems over 3kg filling charge; does not apply for CO_2

The revised F-Gas Regulation applies from 1st July 2015

REFRIGERANT BAN`s UNDER F-GAS REGULATION

2015/01/01
Domestic refrigerators and freezers, **GWP ≥150.** Bans R134a. Natural refrigerants like R600a will be used.

2020/01/01
Commercial refrigerators and Freezers, hermetically sealed, **GWP ≥2500.** Bans R404A/507. Natural refrigerants will be main used refrigerants.

2020/01/01
Servicing equipment using new refrigerants with GWP ≥ 2500 for temperatures ≥ -50°C and charge ≥ 40 tonnes CO2eq. Except for military equipment. Bans servicing of 404A/507 equipment with 10,2kg or more charge using new 404A/507. Recycled refrigerant is still allowed.

2020/01/01
Stationary refrigeration equipment for temperatures above -50°C, **GWP ≥2500.** Bans R404A/507. Natural refrigerants and also new HFC will increase. Many types of solutions.

2022/01/01
Commercial refrigerators and Freezers, hermetically sealed, **GWP ≥150.** Bans R134a. Natural refrigerants will be main used refrigerants. HFO solutions can be used.

2022/01/01
Multipack centralised refrigeration systems for commercial use with a capacity ≥ 40kW, **GWP ≥150 and ≥1500** for primary circulation of cascades. Bans traditional HFC, except R134a in cascades. Also new HFC/HFO blends can play a role.

2025/01/01
Single split A/C systems containing less than 3kg of HFC, **GWP ≥750.** Bans R134a, R407C and R410A. Seems very feasible for A2L refrigerants.

2030/01/01
Servicing equipment using refrigerants with **GWP ≥ 2500** for temperatures ≥ -50°C and charge ≥ 40 tonnes CO2eq. Except for military equipment. Bans servicing of 404A/507 equipment with 10,2kg or more charge.

Source: Danfoss.com

The Main Pillars of the new EU F-Gas rules

2050 Low Carbon Roadmap

Containment & Competence

Regular leak checks

Certification and training of installers

Phase-Down

Consumption Reduction of HFCs

Yr 2020:
-37%

Yr 2030:
-79%

GWP Limits

2015: GWP 150
Domestic Refrigerators & Freezers

2020: GWP 150
Moveable A/C

2020: GWP 2500
New stationary Refrigeration Equipment

2022: GWP 150
Multpack refrigeration systems >40kW (except cascades: GWP1500)

2025: GWP 750
Single split a/c < 3kg

Others

2017:
Traceability systems for pre-charged equipment

2020:
GWP 2500 for service & maintenance

Why a phase-down of HFCs?

It supports responsible HFC management

A phase-down in Europe will help to curb HFC growth:

- It contributes consistently and cost-effectively to the Europe's 2050 goals in terms of climate change.
- It stimulates sustainable innovation & improves market opportunities for alternative technologies refrigerants with low GWP
- It can be consistent with international agreements
- It takes into account the complexity of the sector and refrigerant management

If implemented correctly,

a phase-down makes economic & environmental sense and enables the market placement of innovative RACHP solutions including the growth of applications with natural refrigerants

The impact of the new rules in Europe

- The phase-down is the **major new pillar** of the legislation and is the most important legal instrument that **requires a move towards lower GWP refrigerants**

- The GWP limits will set signposts to steer the phase-down
  - The bans of refrigerants with a GWP of 2500 and above will free up quota for other applications such as air-conditioning.

- Refrigerants with a high GWP such as R-404A and R-507 are the first ones to be impacted

- **Industry needs to act to avoid shortages;**
- **Many solutions exist for the transition to safe, energy-efficient refrigerants with a low GWP – but not yet for all applications. Time & investment in R&D is also a key issue (see CO_2)**
- **Making the rules work remains a key challenge and priority!**

Investment subsidy system in Germany

“National climate protection initiative”

Since 2008 the German Federal Environment Ministry (BMU) supports the use of natural refrigerants and energy efficiency measures for new construction and restructuring.
“systems must be **highly energy efficient**, should use **natural refrigerants** and need to show **drastically CO2 emission reductions**.

Approved projects get support provided by **investment subsidy**.

<u>Investment subsidy's :</u>

Restructuring of existing system : max**. 20% of net investment cost**
New systems : max. **25% of net investment cost**

Max. amount of investment subsidy is 100,000€

Incentive system in Germany

Additional so called bonus incentive is available if the system includes heat recovery functions.

Investment subsidy for the heat pump cycle only (on top of basic incentive) :

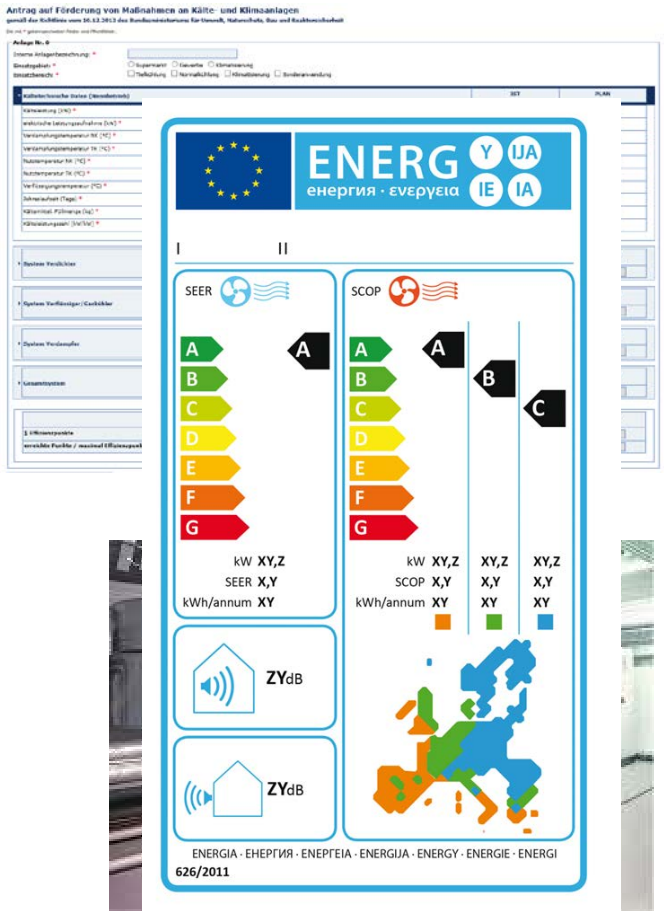
Only for HX : max. 15% of net investment cost
If HP use refrigerant with GWP < 2,500 : max. 20% of net investment cost
If HP use natural refrigerants : max. 25% of net investment cost

Requirement for subsidy`s in Germany

Steps in advance:

- Calculation of system design and desired savings (CO2 emission and energy-efficiency) by certified expert (consultant)
- Approval of system documentation and savings calculations by BMU & BAFA
- BAFA issues an energy-efficiency-pass

After commissioning an efficiency and consumption monitoring must be provided to BMU (for a period of 5 years)



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Country	Specifications
Australia	Australia used to have an HFC tax, but that has been recently been withdrawn. At the moment Australia is working on an HFC phase down similar to the EU F-gas Regulation.
Austria	Austria has introduced its own F-gas bans like Denmark. HFC's are in general banned for systems with more than 20 kg of HFC (including the u-HFC blends). For fixed installation branched systems up to 100 kg is however allowed.
China	The legislative system in China is in practice very different from the western system, as good standing with the administration is still very important. This means that official statements from the administration, such as the HCFC Phase-out Management Plan (HPMP) plan will be treated as a kind of law by the manufactures. The HPMP is a plan prepared by China as part of the obligations under the Montreal Protocol (MP) to phase-out HCFC's such as R22. The HPMP states that the preferred refrigerant for domestic AC is R290, but allows R410A to be used in a transition period. For commercial systems the dominating refrigerant proposed is R32
Denmark	Denmark introduced its own f-gas bans before the first EU f-gas regulation in 2006, and has therefore been allowed to maintain these bans. With the new f-gas regulation (2014) all countries will be allowed to make similar bans, but interest has been low. In Denmark HFC's including u-HFC's and all A2L refrigerants are limited to 10 kg per circuit. For HPs for heat regeneration it is however allowed up to 50 kg. Heat regeneration in this context is linked to a special heat regeneration tax, and the 50 kg allowance only covers very few systems. Denmark also has a tax on HFC's of approximately 20 €/tCO2eq which for 410A is 303 kr/kg or slightly more than 40 €/kg. Refrigerant in hermetic HPs is however exempted from this tax.
France	The Environmental Taxation Committee recommended the introduction of an HFC tax in 2013. This was meant to tax HFCs with a GWP higher than 150. The tax, however, was never introduced and there is no HFC tax in France up to date.
Germany	Germany has no specific HFC tax.
Netherlands	In addition to strict implementation of EU F-gas Regulation, stringent legislation requiring periodic (preventive) inspection and maintenance by certified personnel and companies, for all RACHP equipment with F-gases (since 1992, harmonised with the new EU F-gas Regulation). Similar requirements exist for all RACHP equipment with natural refrigerants (R744, HC and R717), aiming at maximising the application of natural refrigerants without compromising on safety; subsidy schemes (2016-2020) for (domestic) HPs depending on overall GHG emission (including contribution from refrigerant leakage during use phase). No additional national bans or tax measures are in place or expected.

Country	Specifications	
Norway	Norway has a system of HFC tax and refund upon proper recycling of HFCs. The taxes are connected to the GWP. Higher GWP means higher taxes. HFC taxes are partly refundable if HFC is returned to dedicated destruction facilities. Application for refund after testing of substances is also possible. The taxes range up to 40€/kg.	
Refrigerant	Tax in NOK 2016	Approx. tax in €
R32	259 NOK/kg	28 €/kg
R134a	548 NOK/kg	60 €/kg
R407C	679 NOK/kg	74 €/kg
R410A	800 NOK/kg	87 €/kg
Italy	There are no specific taxes for HFCs in Italy.	
Slovenia	Slovenia has an HFC tax of 3,456 €/tonne of CO_2 equivalent (in 2015).	
Spain	Spain has an HFC tax on refrigerant used for service. The tax level is similar to the Danish taxes:	
Refrigerant	Tax in 2016 on service refrigerant	
R32	11 €/kg	
R134a	26 €/kg	
R407C	33 €/kg	
R410A	40 €/kg	
Sweden	Sweden placed a maximum limit on HFC charge sizes, prior to the introduction of the EU F-gas Regulation. Supermarket refrigeration systems were limited with a max. of 200 kg, medium temperature and low temperature systems were limited with respectively 30 kg and 20 kg. In addition to this, Sweden does not have an HFC tax.	
Switzerland	Switzerland has introduced its own F-gas bans, banning HFC in applications based on system types, heating or cooling effect and GWP. There are no bans for HPs with less than 100 kW. For HPs from 100 kW and up there are limits to how much HFC is allowed per kW, for GWP > 1900 (R410A) the limit is 0,18 kg/kw (or 0,22 with heat reclaim) and for GWP < 1900 (R407C, R134a, R32) the limit is 0,4 kg/kW (or 0,48 kg/kW with heat reclaim).	

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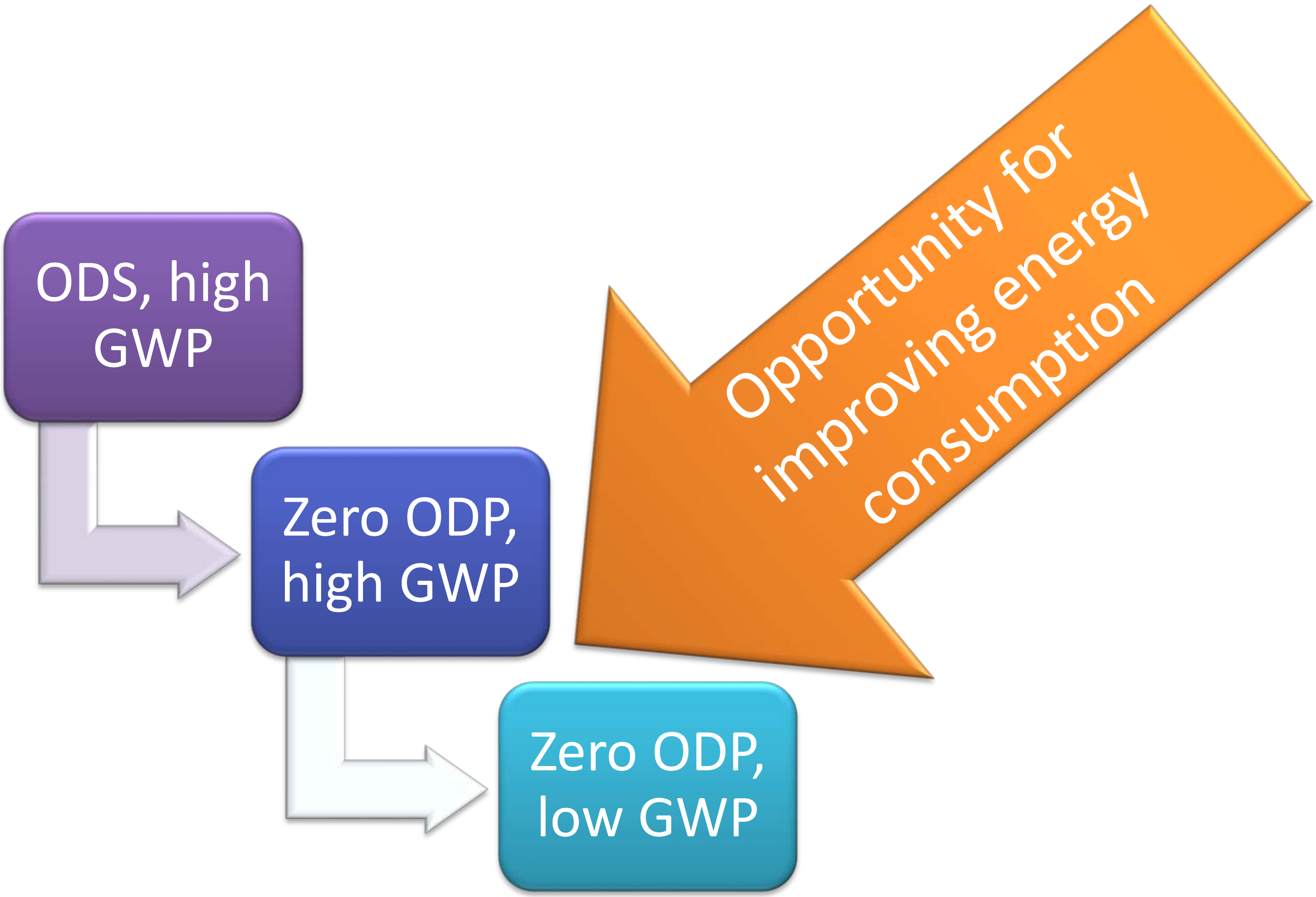
Energy Efficiency Issues



Energy Efficiency Issues

Introduction

"Efficiency" considered as

- the actual energy used to achieve a certain amount of "cold", compared to the minimum amount of energy needed

Less than 100% efficiency due to "losses"

- Energy being used for something that is not wanted (needed)

Taking a current "average" appliance

- Often possible to reduce energy consumption by much more than 50%
- Of course, it depends upon the money…

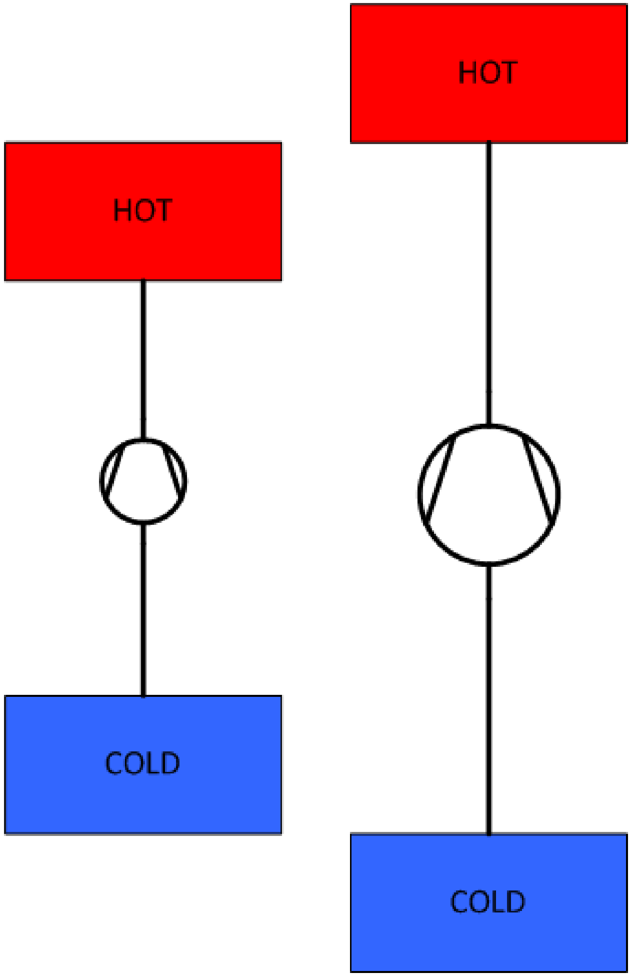
Energy Efficiency Issues

Introduction

- Three fundamental contributors to efficiency
  - Refrigeration cycle
  - Parasitic losses
  - Transient effects
- Also take into account cooling demand (heat load)
  - Less heat absorbed = less energy
- Many of the elements that contribute to efficiency and energy use are interrelated
- List some practical options for how to achieve better efficiency and lower energy use
- Must also consider aspects when servicing/ maintenance

General energy efficiency issues

- Principally the way that the machine creates cold
  - Temperature lift
  - Temperature of the cold refrigerant
  - Temperature of the hot refrigerant
  - Selection of refrigerant circuitry
  - Pressure losses within pipework
  - Properties of refrigerant (type)
  - Oil type
- Essential to focus on component selection and circuit design



Improvement examples

Optimise system balancing	+++
Refrigerant charge size; critical/non-critical charge	+++
Larger evaporator/condenser surface area; improved surface texture	+++
Optimise evaporator/condenser circuitry	++
Forced vs. natural convection evaporator/condenser	++
Clean evaporator/condenser (surface treatment)	+
Minimise superheat	++
Flooded evaporator	++
Reduce piping pressure losses	++
Optimise sub-cooling	+

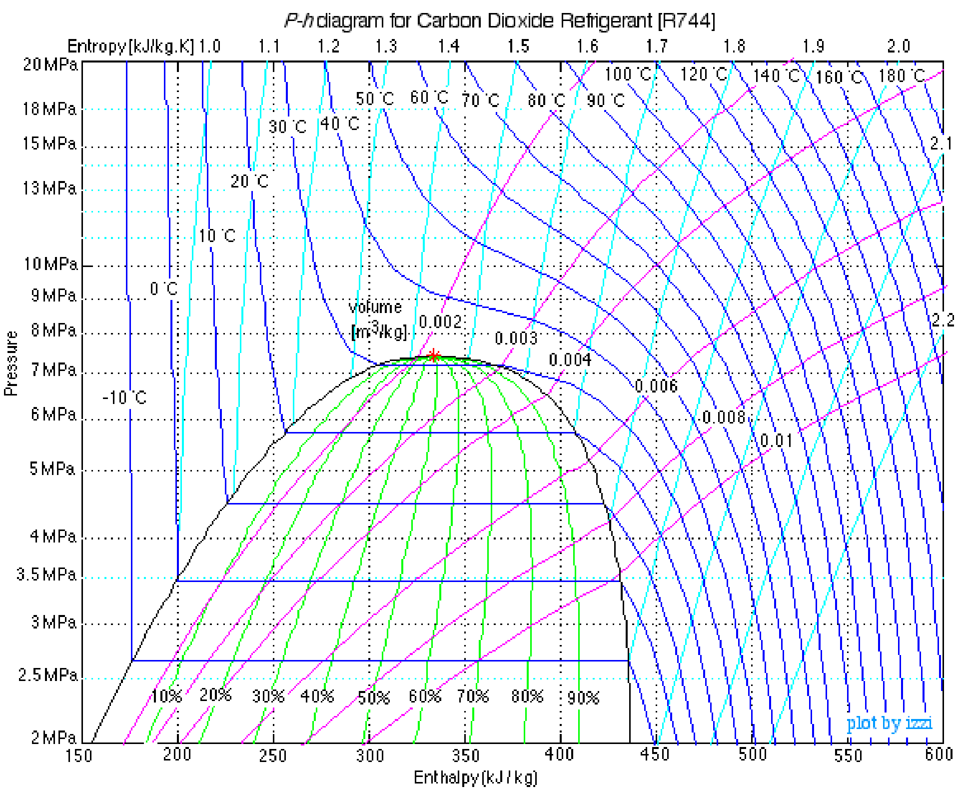
Improvement examples

Selection of compressor with optimum capacity	++
Alternative refrigerants, pure vs. mixtures	++
Use of liquid-suction heat exchanger (some refrigerants)	+
Selection of optimal lubricant	+
Use of oil separator	+
Alternative cooling cycles (e.g., Lorenz, Stirling, etc)	+++
Two, multi-stage system (e.g., for LT)	++
Improved air flow over product	+
Integrated evaporator shelving	+

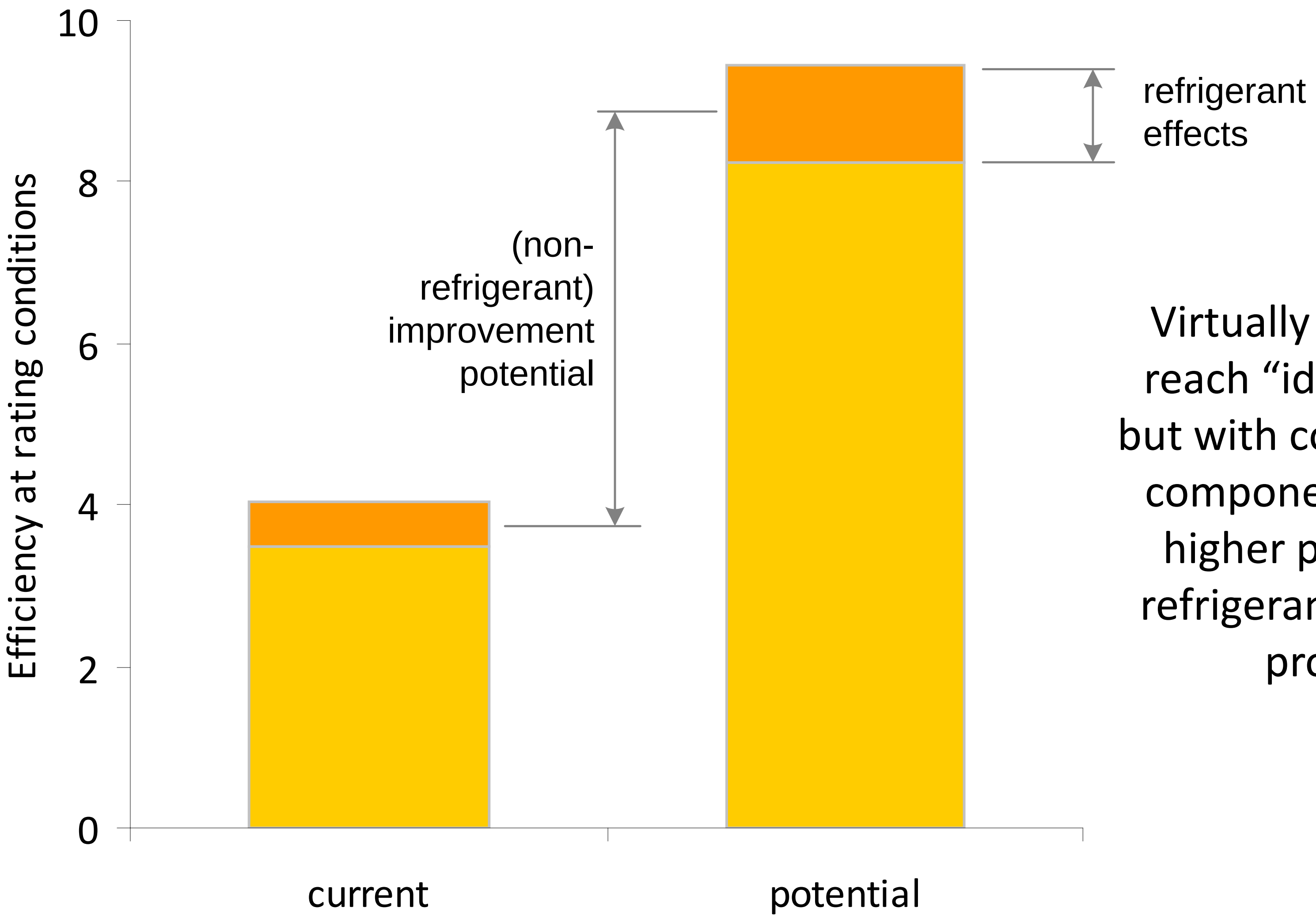
Implications of refrigerant

Refrigerant implication on efficiency

- The issue of refrigerant selection impact on system efficiency is often raised
- The subject is very involved and normally required extensive discussion

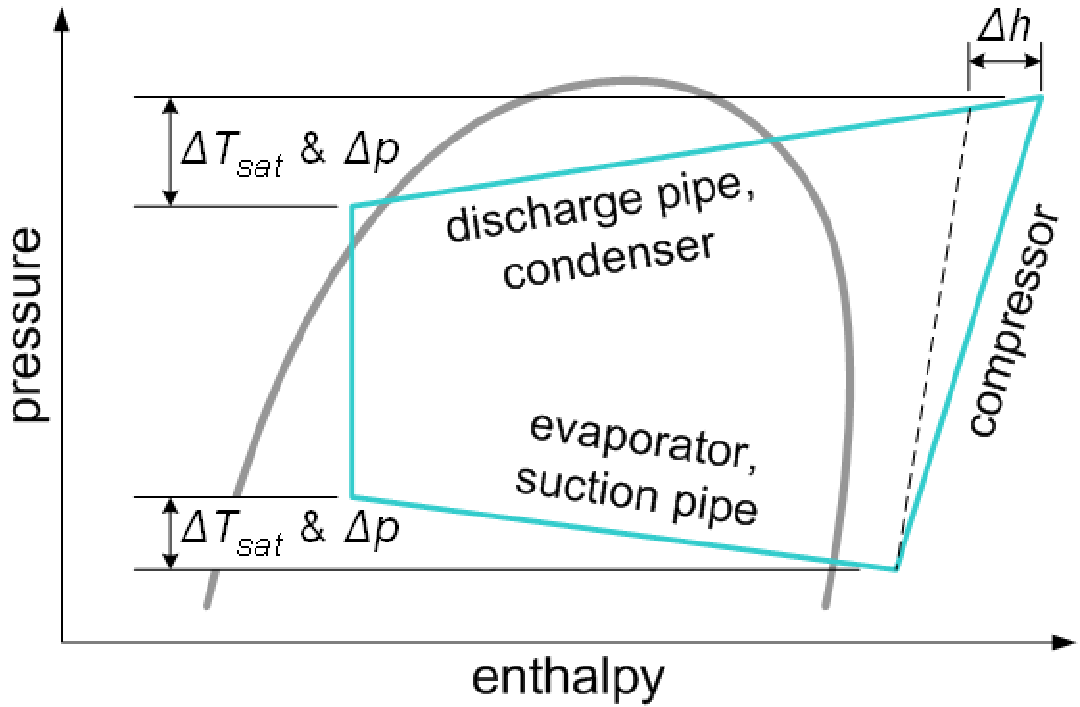


Implications of refrigerant



Virtually impossible to reach “ideal” situation, but with correct design of components, there is a higher potential with refrigerants with better properties

Implications of refrigerant



Preferred properties

- Low liquid and vapour viscosities
- High liquid specific heat
- High liquid and vapour thermal conductivities
- High latent heat
- Small temperature glide

➢ Desirable to have good heat transfer and low pressure drop in evaporator and condenser

Comparison of properties

Refrigerant	Critical temp. (°C)	Liquid viscosity (Pa s ×10[6])	Vapour viscosity (Pa s ×10[6])	Liquid sp. heat (kJ/kg K)	Liq thermal cond (W/m K)	Latent heat (kJ/kg)
R-22	96.1	216	11.4	1.17	0.095	205
R-134a	101.1	267	10.7	1.34	0.092	199
R-404A	72.0	179	11.0	1.39	0.073	166
R-407C	86.0	211	11.3	1.42	0.096	210
R-410A	71.4	161	12.2	1.52	0.103	221
R-717	132.3	170	9.1	4.62	0.559	1262
R-290	96.7	126	7.4	2.49	0.106	375
R-1270	92.4	121	7.8	2.44	0.126	378
R-744	31.0	99	14.8	2.54	0.110	231

Parasitic losses

"Parasitic" losses typically related to ancillary components, e.g.,

- Defrost heaters
- Lighting
- Trim heaters
- Fans
- Pumps

All 'sort of' necessary to achieve the cold, but can normally be reduced



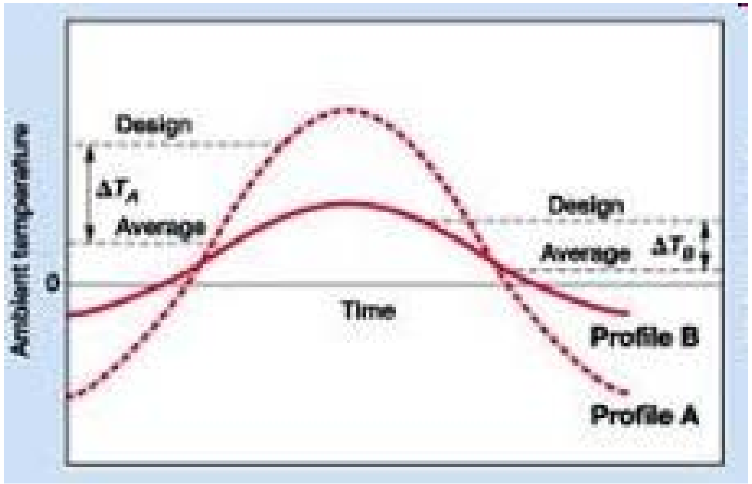


Improvement examples

More efficient compressors (incl. alternative compressor types, start/run methods)	+++
More efficient fan motors (e.g., ECMs)	++
More efficient fan design (higher fan blade efficiency)	+
Variable-/dual-speed fans	+
Discharge heat heaters instead of resistance heaters	+
Forced vs. natural convection evaporator/condenser	+
Off-cycle defrosting	++
Hot gas, cool gas, reverse cycle defrost	+
Low power lighting (LEDs, etc), electronic ballasts for fluorescents	++

Transient effects

- Transient or dynamic losses due to behaviour of the machine at non-design conditions
  - Changes in ambient conditions
  - Changes in heat load
  - Compressor starting
  - Pressure equalisation



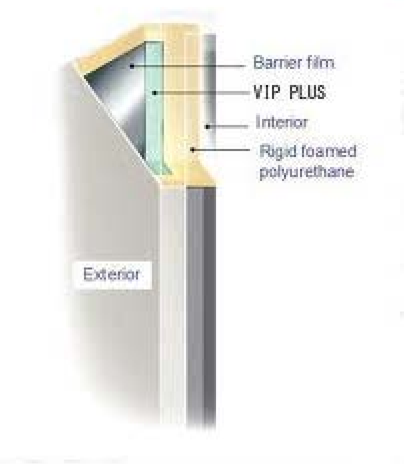
- Often 'hidden' potential for improvement

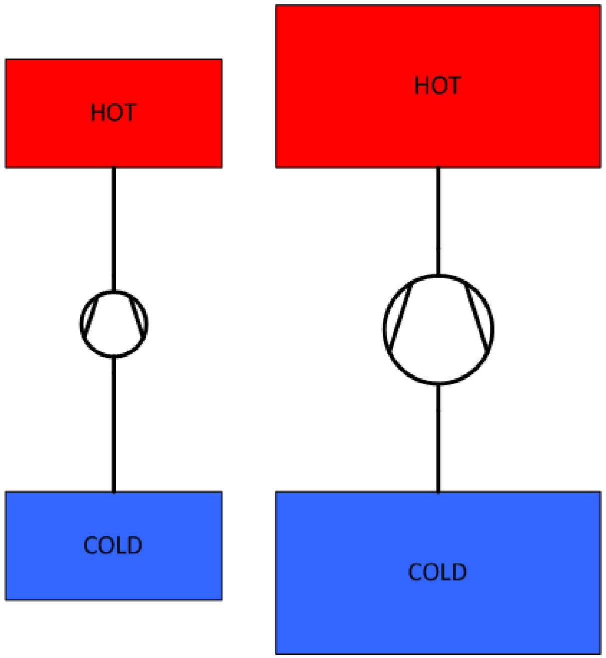
Improvement examples

Variable-speed compressors	+++
Variable-capacity compressors	+++
Adaptive/optimised electronic control	+++
Expansion valve instead of capillary tube	+++
Floating head pressure control	++
Flow regulation valves (for multi-evaporator systems)	+
Phase-change materials within cold box, condenser	++
Off-cycle migration valve (prevent pressure equalisation)	+
Two, multi-compressors	++

Cooling demand

- Not directly related to efficiency, but can reduce energy use
  - Quality of insulation
  - Amount of infiltration
  - Solar gain
  - Electrical loads
  - Product temperature
  - Use patterns
- A greater cooling demand (heat load) increases energy consumption





Improvement examples

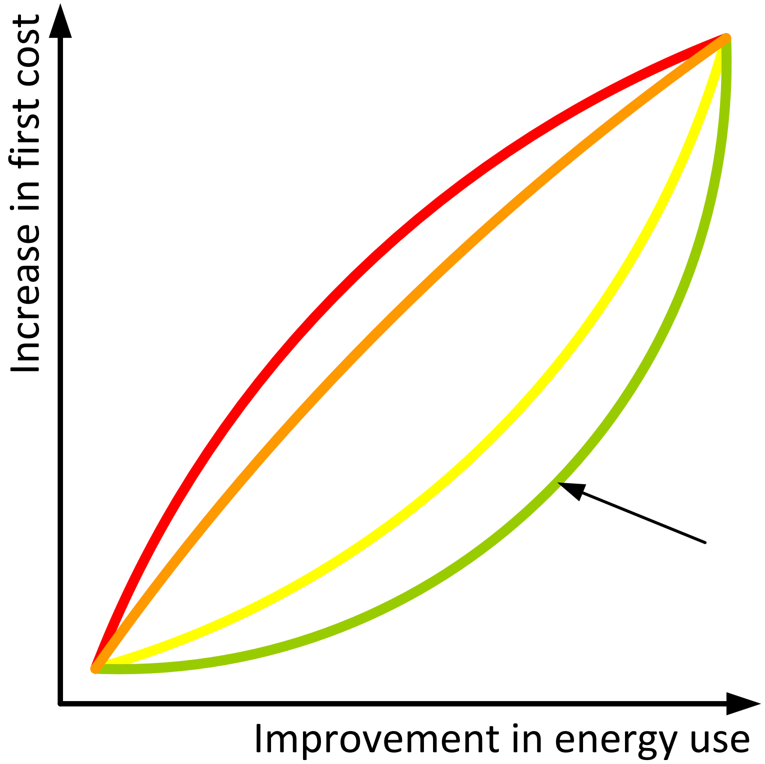
Increase cabinet insulation	++
Better quality insulation (vacuum insulation panels, gas panels, alternative foams)	++
Increase door insulation	+
Decrease door leakage (better gaskets)	+
Use of night blinds	++
Glass door/lid	+++
Adaptive defrosting	++
Off-cycle defrosting	++
Hot gas/reverse cycle defrost	+

Improvement examples

Low power lighting (LEDs, etc), choice of ballasts for fluorescents	++
External lighting	++
Adaptive lighting	+
Reduce IR gain (reflective glass, etc)	++
Improve anti-sweat trim heaters / dew point control	+
Reduce internal volume	+

Integration of measures

- Benefit of above measures rarely additive
  - Typically for each additional measure, effectiveness lessens
- Eventually, adding more and more features simply adds cost
  - Must determine most cost-effective set of options
- Important to first analyse current design to determine most effective measures



Integration of measures

- Essential to select measures wisely
  - May reduce energy in one way but increase in another
  - Everything dependent upon everything else
  - Tend to have to use trial-and-error to optimise for individual situations

- Properly select design conditions, e.g., based on region, anticipated environment
  - Often, test standards based on common set of conditions
  - Specific products in specific environments may be better suited to off-design conditions

Minimum efficiency rules

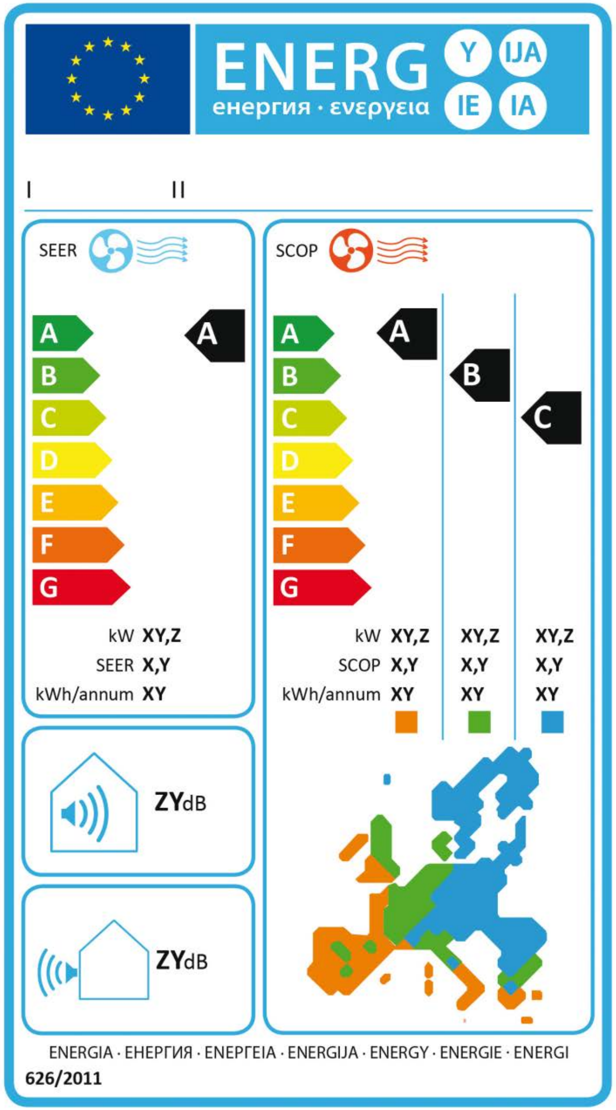
- Under EU (Eco-design), USA, etc, have
  - Minimum efficiency legislation
  - Energy labelling legislation
- Covers many forms of RAC equipment
  - Room air conditioners
  - Multi-splits
  - Ducted units
  - Commercial/display refrigeration
  - Heat pumps
  - Condensing units
  - Chillers
  - etc

Minimum efficiency rules

Means of imposing reduction in energy

- Options
  - Energy labelling

Energy Efficiency Class	SEER	SCOP
A+++	SEER ≥ 8,50	SCOP ≥ 5,10
A++	6,10 ≤ SEER < 8,50	4,60 ≤ SCOP < 5,10
A+	5,60 ≤ SEER < 6,10	4,00 ≤ SCOP < 4,60
A	5,10 ≤ SEER < 5,60	3,40 ≤ SCOP < 4,00
B	4,60 ≤ SEER < 5,10	3,10 ≤ SCOP < 3,40
C	4,10 ≤ SEER < 4,60	2,80 ≤ SCOP < 3,10
D	3,60 ≤ SEER < 4,10	2,50 ≤ SCOP < 2,80
E	3,10 ≤ SEER < 3,60	2,20 ≤ SCOP < 2,50
F	2,60 ≤ SEER < 3,10	1,90 ≤ SCOP < 2,20



Minimum efficiency rules

Means of imposing reduction in energy

- Options
  - Minimum efficiency rules
  - Test standards

E DIN EN 14825:2015-08 (D/E)
Erscheinungsdatum: 2015-07-03

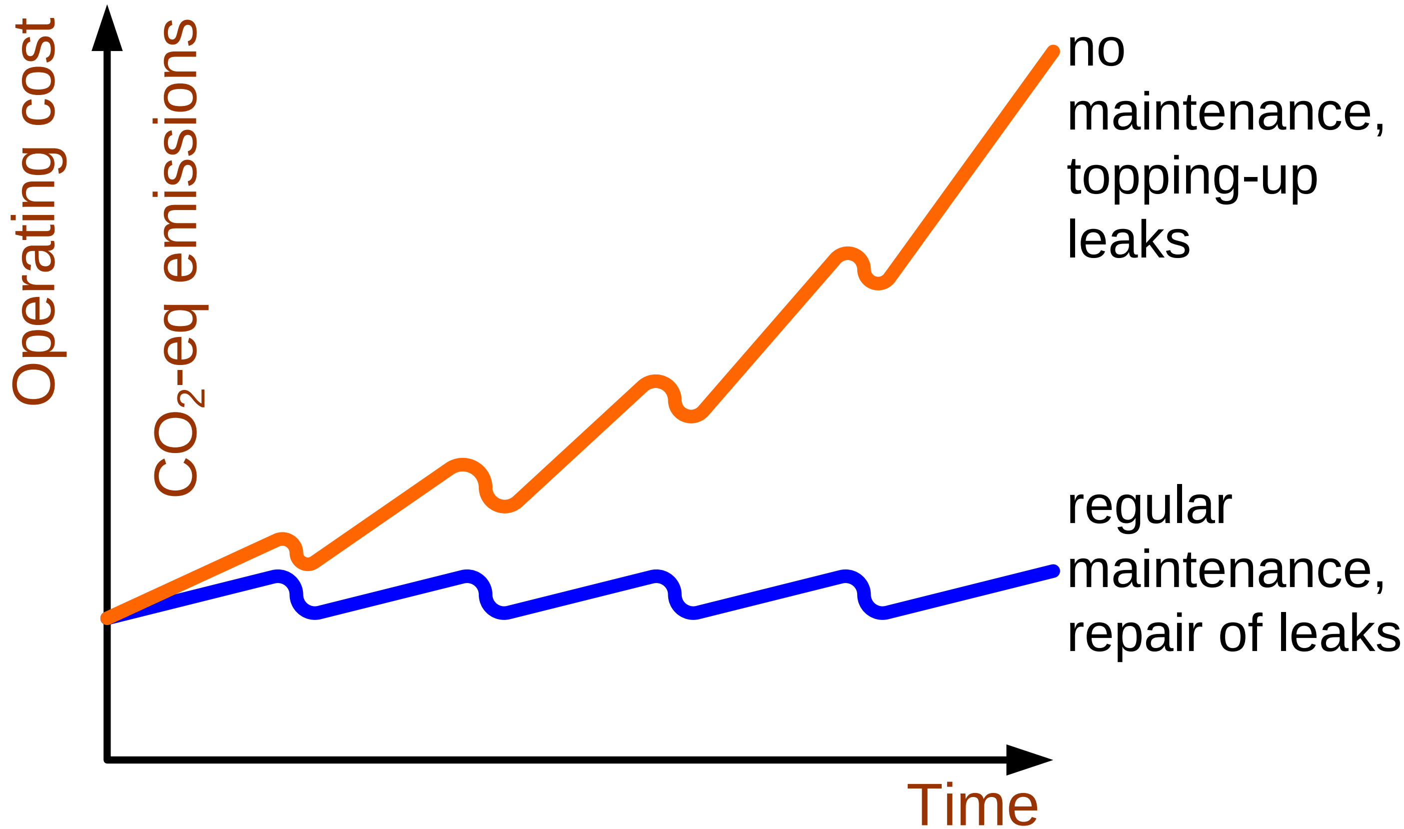
Luftkonditionierer, Flüssigkeitskühlsätze und Wärmepumpen mit elektrisch angetriebenen Verdichtern zur Raumbeheizung und -kühlung - Prüfung und Leistungsbemessung unter Teillastbedingungen und Berechnung der saisonalen Arbeitszahl; Deutsche und Englische Fassung FprEN 14825:2015

Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance; German and English version FprEN 14825:2015

Capacity	GWP	Air conditioners, except double and single duct type		Double duct Air conditioners		Single duct air conditioners	
		SEER	SCOP	EER	COP	EER	COP
< 6 kW	>150	4.60	3.80	2.60	2.60	2.60	2.04
< 6 kW	<150	4.14	3.42	2.34	2.34	2.34	1.84
6 - 12 kW	>150	4.30	3.80	2.60	2.60	2.60	2.04
6 - 12 kW	<150	3.87	3.42	2.34	2.34	2.34	1.84

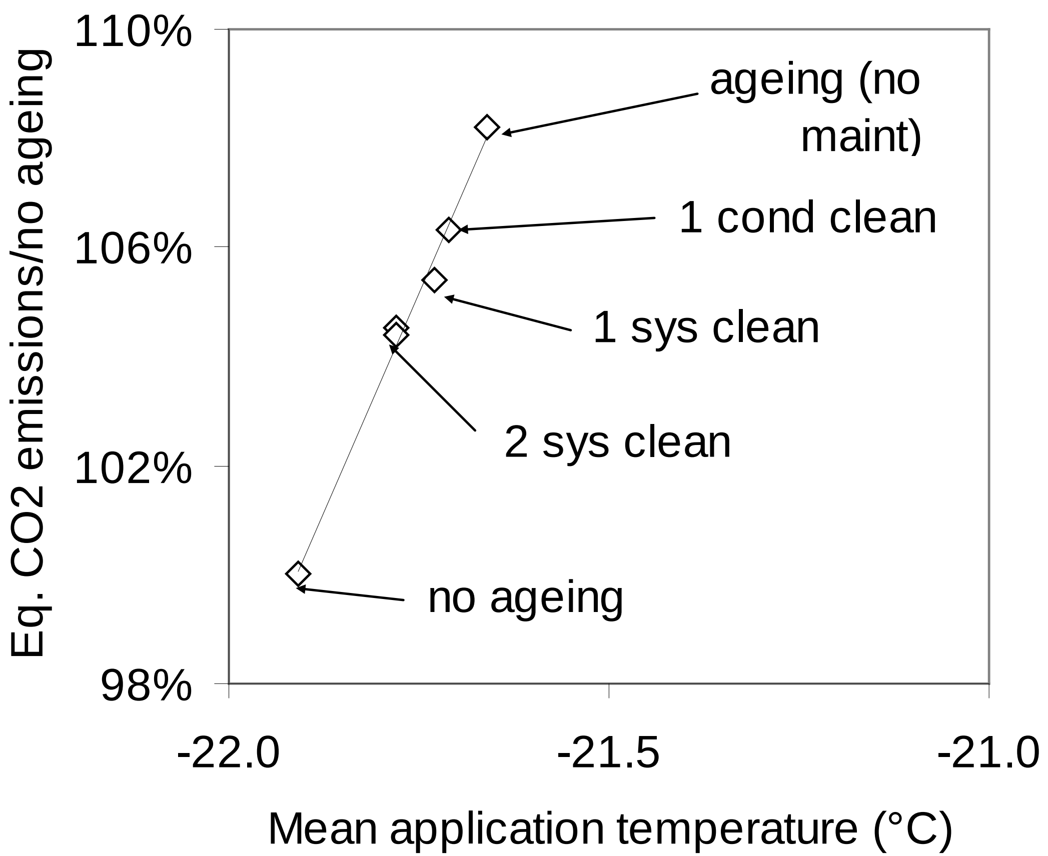
Implications of service and maintenance

- Systems can loose 1 – 10% efficiency
  - Larger losses due to poor maintenance
  - Important to ensure equipment is maintained over lifetime



Implications of service and maintenance

- System/condenser fouling affects performance
  - Ageing always degrades performance
  - Frequent system/ exchanger cleaning reduces TEWI and improves temperature



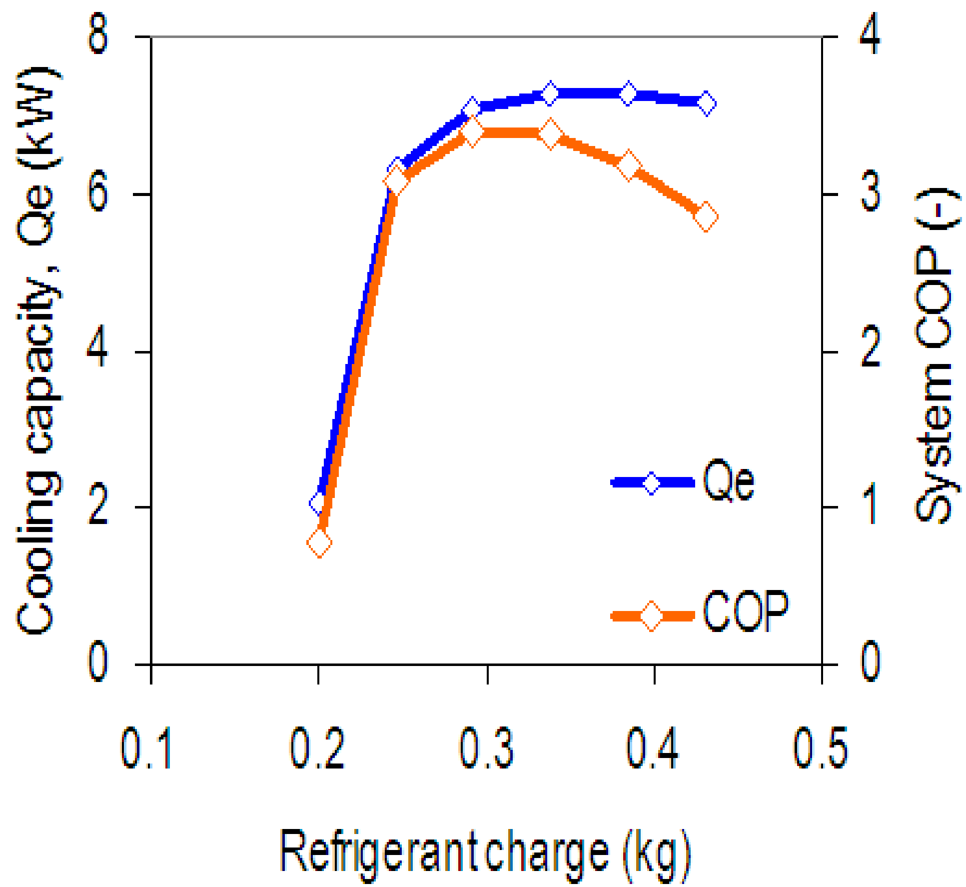
Tweaks to existing systems

- Improve system efficiency; can be divided into two approaches
  - “soft” modifications; easy to do
  - “hard” modifications”; not so easy

- Soft modifications
  - Cleaning heat exchangers, especially condenser
  - Adjusting expansion valve to low superheat setting
  - Replacing old oil with new clean oil
  - Resetting thermostats to intended/higher level
  - Rest head pressure control to lower pressure
  - Checking all condenser fans operating; replace if not
  - Ensure defrost operation is optimum, avoid too much

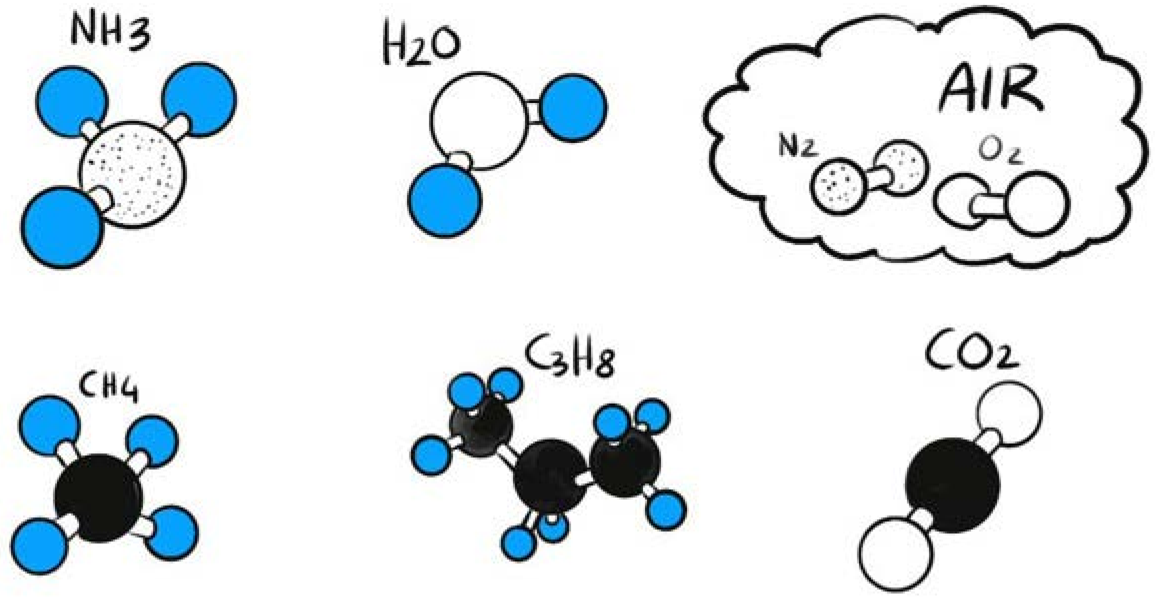
Tweaks to existing systems

- Hard modifications
  - Repairing leaks!!! And ensuring charge is correct
  - Changing capillary tube length (when changing refrigerant)
  - Fitting liquid-suction heat exchanger (when changing to HCs)
  - Replacement of components – old compressor, small condenser, evaporator, etc



Final remarks

- Performance of existing systems generally better
  - Sometimes capacity not as good if retrofitting; depends upon blend
  - Overall "environmental" performance is always better than HCFCs, HFCs, etc
- Various options available for improving system efficiency during service, maintenance and conversions



Thank You for Your attention!