On behalf of

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

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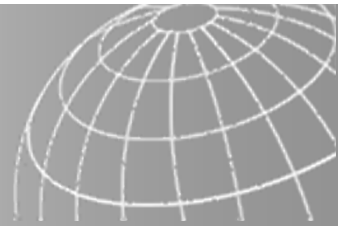

NAMA
Technical Options and Costs

25th July 2012, Bangkok, Thailand

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Agenda

- 1. Description of subsectors and system types
  - Selection
- 2. Discussion of technical options (TOs)
  - Initial filtering and selected TOs
  - Reducing energy consumption
- 3. Implications and barriers of TOs
- 4. Overview of costs
- 5. Penetration potential of TOs in specific subsectors

1. Subsectors

- Many different uses of refrigerants
- Important to reduce down to manageable categories
- Main sectors: Refrigeration; Air conditioning; (Foams)
- Initially divide system types, then categorise into subsectors where evaluation of TOs is similar
  - Not practicable to evaluate TOs for each and every miniscule system type
- Neglect certain subsectors
  - Small market (minimal refrigerant use)
  - Complicate, non-uniform types of systems

1. Subsectors

- Unitary air conditioning

Portable units	*Self-contained air conditioners*
Window units	
Through-wall units	
Single split units (condensing unit) *Mini-split units (condensing unit)*	*Split residential air conditioners*
	Split commercial air conditioners
Multi-split/VRF (centralised)	*Multi-splits*
Rooftop ducted (integral)	*Rooftop ducted*
Central ducted splits (condensing unit)	*Duct split residential air conditioners* *Commercial ducted splits*

1. Subsectors

- Chillers

Positive displacement chillers (air-cooled)	*Chillers*	*Air conditioning chillers*
Positive displacement chillers (water-cooled)		*Process chillers*
Centrifugal chillers		

Accounted for under industrial/food processing

1. Subsectors

- Mobile air conditioning

Mobile AC	*Car air conditioning*	
	Large vehicle air conditioning	*Bus AC*
		Truck AC
		Industrial vehicle AC
		Train AC

Relatively small volume, so neglected at this stage

1. Subsectors

- Domestic refrigeration

Domestic refrigeration	*Fridge/freezers*
	Refrigerators
	Freezers

1. Subsectors

- Commercial refrigeration
  - Includes display cabinets , storage cabinets, coldstores

Commercial refrigeration	*Stand-alone equipment*
	Condensing units
	Centralised systems for supermarkets

1. Subsectors

- Industrial refrigeration

Neglected due to vast variety of bespoke systems

Industrial refrigeration	*Low-temperature non-food-industry*	
	Food industry and warehouses	*Stand-alone*
		Condensing units
		Centralised systems

Includes storage cabinets, process cooling/freezing, coldstores

Includes process chillers

1. Subsectors

- Transport refrigeration

Refrigerated trucks/trailers	*Road transport trucks*
	Refrigerated trailers
	Refrigerated railcars
	Marine refrigeration

Neglected due to complications over national ownership

1. Subsectors

- Summary of subsectors – air conditioning

Unitary air conditioning	*Self-contained air conditioners*	*R22, R410A, R407C*
	Split residential air conditioners	*R22, R410A, R407C*
	Split commercial air conditioners	*R22, R410A, R407C*
	Duct split residential air conditioners	*R22, R410A, R407C*
	Commercial ducted splits	*R22, R410A, R407C*
	Rooftop ducted	*R22, R410A, R407C*
	Multi-splits	*R22, R410A, R407C*
Chillers	*Air conditioning chillers*	*R22, R410A, R407C*
	Process chillers	*R22, R410A, R407C*
Mobile AC	*Car air conditioning*	*R22, R410A, R407C*

R22 GWP = 1800; R410A GWP = 2100, R407C GWP = 1700

1. Subsectors

- Summary of subsectors - refrigeration

Domestic refrigeration	*Domestic refrigeration*	*R134a*
Commercial Refrigeration	*Stand-alone equipment*	*R134a, R404A*
	Condensing units	*R22, R404A*
	Centralised systems for supermarkets	*R22, R404A*
Industrial refrigeration	*Low-temperature non-food-industry*	*R22, R404A*
	Stand-alone (FPCS)	*R134a, R404A*
	Condensing units (FPCS)	*R22, R404A*
	Centralised systems (FPCS)	*R22, R404A*
Transport Refrigeration	*Refrigerated trucks/trailers*	*R134a, R404A*

*FPCS = food processing and cold storage

R22 GWP = 1800; R134a GWP = 1400, R404A GWP = 3800

2. Technical Options (TOs)

- Purpose of adopting TOs – to reduce emissions
  - (Direct) refrigerant-related emissions
  - Energy-related emissions
- Several different categories of technical options
  - Containment
  - Alternative refrigerants
  - Alternative refrigerants and alternative system
  - Not-in-kind cycles

2. Technical Options (TOs)

- Containment (and similar)
  - Leak reduction (design/construction of system)
  - Leak reduction (through service & maintenance practices)
  - Charge size reduction (system/component design)
  - Recovery and recycling (improved tooling and practices)

2. Technical Options (TOs)

- Alternative refrigerants
  - HC R600a (GWP = 3, flammable, low pressure)
  - HC R290/ R1270 (GWP = 3, flammable)
  - HFC R161 (GWP = 12, flammable, toxivity under reveiw)
  - HFC R152a (GWP = 140, flammable)
  - R717 (GWP = 0, low flammability, higher toxicity)
  - R744 (GWP = 1, high pressure, low critical temperature)
  - R718 (GWP = 0, very low pressure, freezing point = 0 deg C)
  - unsat-HFC (e.g., R1234yf, R1234ze, etc; GWP < 10, low flammability)
  - HFC R32 (GWP = 700, low flammability; for refts with higher GWP)
  - HFC/unsat-HFC blends (unknown to date; GWP maybe 300 – 700...)
  - DME/R-E170 (GWP = 3, flammable)
  - HFC R134a (GWP 1400; to replace refrigerants with higher GWP)

2. Technical Options (TOs)

- Alternative refrigerants + systems
  - Low-GWP + liquid secondary [centralised] (e.g., glycol, brine)
  - Low-GWP + PCM secondary [centralised] (e.g., ice slurry)
  - Low-GWP + evaporating secondary [centralised] (e.g., CO2)
  - Low-GWP + liquid secondary [discrete] (e.g., glycol, brine)
  - Low-GWP + cascade (typically with CO2)
  - Distributed water-cooled (central chiller with localised water-cooled condensing units)
  - District cooling (incl. district heat pump heating)

* “Low-GWP” includes any low-GWP refrigerant (HCs, R717, unsat HFCs, etc)

2. Technical Options (TOs)

- Not-in-kind cycles
  - Air cycle (Brayton)
  - Absorption (liquid) (solar or gas driven)
  - Adsorption (solid) (solar or gas driven)
  - Desiccant/evaporative (solar or gas driven)
  - Thermo-electric (Peltier)
  - Magnetic
  - Stirling
  - Ejector cycle (solar or gas driven)

2. Technical Options (TOs)

- Possible number of combinations to evaluate excessive
  - Number of system types: 19
  - Number of TOs: 31
  - Overall, approximately 550 combinations
- Many TOs are not viable for certain applications
- Necessary to carry out filtering exercise to identify the “optimum” TOs for subsectors

2. Technical Options (TOs)

- Filtering exercise based on simple ranking approach
- Combines three different measures to provide an overall indicator
- TEWI rating (incl. energy related + GWP emissions)
  - GWP, charge size, in-use leak rate, EOL leakage, seasonal efficiency, energy production emissions factor
- Degree of demonstration (for subsector)
  - Has TOs been proven, demonstrated, only theory, etc
- Extent of application of TOs (for subsector)
  - What is maximum percentage of subsector that could be viably covered by TOs (limited by cost, efficiency, regs, etc)

Air conditioning I

	Unitary air conditioning							Chillers		Transport AC	
	Self-contained	Res split	Res duct split	Comm split	Multi-split	Rooftop duct	Comm duct split	AC chiller	Process	Car AC	Large vehicle AC
Leak reduction (design/const)		X	X	X		X	X	X	X		X
Leak reduction (maintenance)			X	X		X	X	X	X	X	X
Charge size reduction					X						X
Recovery and recycling											X
HC R600a											
HC R290/ R1270	X	X	X	X		X		X	X	X	
HFC R161											
HFC R152a											
R717								X	X		
R744									X		
R718											
unsat-HFC	X				X					X	
HFC R32		X	X	X							
HFC/unsat-HFC blends							X				
DME/R-E170											
HFC R134a											
Low-GWP + liquid sec (centralised)	X				X	X	X				
Low-GWP + PCM sec (centralised)											
Low-GWP + evap sec (centralised)											

Air conditioning II

	Unitary air conditioning							Chillers		Transport AC	
	Self-contained	Res split	Res duct split	Comm split	Multi-split	Rooftop duct	Comm duct split	AC chiller	Process	Car AC	Large vehicle AC
Low-GWP + cascade (centralised)											
Low-GWP + liquid sec (discrete)											
Low-GWP + PCM sec (discrete)											
Low-GWP + evap sec (discrete)											
Low-GWP + distrib W-C (centralised)											
Air cycle (Brayton)											
Absorption (liquid) (gas driven)											
Adsorption (solid) (gas driven)											
Absorption (liquid) (solar driven)											
Adsorption (solid) (solar driven)											
Desiccant/Evaporative (gas driven)											
Desiccant/Evaporative (solar driven)											
Thermo-electric (Peltier)											
Magnetic											
Stirling											
Low-GWP + ejector cycle (gas driven)											
Low-GWP + district cooling	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**			
Ground water											

Refrigeration II

	Dom ref	Comm ref			Industrial (FPCS)			Transport refrig
	Dom ref	Stand-alone	Cond units	Centralised (s/markets)	Stand-alone	Cond units	Centralised	Ref trucks/trailers
Leak reduction (design/const)	X	X	X					X
Leak reduction (maintenance)	X	X						
Charge size reduction	X							
Recovery and recycling					X			
HC R600a	X	X			X			
HC R290/ R1270		X			X			X
HFC R161								
HFC R152a								
R717						X		
R744			X	X	X	X		X
R718								
unsat-HFC			X					
HFC R32								
HFC/unsat-HFC blends								
DME/R-E170								
HFC R134a								
Low-GWP + liquid secondary (centralised)				X			X	
Low-GWP + PCM secondary (centralised)								
Low-GWP + evap secondary (centralised)				X			X	

Refrigeration II

	Dom ref	Comm ref			Industrial (FPCS)			Transport refrig
	Dom ref	Stand-alone	Cond units	Centralised (s/markets)	Stand-alone	Cond units	Centralised	Ref trucks/trailers
Low-GWP + cascade (centralised)				**X**			**X**	
Low-GWP + liquid secondary (discrete)			**X**			**X**		
Low-GWP + PCM secondary (discrete)								
Low-GWP + evap secondary (discrete)								
Low-GWP + distributed W-C (centralised)				**X**			**X**	
Air cycle (Brayton)								
Absorption (liquid) (gas driven)								
Adsorption (solid) (gas driven)								
Absorption (liquid) (solar driven)								
Adsorption (solid) (solar driven)								
Desiccant/Evaporative (gas driven)								
Desiccant/Evaporative (solar driven)								
Thermo-electric (Peltier)								
Magnetic								
Stirling								
Low-GWP + ejector cycle (gas driven)								
Low-GWP + ejector cycle (solar driven driven)								
Low-GWP + district cooling								
Ground water								

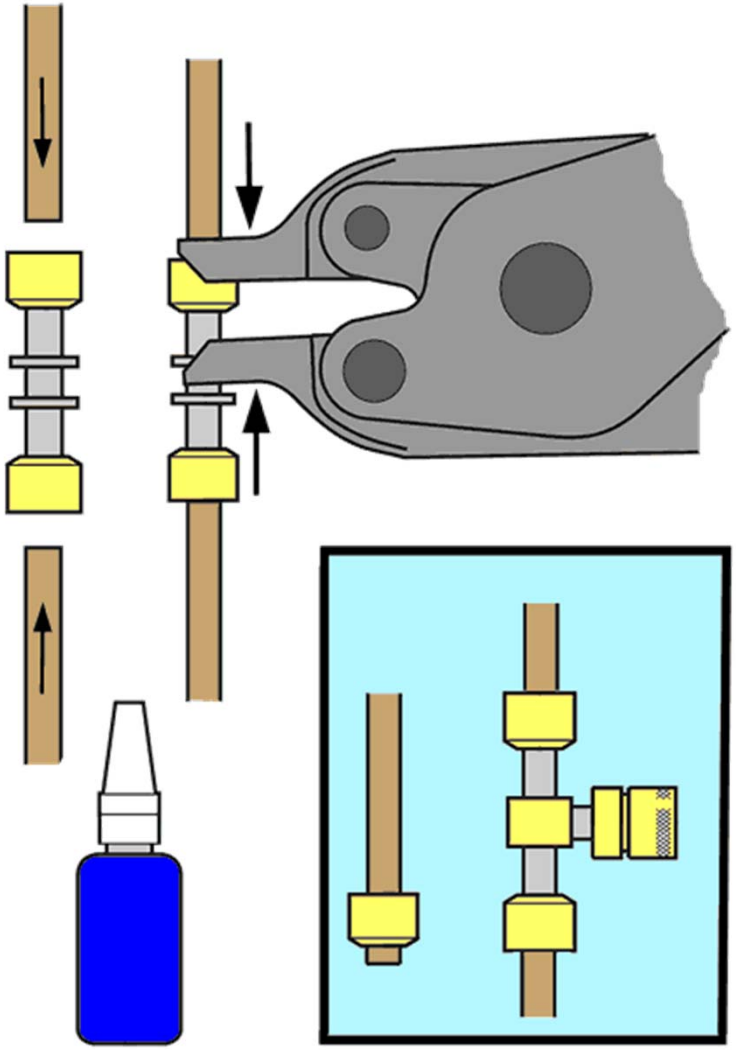
2. Technical Options (TOs)

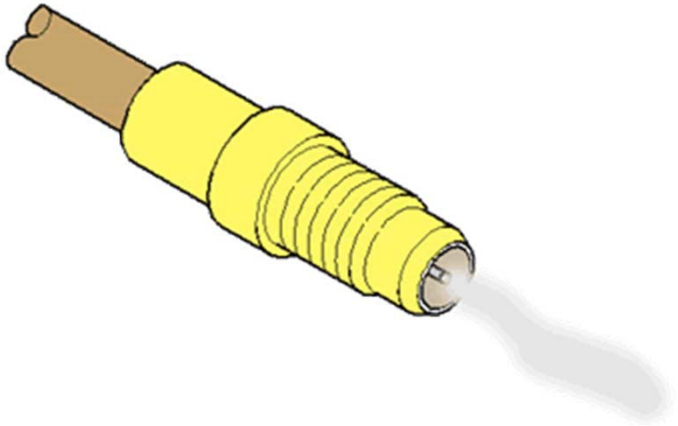
- Selected TOs used for deeper evaluation
  - Leak reduction (design/const)
  - Leak reduction (maintenance)
  - Charge size reduction
  - Recovery and recycling
  - HC R600a
  - HC R290/ R1270
  - R717
  - R744
  - unsat-HFC
  - HFC R32
  - HFC/unsat-HFC blends
  - Low-GWP + liquid secondary (centralised)
  - Low-GWP + evap secondary (centralised)
  - Low-GWP + cascade (centralised)
  - Low-GWP + liquid secondary (discrete)
  - Low-GWP + distributed water-cooled (centralised)
  - Low-GWP + district cooling

2. TOs – Leak reduction (design/construction)

- Improve the tightness of systems (use existing refrigerant)
- Good design
  - Avoid vibration, external mechanical impact, possibility of corrosion, etc
- Selection of components
  - Avoiding flare connections, schraeder valves, good parts
  - Components tested under EN 16084 (Qualification of tightness of components and joints)
- Tightness testing
  - Systematic testing of systems, use of helium tracer gas and high sensitivity gas detectors
- NEXT PRESENTATION PROVIDES MORE DETAIL

2. TOs – Leak reduction (design/construction)



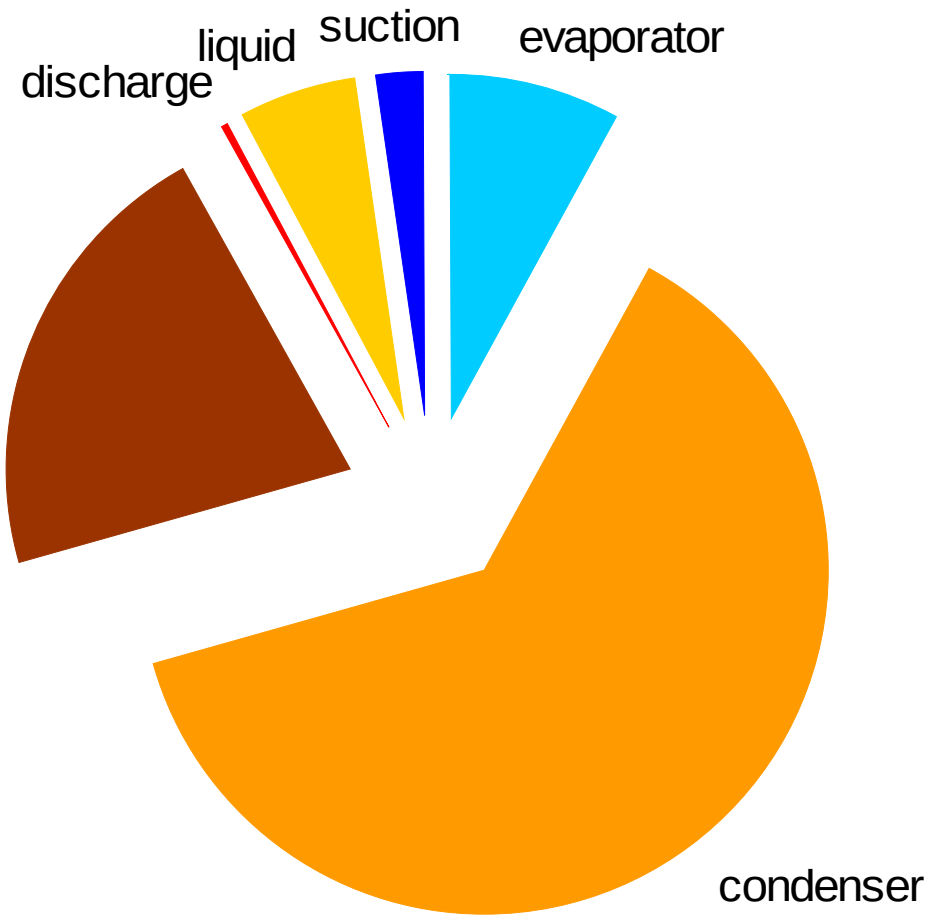


2. TOs – Leak reduction (maintenance)

- Minimise emissions of refrigerant by improved service and maintenance
- Encourage more conscientious behaviour of technicians
- NEXT PRESENTATION WILL PROVIDE MORE DETAIL

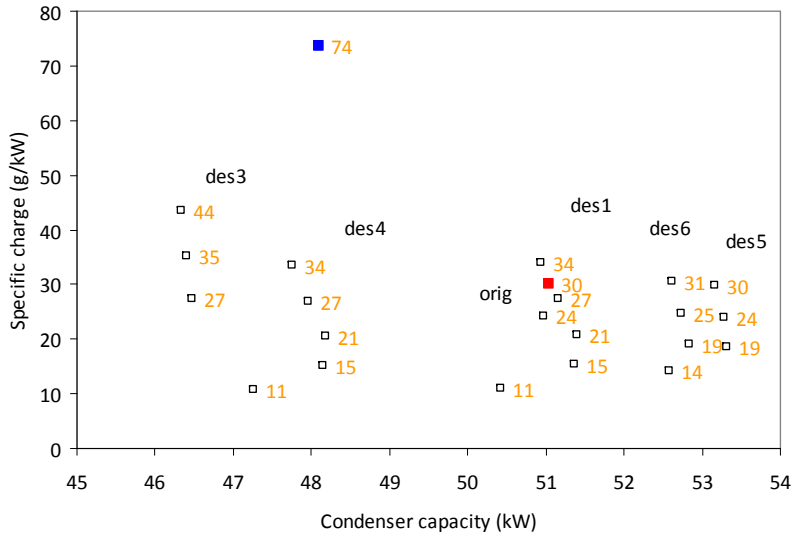
2. TOs – Charge size reduction

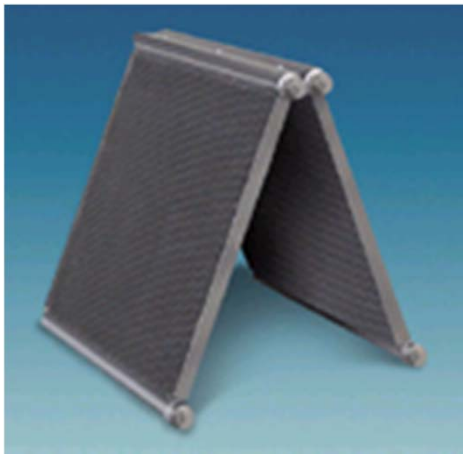
- If refrigerant charge can be reduced, total emitted quantity will be less
- Standard techniques
  - —Compact HXs, brazed plate, etc
  - —Smaller liquid line sizes Mini-channel condensers
  - —Avoid receivers (use subcooling region)
  - —Minimise accumulator volume
  - —Carefully selected oil (low solubility)

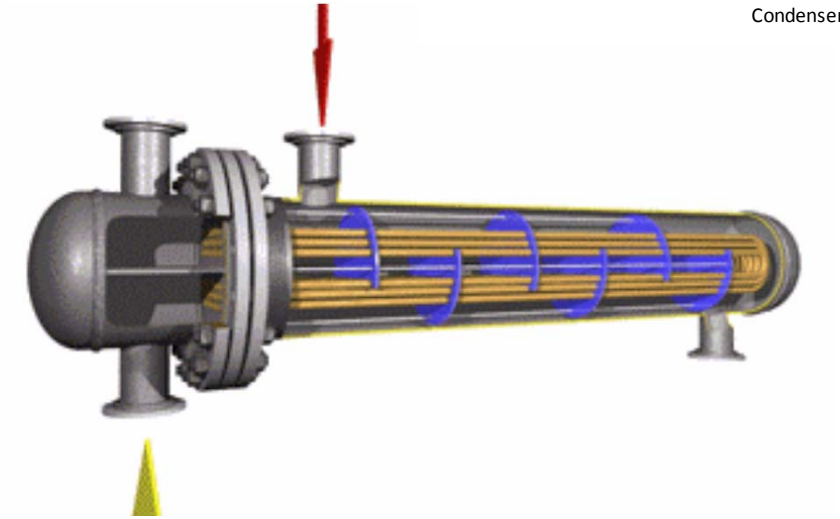


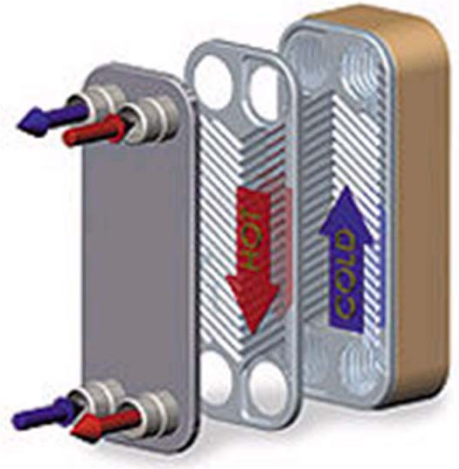
2. TOs – Charge size reduction

- Selection of heat exchangers









2. TOs – Recovery and recycling

- Minimise emissions of refrigerant by improved refrigerant recovery
  - During service and maintenance and particularly at end of life/disposal
- Encourage more conscientious behaviour of technicians
- Availability of recovery machines, recovery cylinders and take-back scheme for recovered refrigerant
- NEXT PRESENTATION WILL PROVIDE MORE DETAIL

2. TOs – general – alternative refrigerants

Refrigerant	R-600a (iso-butane)
Type	Hydrocarbon
ODP	0
GWP	<3
Safety classification	A3 (high flammable, low toxicity)
Vapour pressure	3.5 bar @ 25 deg C
Experience	Extensive
Availability	Good
Price	$2 – 6 / 7 – 20 per kg

2. TOs – general – alternative refrigerants

Refrigerant	R-290 (propane)
Type	Hydrocarbon
ODP	0
GWP	<3
Safety classification	A3 (high flammable, low toxicity)
Vapour pressure	9.5 bar @ 25 deg C
Experience	Extensive
Availability	Good
Price	$2 – 6 / 7 – 20 per kg

2. TOs – general – alternative refrigerants

Refrigerant	R-1270 (propylene)
Type	Hydrocarbon
ODP	0
GWP	<3
Safety classification	A3 (high flammable, low toxicity)
Vapour pressure	11.5 bar @ 25 deg C
Experience	Extensive
Availability	Good
Price	$2 – 5 / 3 – 20 per kg

2. TOs – general – alternative refrigerants

Refrigerant	R-717 (NH3)
Type	Ammonia
ODP	0
GWP	0
Safety classification	B2 (low flammable, higher toxicity)
Vapour pressure	10.0 bar @ 25 deg C
Experience	Extensive
Availability	Good
Price	$0.5 – 2 / 1 – 4 per kg

2. TOs – general – alternative refrigerants

Refrigerant	R-744 (CO2)
Type	carbon dioxide
ODP	0
GWP	1
Safety classification	A1 (non-flammable, low toxicity)
Vapour pressure	64.3 bar @ 25 deg C
Experience	Extensive
Availability	Good
Price	$0.5 – 2 / 5 – 7 per kg

2. TOs – general – alternative refrigerants

Refrigerant	R-1234yf
Type	HFC
ODP	0
GWP	3
Safety classification	A2 (low flammable, low toxicity)
Vapour pressure	6.8 bar @ 25 deg C
Experience	Limited
Availability	Not commercially available
Price	$45 – 65 / 45 – 80 per kg

2. TOs – general – alternative refrigerants

Refrigerant	R-1234ze
Type	HFC
ODP	0
GWP	12
Safety classification	A2 (low flammable, low toxicity)
Vapour pressure	5.0 bar @ 25 deg C
Experience	Limited
Availability	Limited
Price	$30 – 50 / 30 - 65 per kg (?)

2. TOs – general – alternative refrigerants

Refrigerant	R-32
Type	HFC
ODP	0
GWP	700
Safety classification	A2 (low flammable, low toxicity)
Vapour pressure	16.9 bar @ 25 deg C
Experience	Limited
Availability	Limited
Price	$7 – 9 / 30 – 50 per kg

2. TOs – general – alternative refrigerants

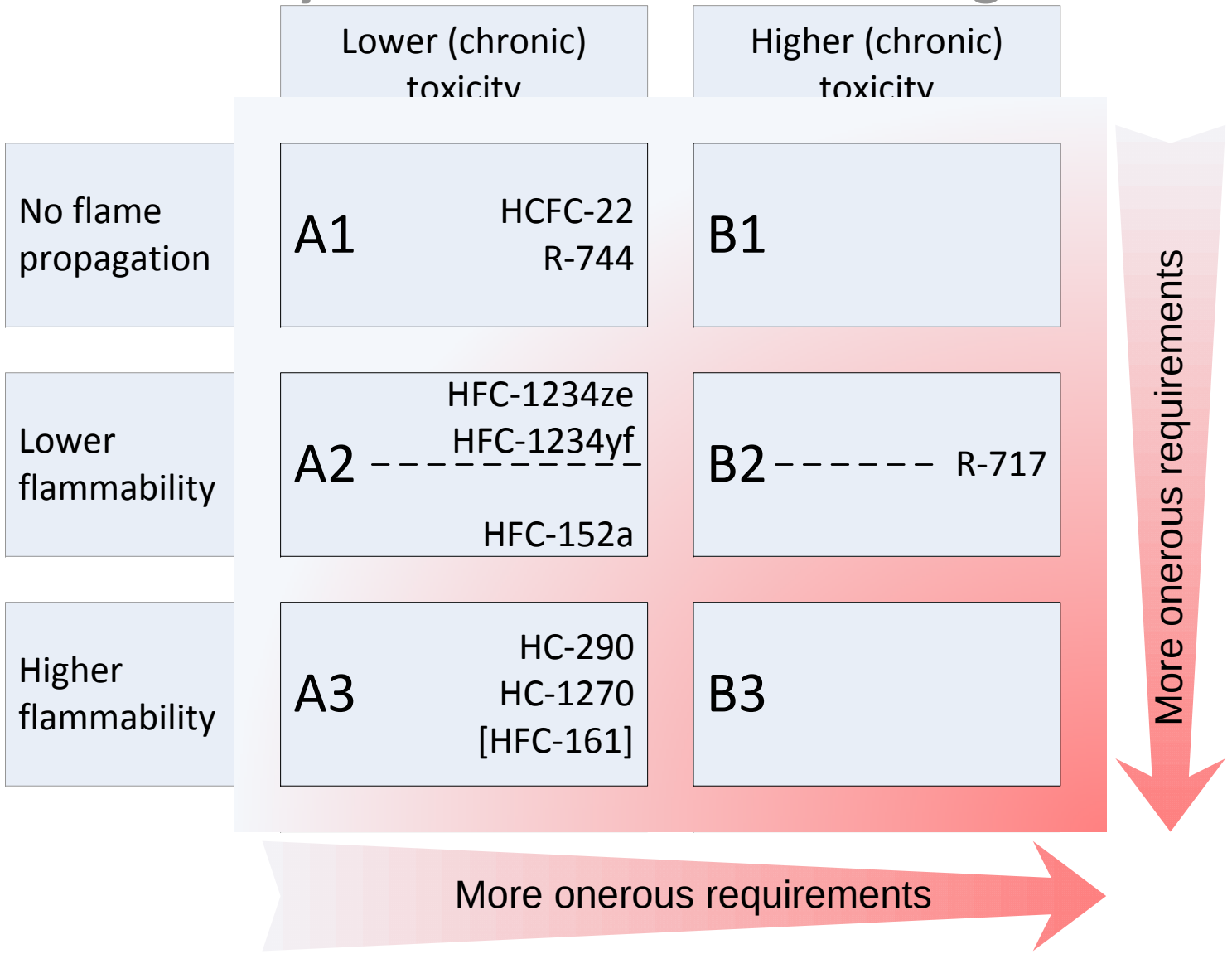
Refrigerant	R-4?? [not yet known]
Type	HFC blend
ODP	0
GWP	300 – 1500
Safety classification	A1, a” (non-/low flammability, low toxicity)
Vapour pressure	[not known]
Experience	None
Availability	Not commercialised
Price	$ high

2. TOs – general – alternative 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	0.01	2.5%	11.5
HC-290	A3	0.09	2.1%	9.5
R-717	B2(L)	0.00035	13%	10.0

2. TOs – general – safety rules for alternative refrigerants

Implications of refrigerant classification



2. TOs – general – safety rules for alternative refrigerants

Main topics within RAC safety standards

- Classification of refrigerants, occupancy, systems
- Refrigerant charge size – limits
- Safe design and testing of components and pipes
- Safe design and testing of assemblies (systems)
- Electrical safety, sources of ignition
- Installation areas, positioning, pipework, mechanical ventilation, gas detection
- Instructions, manuals, data-plates
- Refrigerant handling

2. TOs – general – safety rules for alternative refrigerants

Standard	Equipment type	Covers
EN 378	Commercial and industrial	Components, safety devices, system design, location, charge size limits, refrigerant classification, installation site, maintenance
[ISO 5149]*	Commercial and industrial	
60335-2-24	Domestic fridges and freezers	Marking, pressure testing, electrical
60335-2-40	Factory built a/c and heat pumps	Marking, pressure testing, maintenance, electrical, charge limits
60335-2-89	Factory built commercial fridges	Marking, pressure testing, electrical

** Currently still at draft stage*

2. TOs – general – safety rules for alternative refrigerants

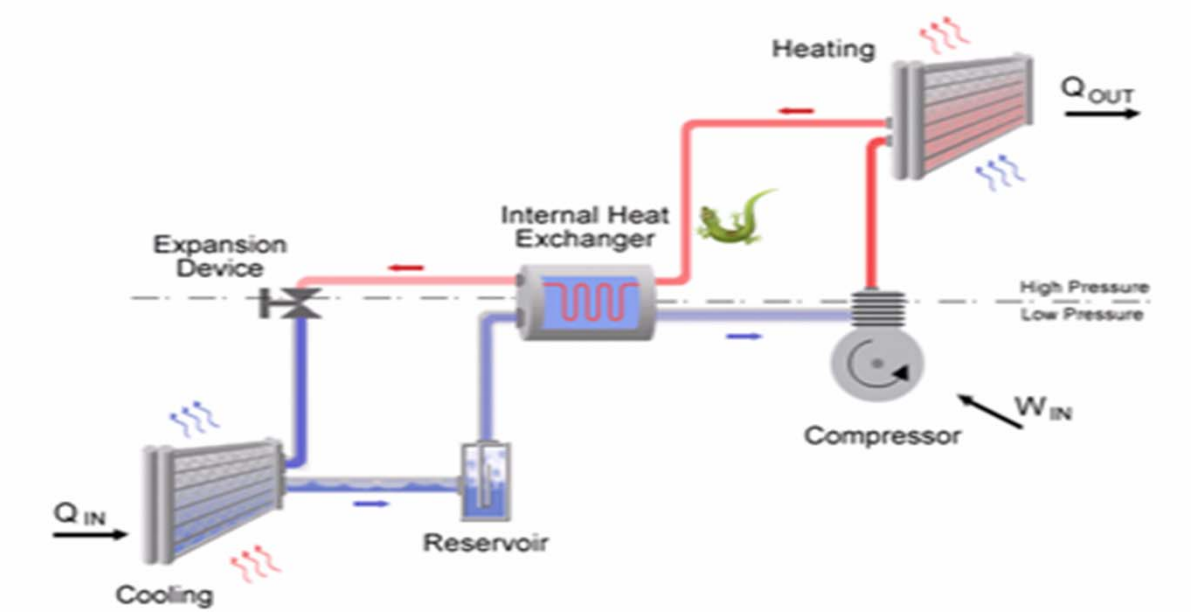
	Max charge (occupied)	PL (g/m^3)	Max charge - outside	Safe electrics
HCFC-22	**No limit**	**300**	**No limit**	**No**
R-744	No limit	100	No limit	No
HFC-1234ze	3.1 – 25 kg	[40]	No limit	Yes
HFC-1234yf	2.3 – 25 kg	60	No limit	Yes
HFC-152a	5 – 25 kg	27	No limit	Yes
HC-290 HC-1270	1 – 2.5 kg	8	25 kg/no limit	Yes
R-717	2.5 – 25 kg	0.4	No limit	Some

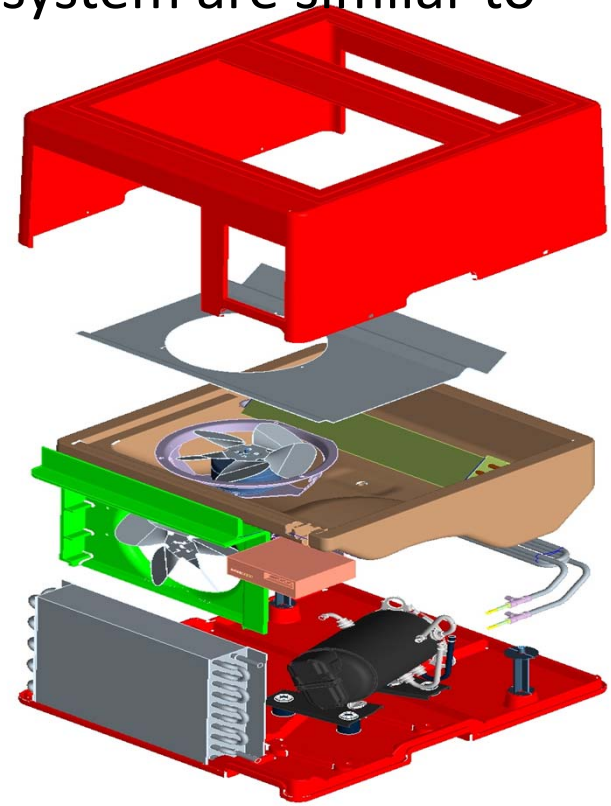
2. TOs – Commercial refrigeration (stand-alone) – HC-600a, HC-290

- Many integral commercial units on HCs
  - Numerous manufacturers
  - Range from mini glass door bottle coolers, vending machines, ice-cream freezers, catering units, to multi-deck cabinets
  - Charge sizes from 100g to 1kg

2. TOs – Commercial refrigeration (stand-alone) – R744 (CO2)

- Coca Cola adopting “cassette” concept for bottle coolers and vending machines
  - The components of a CO2 refrigeration system are similar to those used in an R134a system





2. TOs – Commercial refrigeration (stand-alone) – R744 (CO2)

FKDv3412

CDM550

CDM1000

Europa 130

MD600

V544

FV650

2. TOs Commercial refrigeration (standalone) – R744 (CO2)

- CO2 and R134a global S-Cassette (Cassette design 1) tested in a 510L cabinet
  - Energy savings between brackets
  - CO2 cassette equipped with capillary tube. R134a cassette equipped with expansion valve. This gives an advantage of few % for R134a system

TCCC's Test Conditions	CO2 - (KWh/day)	R134a – (KWh/day)
D (40.6°C - 75%RH)	8.25	7.78 (5.7% lower)
C (32.2°C - 65%RH)	5.79 (16% lower)	6.91
B (23.9°C - 45%RH)	4.97 (3.3% lower)	5.14

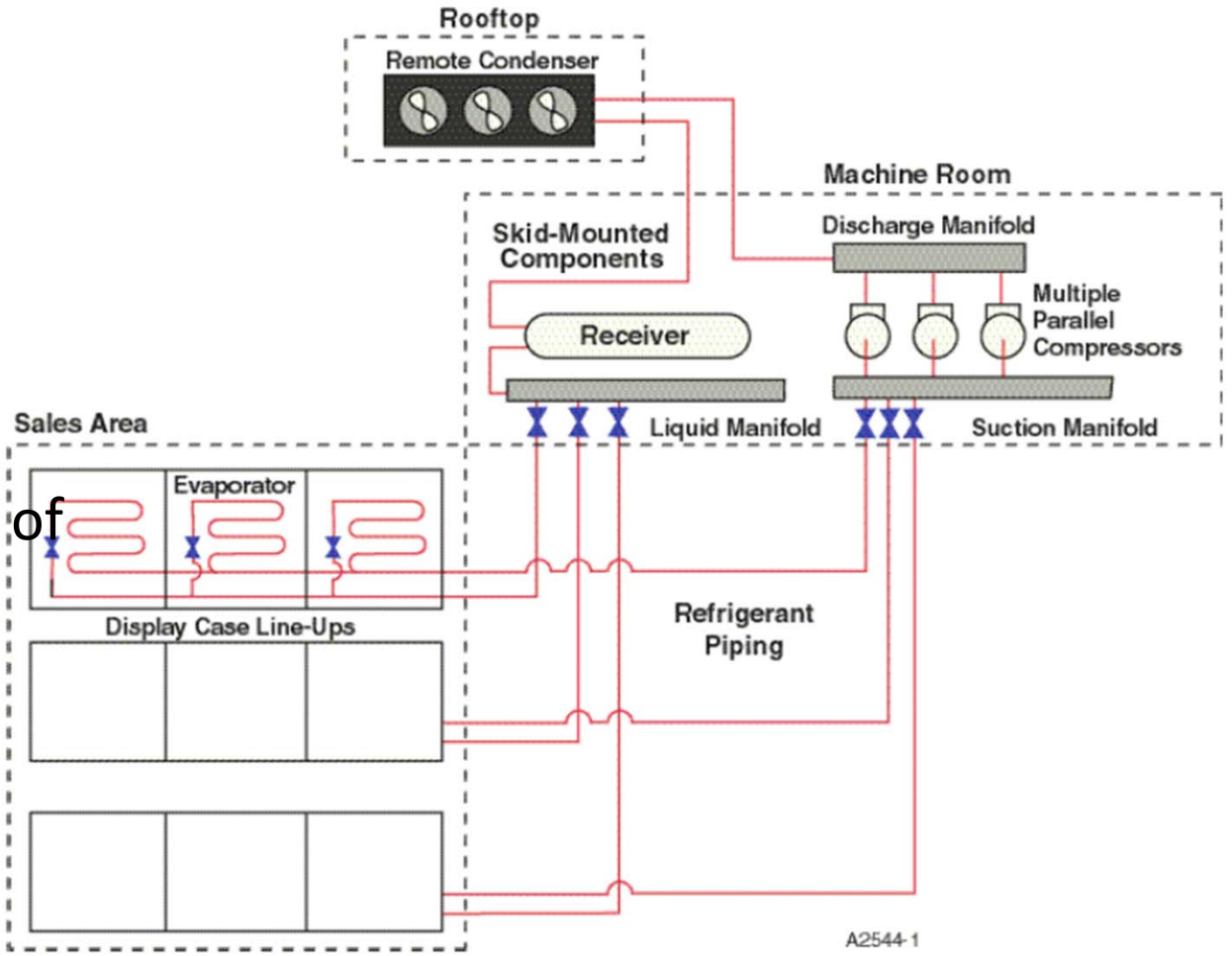
2. TOs – Commercial refrigeration (stand-alone) – R744 (CO2)

- CO2 and R134a global S-Cassette (cassette design 2) tested in 550L cabinet & different CO2 comp
  - Energy savings between brackets
  - Both CO2 AND R134a cassettes are equipped with capillary tube

TCCC's Test Conditions	CO2 - (KWh/day)	R134a – (KWh/day)
D (40.6°C - 75%RH)	9.67 (24% lower)	12.77
C (32.2°C - 65%RH)	5.78 (30% lower)	8.30
B (23.9°C - 45%RH)	4.40 (21.8% lower)	5.63

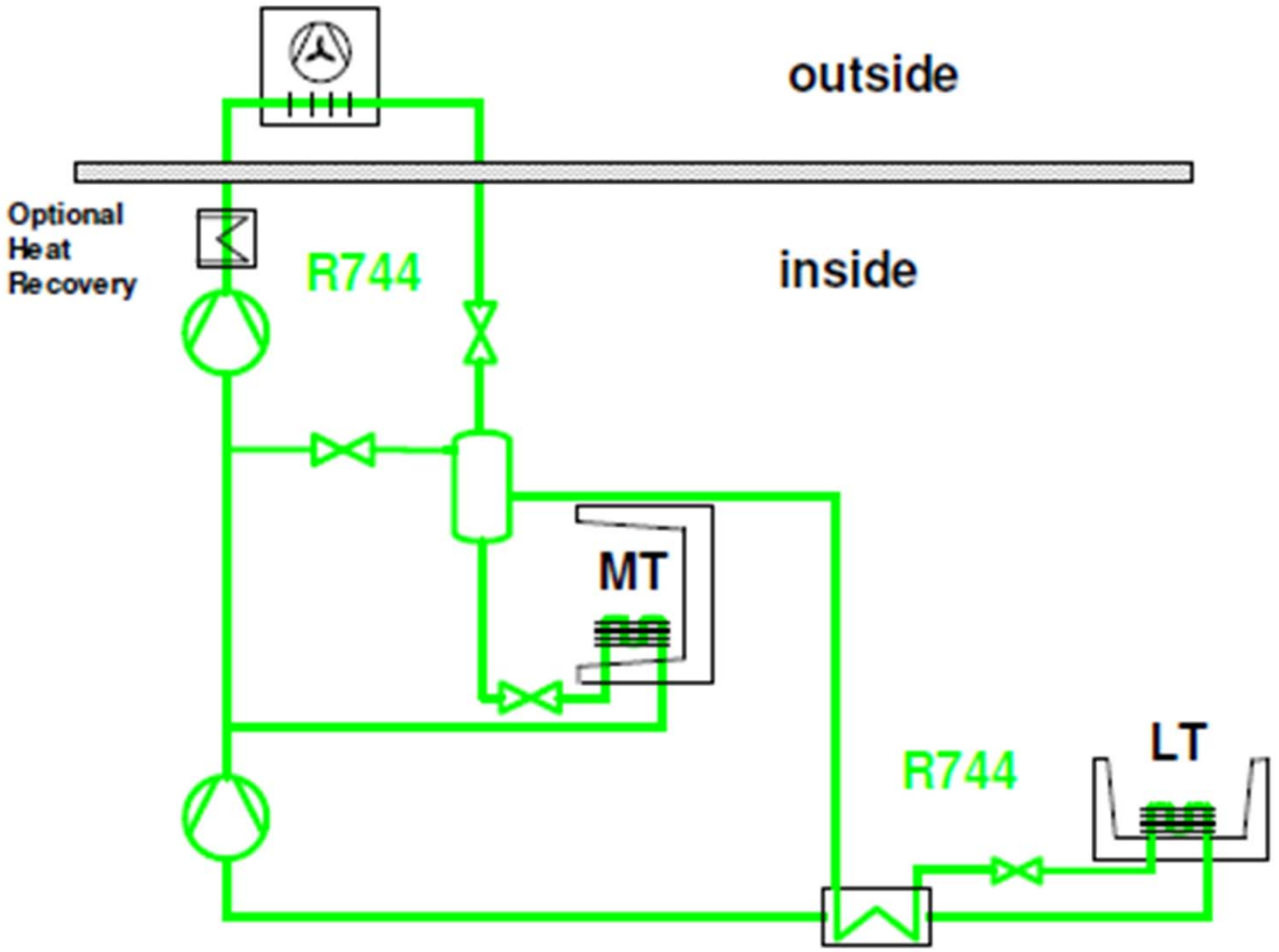
2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary

- Conventional system
  - Pack system, pipework distributed to cases and coldstores
  - Large quantities of R404A
- Separate ventilation and heating system



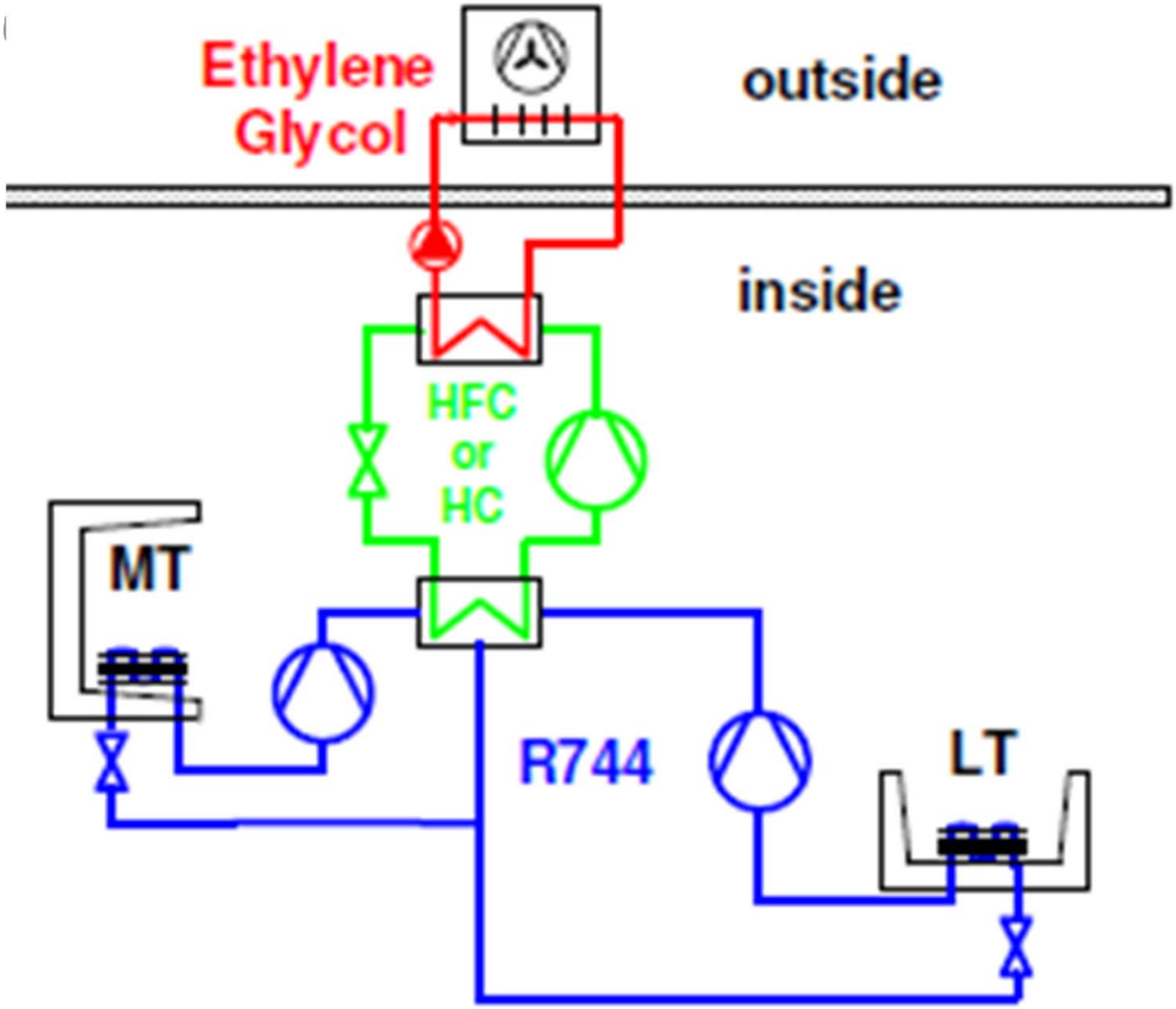
2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary

- Two stage CO2 system
  - Entirely CO2



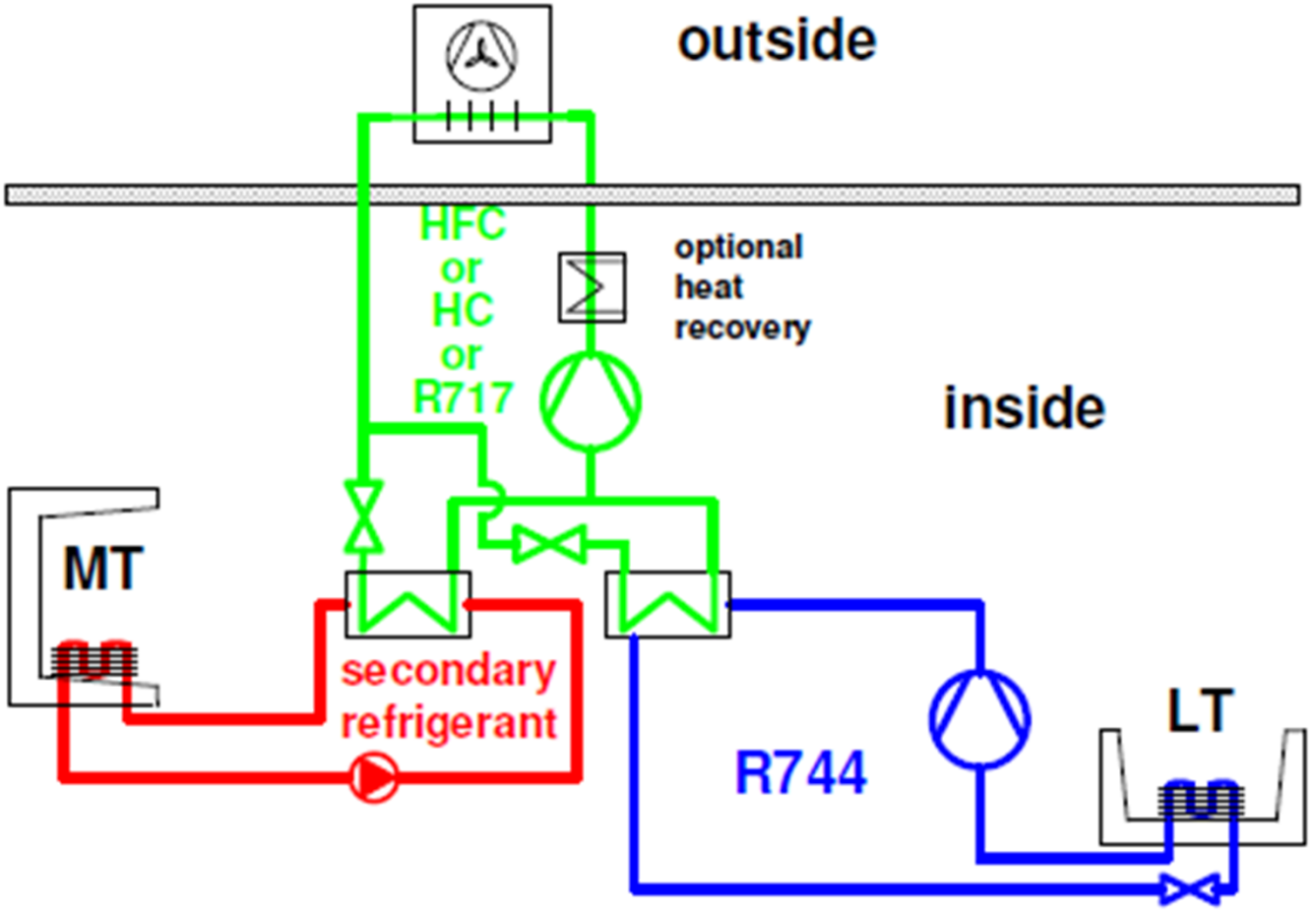
2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secon

- Cascade Indirect Multiplex System with CO2
  - Utilises HFC, HC or NH3 in high stage
  - CO2 in low (LT and MT) stages



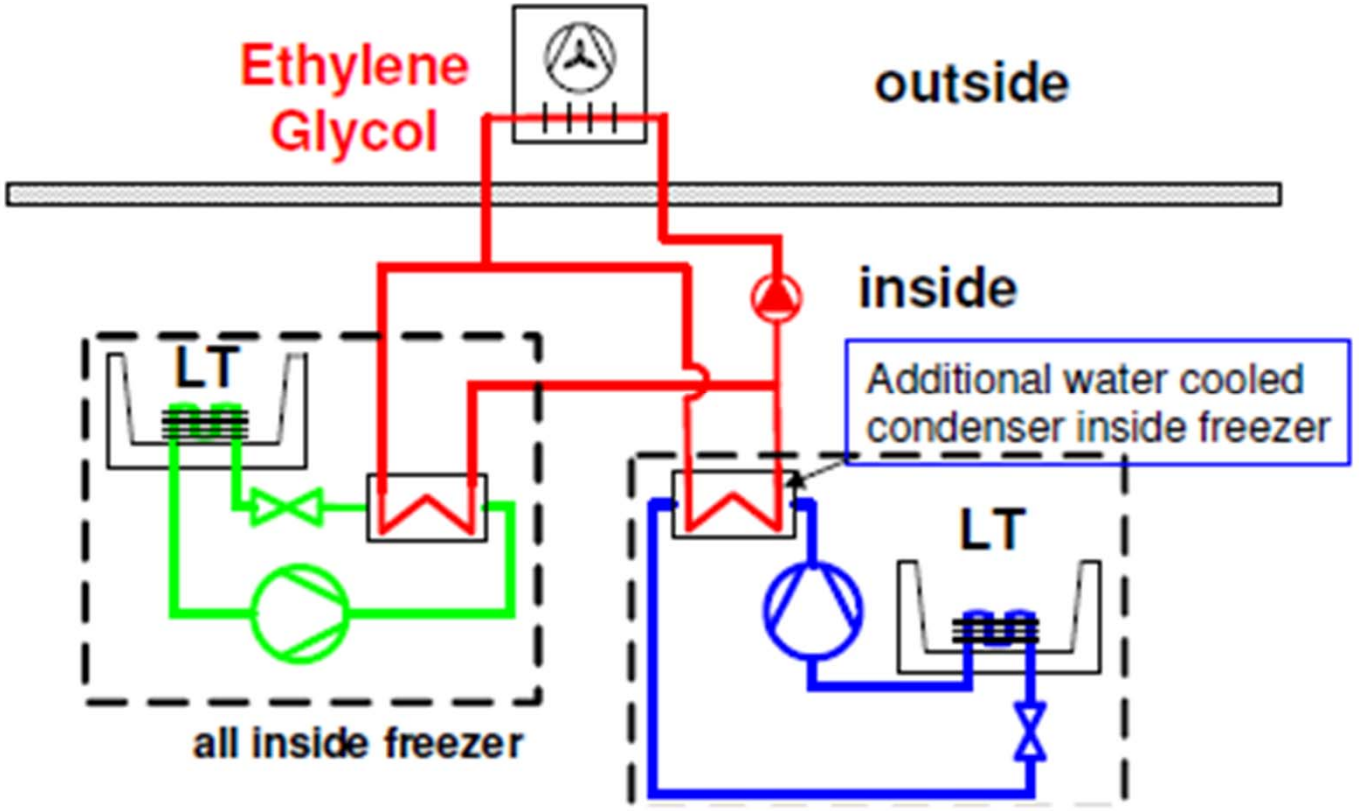
2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary

- Part Indirect Multiplex System with CO2

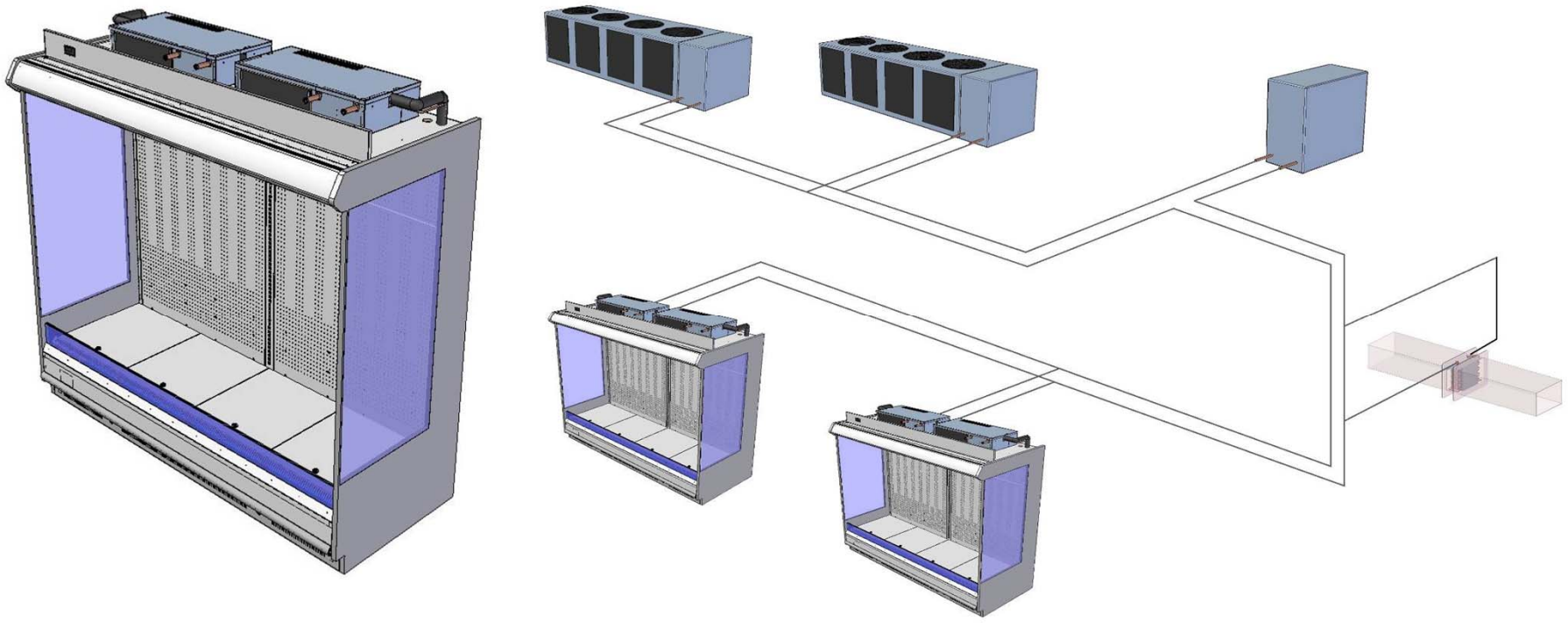


2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary

- Indirect circuit with integral condensing units



2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary



2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary

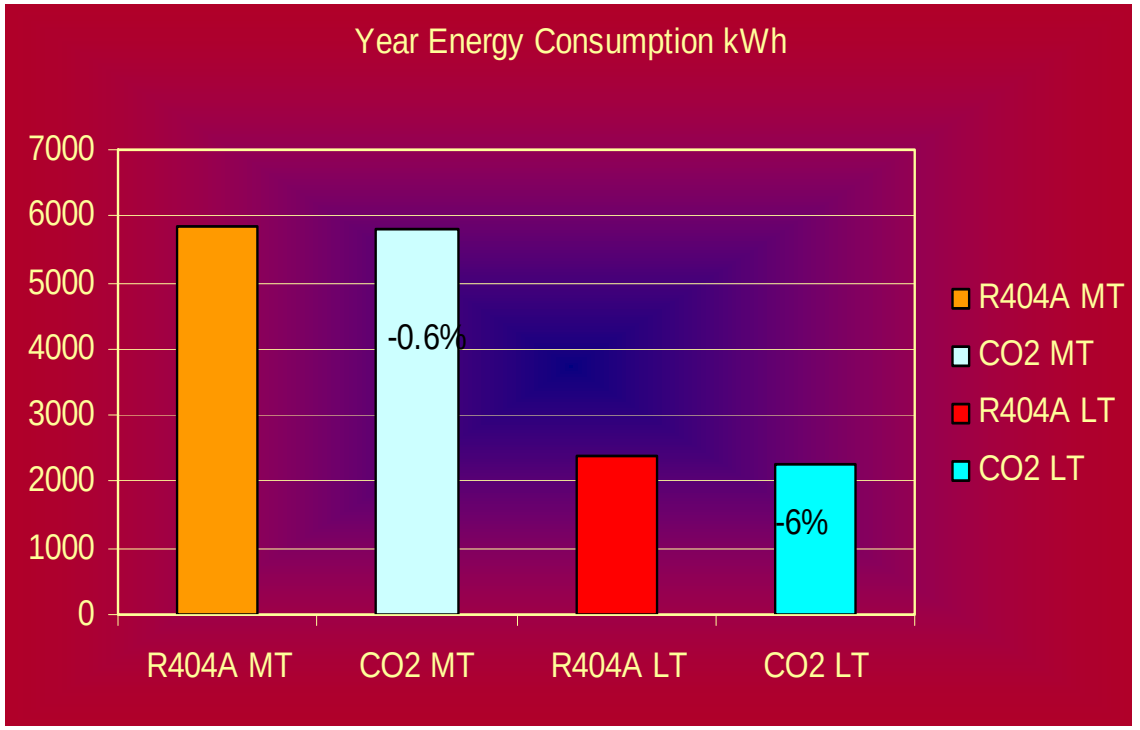
- Example of
  - Supermarket installation
  - water cooled packs

2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary

- Example of
  - Supermarket installation
  - air-cooled gas cooler
  - Compressor racks

2. TOs – Commercial refrigeration (centralised systems) – low-GWP + secondary

- Comparison of supermarket systems
  - MT 120kW, LT 20kW
  - HER weighted upon internal thermal load
  - Minimum condensing temperature +25 C (R404A), +15° C (CO2)



2. TOs – Chillers – HC290/HC1270

- Several current manufacturers
  - —Benson, Bright, Earthcare, Frigadon, Futron, Klima-therm, Weatherite, York/JCI, others…
- All produce chillers using HC and other refrigerants (HFC, HCFC, ammonia, etc)
- Used for both refrigeration as well as air conditioning applications

2. TOs – Chillers – HC290/HC1270

- York/JCI
  - Air-cooled chillers
- Safety aspects
  - Designed to EN 378; up to 25 kg of R290
- Cost is marginally more than HFC products, but apply “green premium”
- R290 gives ~15% higher COP than R407C, R410A products

Type	Cap.* kW at 50 Hz	Power input kW	COP unit dim
HSAS-95-1	95	27,6	3,84
HSAS-95-2	95	27,0	3,84
HSAS-140-1	132	38,8	4,01
HSAS-140-2	132	35,1	3,95
HSAS-200-1	178	53,2	4,24
HSAS-200-2	178	46,0	4,29
HSAS-260-1	218	59,2	4,01
HSAS-260-2	218	54,2	4,01
HSAS-340-1	265	75,5	4,22
HSAS-340-2	265	68,1	4,19