Guideline on the Manual Dismantling of Refrigerators and Air Conditioners

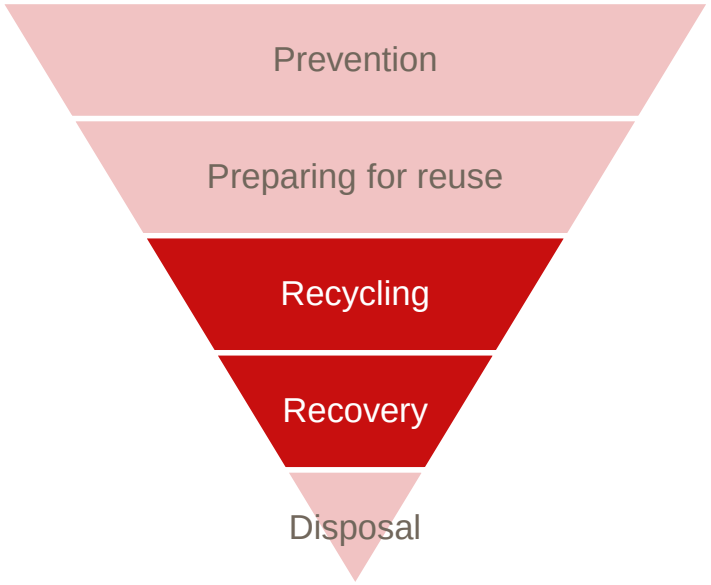
GIZ Proklima

Eschborn, 2017

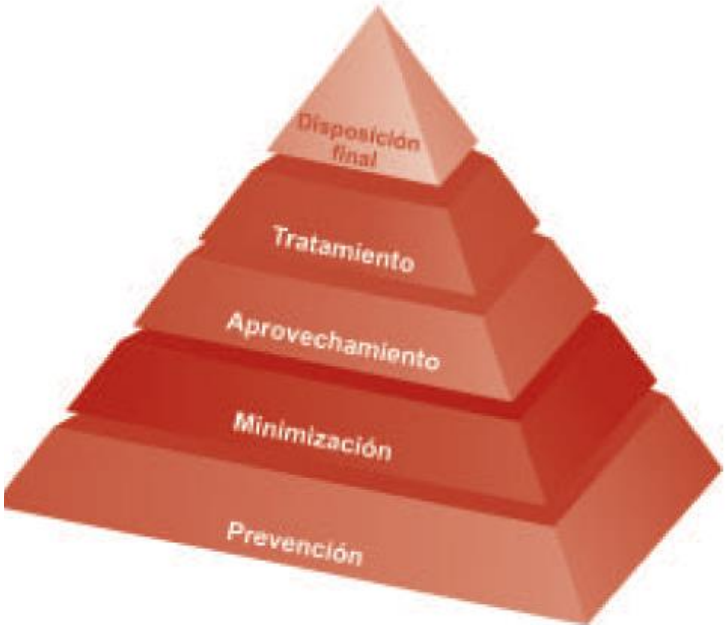
Agenda

- **INTRODUCTION AND PRINCIPLES OF WEEE MANAGEMENT**
- THE COMPOSITION OF REFRIDGERATORS AND AIR CONDITIONERS
- TRANSPORTATION
- RECORD KEEPING, RECOVERY RATES AND CATEGORIES
- EQUIPMENT, TOOLS AND JOB SAFETY
- MANUAL DISMANTLING OF REFRIDGERATORS AND AIR CONDITIONERS
- PROCESSING AND VALORISATION OF EXTRACTED MATERIALS
- CHECKLIST AND OUTLOOK

Waste hierarchy: First try to avoid WEEE



http://ec.europa.eu/environment/waste/framework/



Política Ambiental para la Gestión Integral de Residuos o Desechos Peligrosos, Ministerio de Ambiente, Vivienda y Desarrollo Territorial

WEEE is a global problem, because…

- Rapidly growing worldwide: Globally 20-50 million tonnes WEEE discarded per year
- Can contain hazardous waste, thus is a toxic waste stream!
- Environmental and health problem in the absence of proper waste management

Ongondo et al., 2011

WEEE can consist of…

- … computers, TV-sets, cell phones etc.
- … and **refrigeration** and **air conditioning** equipment.

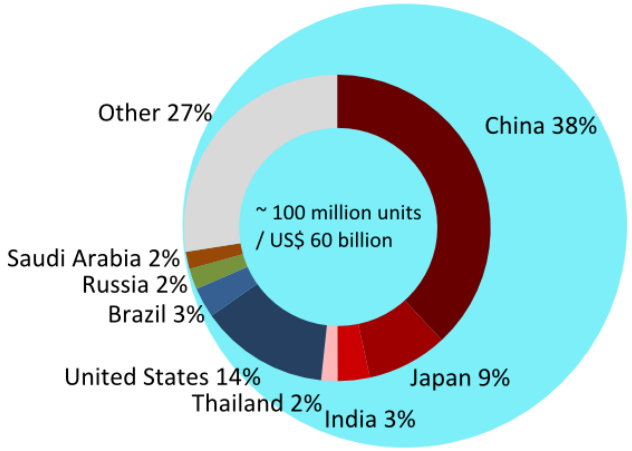
https://cassrecycle.wordpress.com/

learn.compactappliance.com

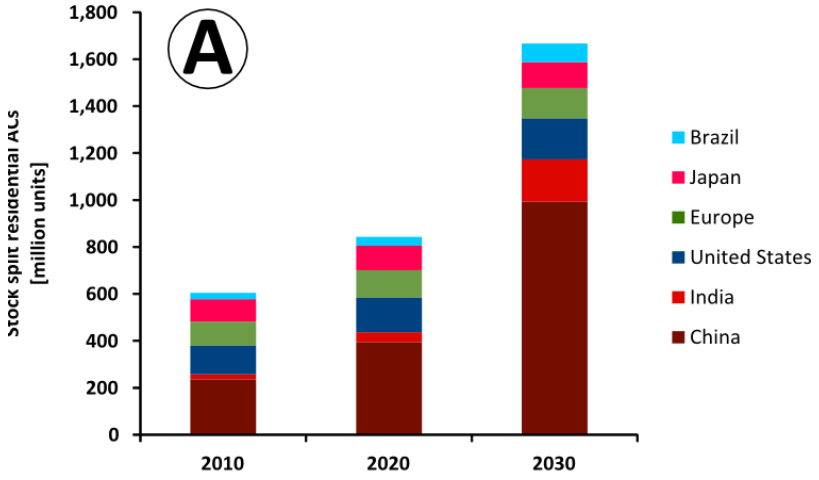
Here we focus on refrigerators and air conditioners

- Refrigerators and air conditioners are widely distributed end-user appliances

Unitary AC demand



Unitary AC stock

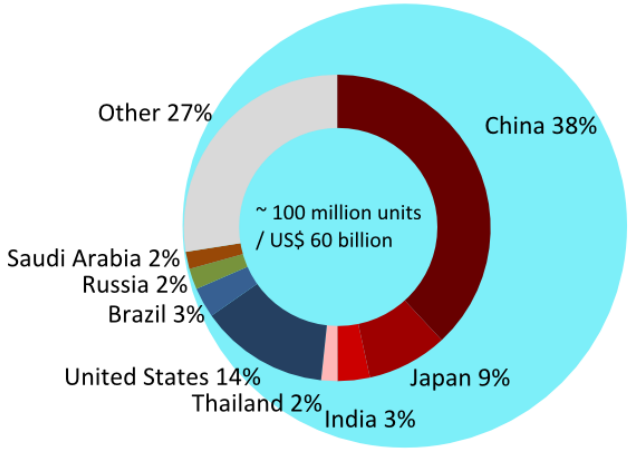


GIZ 2014, Green Cooling Technologies

Here we focus on refrigerators and air conditioners

- Very high sales figures, therewith stock figures and high waste streams

Unitary AC demand



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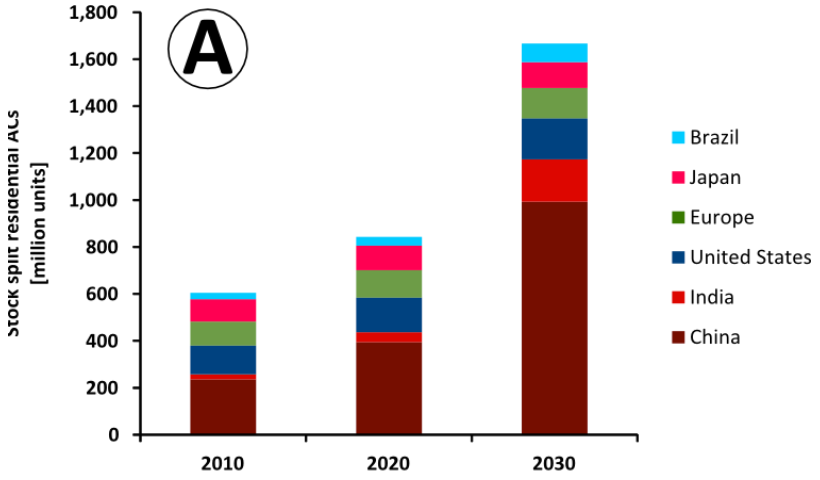
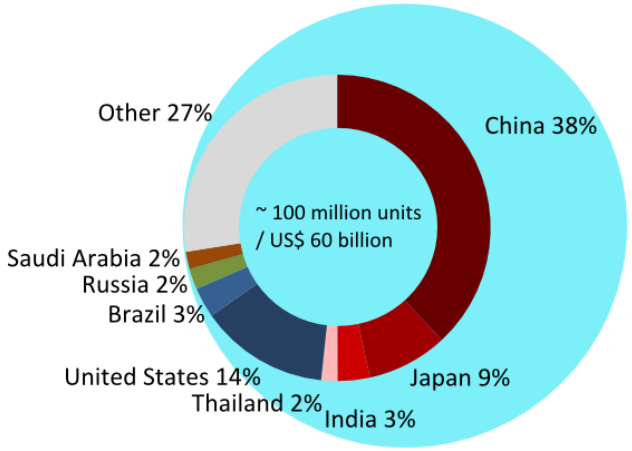


GIZ 2014, Green Cooling Technologies

Here we focus on refrigerators and air conditioners

- Represent a considerable environmental risk, if not managed properly at end of life

Unitary AC demand



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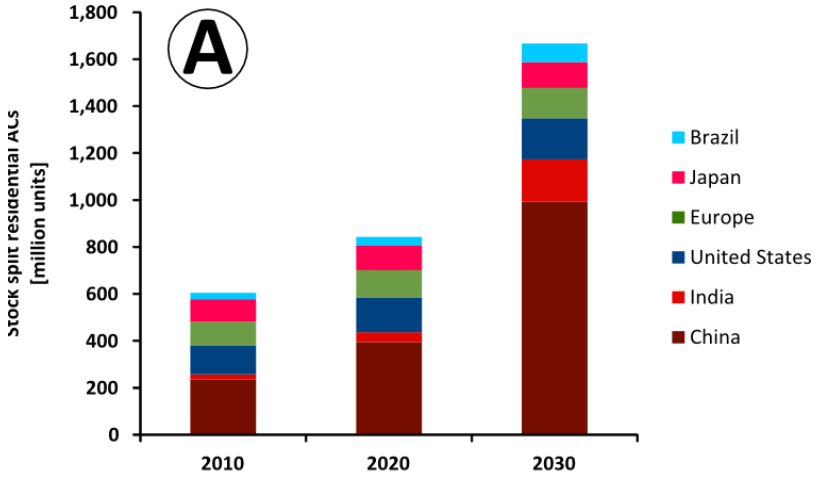


GIZ 2014, Green Cooling Technologies

What are we talking about?

Refrigerators

Air conditioners

GIZ 2014, Green Cooling Technologies

End-of-life management of refrigerators and air conditioners is

- … challenging, because there are harmful substances!

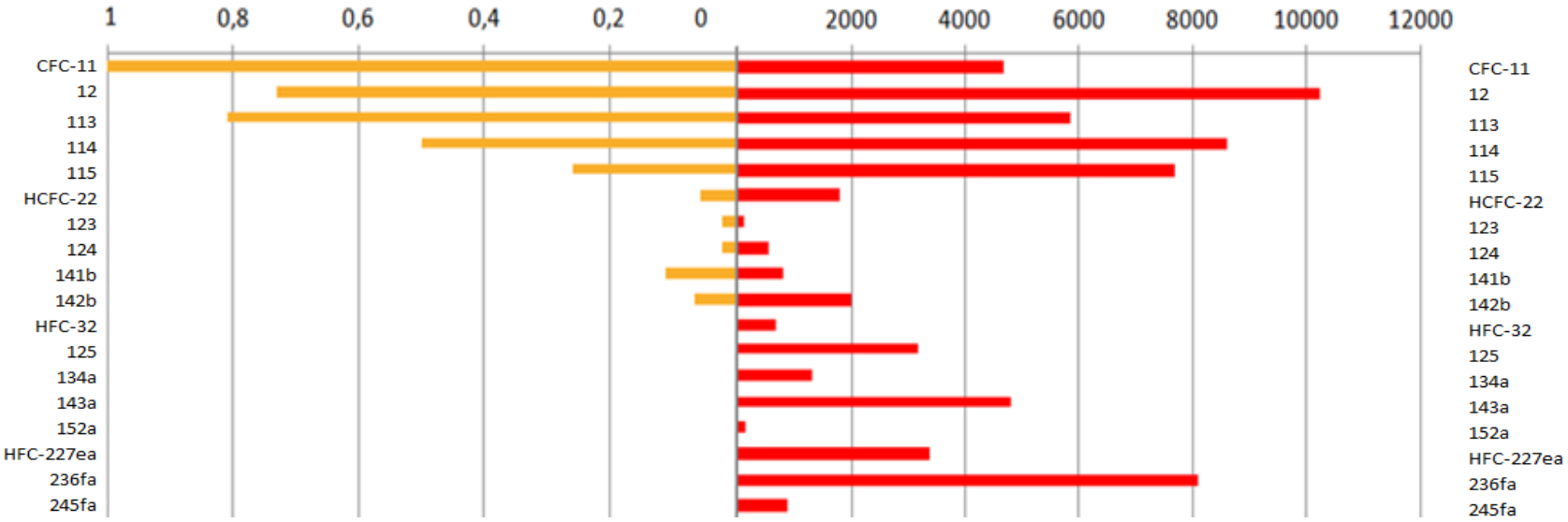
End-of-life management of refrigerators and air conditioners is

- … more complicated than other e-waste, because refrigerators and air conditioners contain refrigerants and blowing agents which require special treatment

The environmental impact of refrigerants and blowing agents

Damage to ozone layer (ODP values)

Climate change (GWP)



The environmental impact of refrigerants and blowing agents

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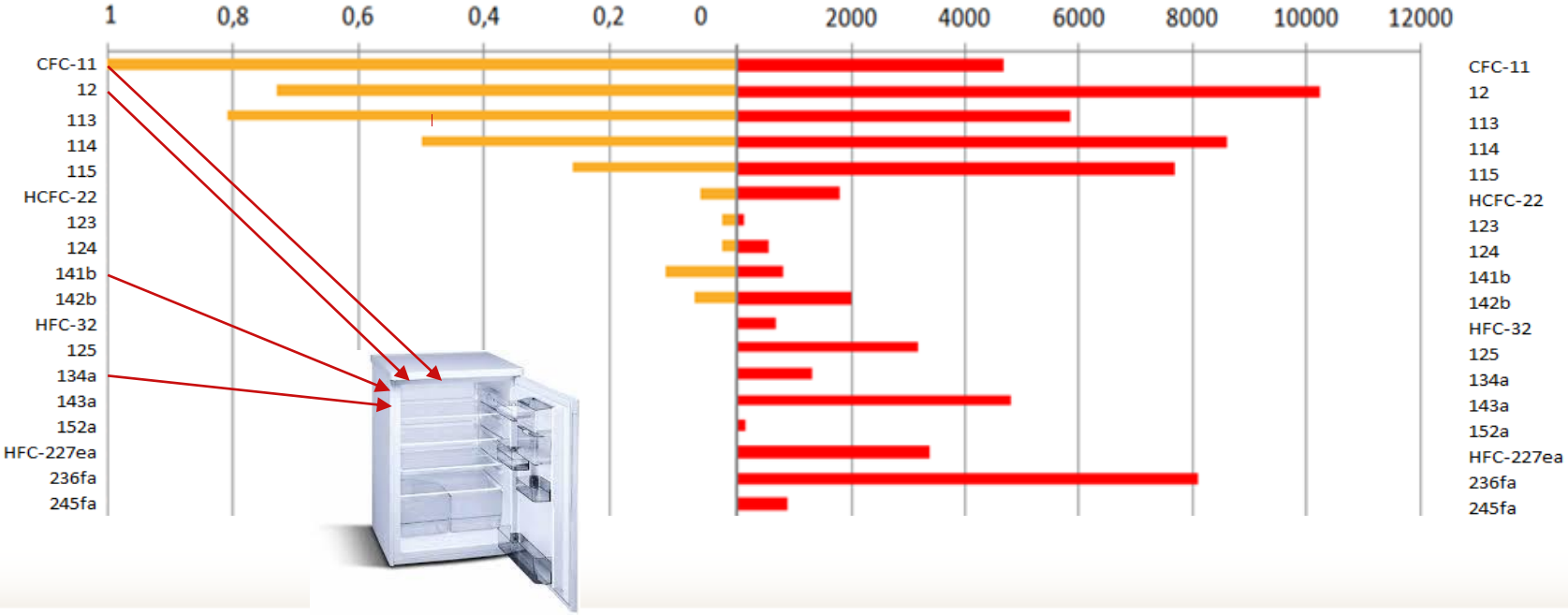

The environmental impact of refrigerants and blowing agents

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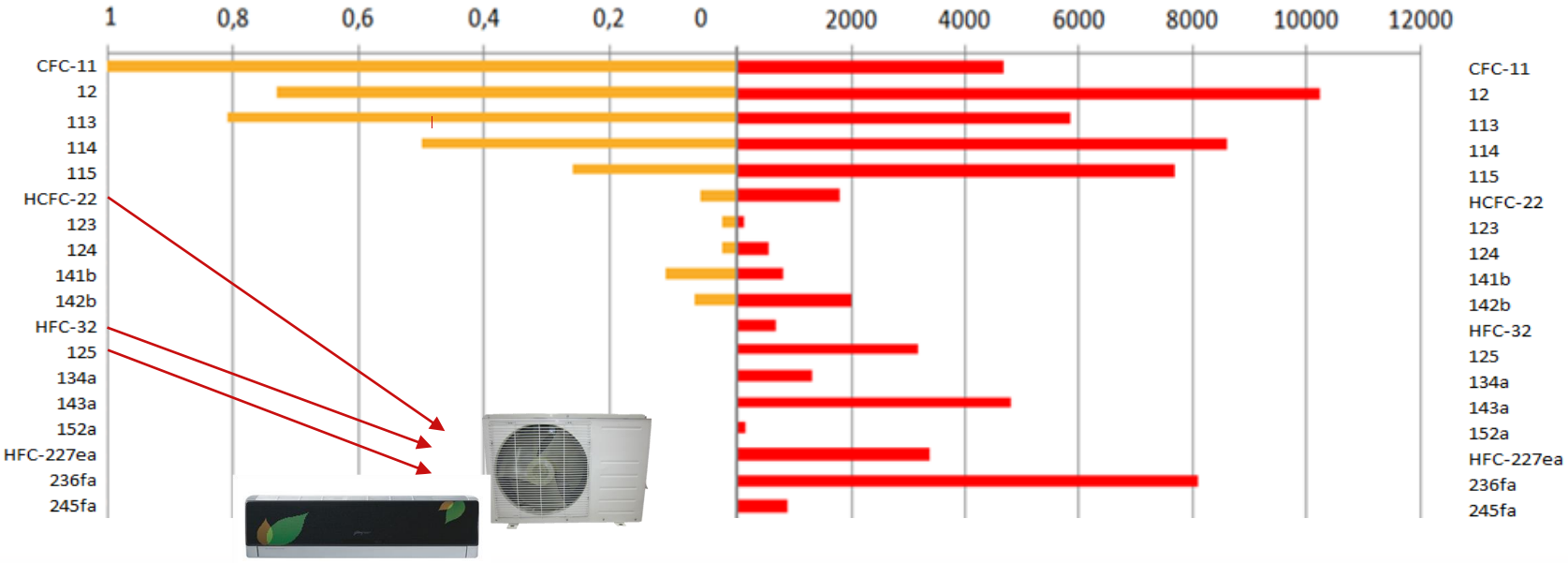


Domestic refrigerator – End-of-life environmental impact

Refrigerant	CFC-12	HFC-134a
Blowing agent	CFC-11 (foam)	HCFC-141b
ODP	CFC-12 = 0.73 CFC-11 = 1	HFC-134a = 0 HCFC-141b = 0.11
GWP	CFC-12 = 10,200 CFC-11 = 4,660	HFC-134a = 1300 HCFC-141b = 725
Climate impact: End-of-life emission (kg CO_2eq)	3,627	547
Ozone impact: End-of-life emission (ODP kg)	0.56	0.05

Split air conditioner – End-of-life environmental impact

Refrigerant	HCFC-22	HFC-410A
ODP	0.055	0
GWP	1760	2087
Climate impact: End-of-life emission (kg CO_2eq)	2,640	2,885
Ozone impact: End-of-life emission (ODP kg)	0.08	0

Why is the end-of-life management of other hazardous substances important?

Hazardous substances	Where to be found?	How are they released?	Why are they dangerous?
Lead	• Solder	• Heating up solder	• Heavy metal accumulates in body tissue through unprotected contact
Cadmium	• Contacts • Coloring of plastic casing	• Burning/ heat treatment	• Brain damage, even death
Mercury	• Switches • Sensors • Contacts	• Heat treatment • Shredding	• Nerve toxin, deadly in small doses • Severe polluter of water, soil, air

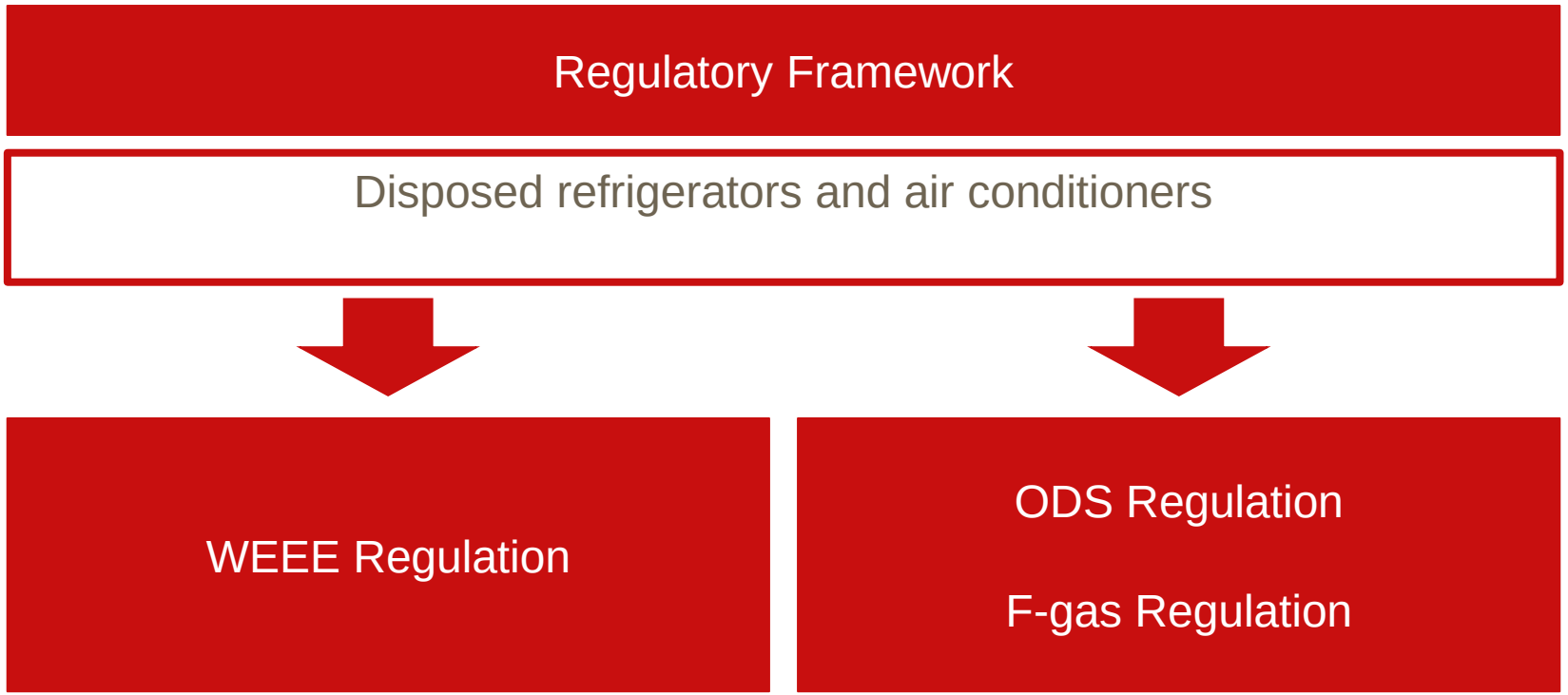
GIZ 2013: Best Practice Guidebook for SMALL South African E-Waste Businesses

Why is the end-of-life management of other hazardous substances important?

Hazardous substances	Where to be found?	How are they released?	Why are they dangerous?
Hexavalent Chromium	• Plating • Anti corrosion agent • Pigment in plastics	• Melting • Burning plastic	• Cause cancer
Flame retardants: • Polychlorinated Biphenyls • Polychlorinated Diphenyl-Ether	• Plastic casing and housing • Plastic wiring and cables • Printed wire boards	• Melting • Burning plastics • Shredding	• Causes cancer

GIZ 2013: Best Practice Guidebook for SMALL South African E-Waste Businesses

Regulatory framework for a successful management of ODS/HFC and WEEE containing ODS/HFC



Regulatory framework in the European Union

Regulatory Framework

Disposed refrigerators and air conditioners

- WEEE Directive 2012/09/EU
  - → Promoting recycling of WEEE and/ or re-use
  - → Remove components classified as HW

→ (RoHS recast Directive 2011/65/EU)
  - → Restrict the use of hazardous substances in electrical and electronic equipment

ODS Regulation (EC) 1005/2009
→ Defines requirements for the handling of ODS throughout their use

The F-Gas Regulation (EC) 517/2014

- → Recovery and reporting requirements
- → Requirements for technicians' education/ certification etc.

Regulatory Framework in Colombia

Regulatory Framework

Disposed refrigerators and air conditioners

Law 1672 (became effective in 2013)

- EPR and handling of residues
- Promoting recycling and environmentally safe handling of residues
- Sacntions for those who do not comply

Hazardous waste:
Política Ambiental para la Gestión Integral de Residuos o Desechos Peligrosos (Ministerio de Ambiente, Vivienda y Desarrollo Territorial)

- Law 1252 (year 2008) Defintion and framework)
- Decree 1076 (2015, title 6): regulations for producers and recipients of HW (specification to personnel, certifications, etc.)
- Decree 1079 (2015, section 8): transport of HW
- NOTA TECNICA: Dealing with CFC, HCFC, HFC, HC containing equipment

The advantages of EOL management

- Avoidance of negative environmental impacts with
  - Protection of the ozone layer
  - Protection of the climate systems
  - Preventing toxic substances the enter ecosystems
- Saving (depleting) raw materials
- Economic benefits from precious materials

Ongondo et al., 2011

The advantages of manual dismantling

- Employment opportunities and therewith income, also fro population segments with low levels of education
- High degree of homogenous sorted plastics and metals, which are precious goods/ commodities on the recycling market
- Less investment costs for preparations techniques and sorting procedures

Ongondo et al., 2011

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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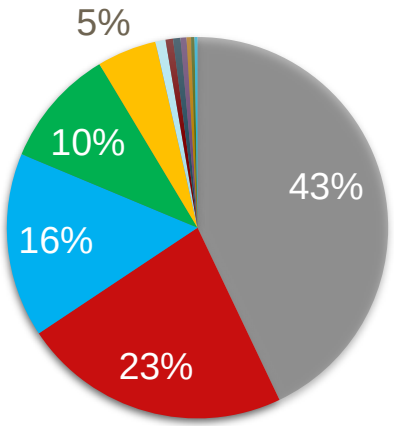
Average material composition of refrigerators in Europa



Öko-Institut, 2007

Dominating parts

- Steel
- Compressor
- Plastics
- PUR

Detailed average material composition of refrigerators

Components	CFC Domestic refrigerator(kg/per piece)	Percentage*
Steel	17	43%
Compressor	9	23%
Plastics without PUR	6,2	16%
PUR	4	10%
Non-iron fraction from the casing	2	5%
CFC-11	0,34	0,9%
Water	0,25	0,6%
Glass	0,25	0,6%
Oil	0,2	0,5%
Cable	0,15	0,4%
CFC-12	0,115	0,3%
Rest	0,1	0,3%
Total	39,6	100%

*average in Europe

Öko-Institut, 2007

Average material composition of self-contained air conditioners in Germany

Material	Percentage
Steel	5.3%
Compressor	39.3%
Non-ferrous metals	21% (12.7% copper, 8.3% aluminium)
Plastics	26.4%
Printed circuit board	1.0%
Refrigerant	2.4%
Other materials	4.6%
Total	100%

Compressor and remaining steel

- Compressors
  - Heaviest single part of refrigerators
  - Consist of copper (8%), iron (57%), cast alloy (35%)
  - Compressor iron component: 85% of compressors are of iron and 15% of cast iron
- Steel
  - Corpus of refrigerators (surrounding of the fridges)
  - Grid shelves
- Heat exchanger of refrigerators is of iron
  - Iron (refrigerators) vs. copper-aluminium (air conditioners)

Insulating foam in refrigerators

- Different types of foam are found
  - PUR foam (common)
  - Glass wool
  - Foamed polystyrene

  } Commercial refrigerators (rare)
  - EPS (rare)
- PUR foam containing blowing agents
  - CFC-11 in old refrigerators produced before 1995 (1997 in Colombia)
  - HCFC-141b in developing countries and currently replaced (conversion to pentane in Colombia some years ago)

Plastics

- Refrigerator
  - PS (polystyrene)
  - PP (polypropylene)
  - ABS (acrylonitrile butadiene styrene)
  - PVC (polyvinyl chloride, rare)
  - Plastics sometimes contain flame-retardants (PBB, PBDE)
- Air conditioner
  - PP (polypropylene)
  - ABS (acrylonitrile butadiene styrene, rare)
  - Plastics often contain flame-retardants (PBB, PBDE)

Refrigerants in refrigerators

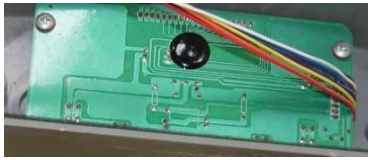
- CFC-12 only found in old fridges
- HFC-134a still commonly used in developing countries
- R-600a is widely used, especially in Europa and China
- R-22, R-290 propane-butan mixture, ammonia solutions containing chromium-VI(all refrigerants in refrigerators > 180 liters)
- Ammonia refrigerants are found in commercial refrigerators (e.g. mini-bars in hotels)

Refrigerants in air conditioners

- Refrigerants in air conditioners
  - HCFC-22 still very common in developing and emerging countries
  - HFC-410A dominating refrigerant in developed countries
  - HFC-32 upcoming refrigerant in developed countries
  - HC-290 currently only in China and India and as pilot and demonstration projects in a few other countries

Printed circuit boards

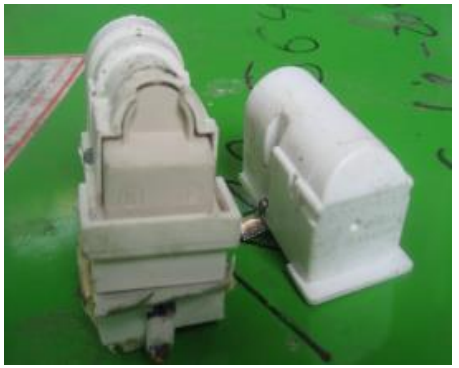
- Found in air conditioners and new or commercial refrigerators (>500 liters)
- Printed circuit boards can contain:
  - Antimony
  - Beryllium
  - Cadmium
  - Chlorine in electronic components
  - Brominated flame retardants
  - Lead in solder



- Either categorized as hazardous waste or e-waste (depending on the national legislation)

Mercury

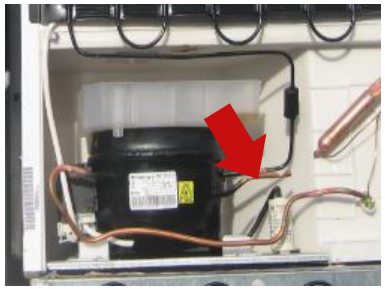
- Mercury is sometimes found in commercial refrigerators and chest freezers; mercury can be found in the following components:
  - Thermostats
  - Sensors
  - Relays
  - Switches
  - Lightning



- Normally not present in air conditioners

Capacitors containing Polychlorinated biphenyls (PCBs)

- Extensively used in electrical equipment before 1970, new equipment produced since mid-1980 generally does not contain PCBs anymore
- PCB generally found in capacitors and transformers
- Transformers are not found in refrigerators only in air conditioners
- The transformers used in air conditioners do not contain PCB
- PCB might be present in capacitors of old refrigerators and air conditioners



Oil

- 200 - 300 g oil in old CFC-refrigerators, less in CFC-free refrigerators
- Up to 1 kg oil in air conditioners depending on the size
- Refrigerants are partly dissolved in the oil

Is the special heat treatment of extracted oil relevant?

1. Many injection nozzles of the disposal plants are having problems with oil e.g. get blocked quickly
2. Oil increases the probability of dioxin and furan production
3. Determination of the refrigerant recovery rate has shortcoming when oil has not removed before
4. Oil should be reused instead of being destroyed

Glass

- Found in refrigerators as shelves (< 1%)
- Air conditioners generally do not have a glass fraction

Non-iron fraction from enclosure

- Non-iron fractions are brass, copper and aluminium
- Heat exchanger of air conditioners generally consist of copper and aluminum
- Brass is sometimes used for connections in air conditioners

Summary of hazardous substances

- Most important critical refrigerants: CFC-12, HCFC-22, HFC-410A, HFC-32, ammonia solution containing chromium-VI
- Most important critical blowing agents: CFC-11, HCFC-141b
- Mercury
- Printed circuit boards components
  - Lead
  - Cadmium
  - Hexavalent chromium and flame retardants
- PCB in capacitors
- PBB and PBDE in plastics as flame retardants

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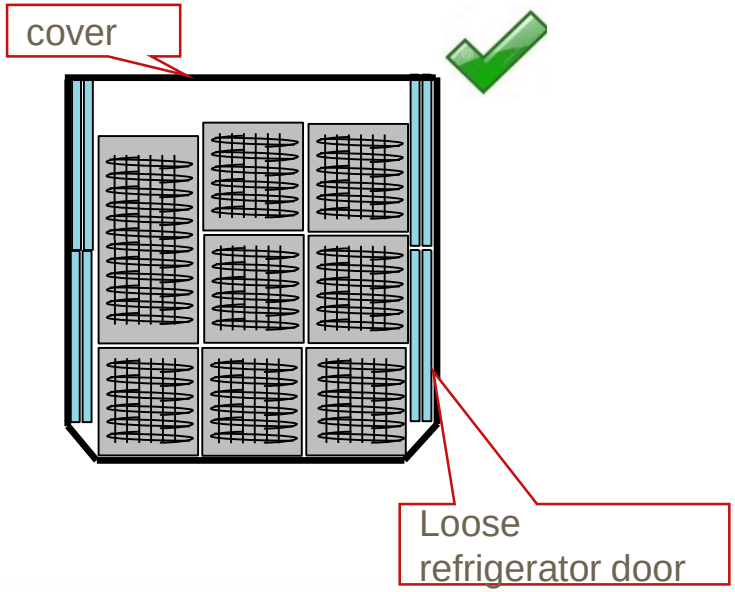
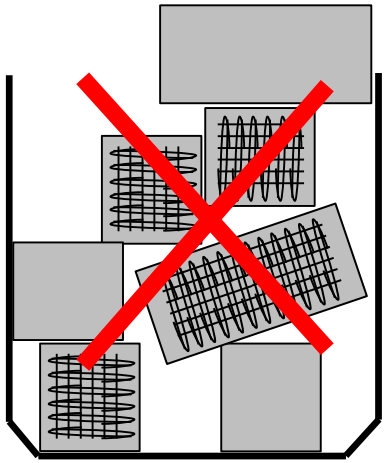
Recommendations for transportation

To prevent the uncontrolled release refrigerants or other harmful substances such as oil:

Correctly filled roller container

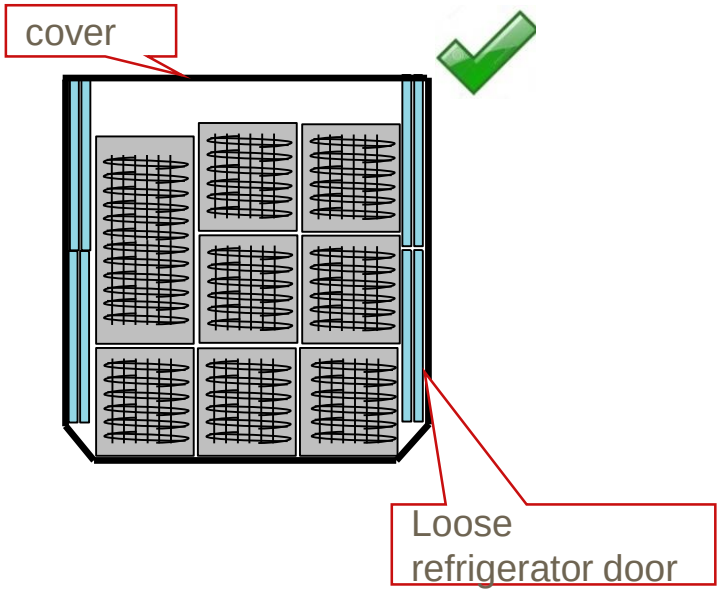


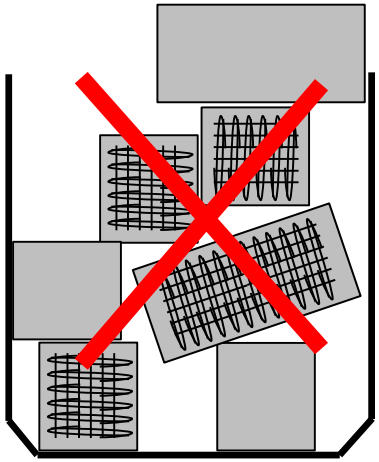
NOT correctly filled roller container



Recommendations for transportation

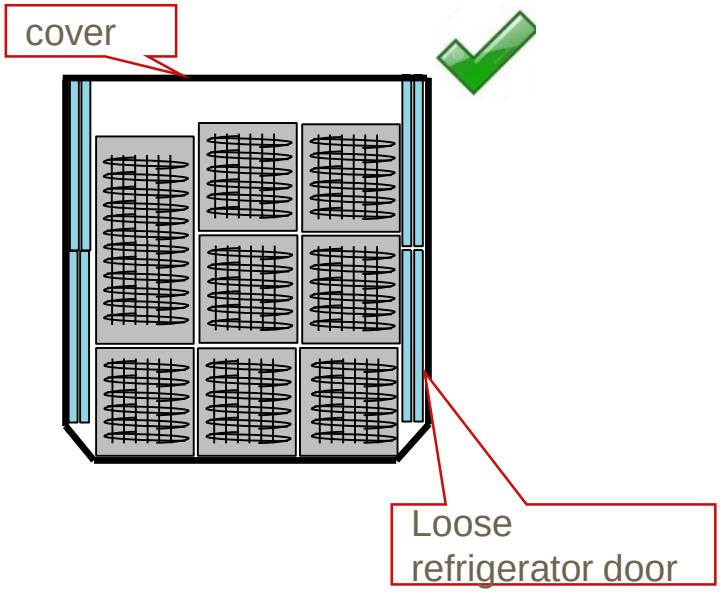
- Appliances should be fastened to the transport vehicle to avoid damage (tension belts or sufficient packing density)
  → Fill up empty loading space with loose doors of refrigerators

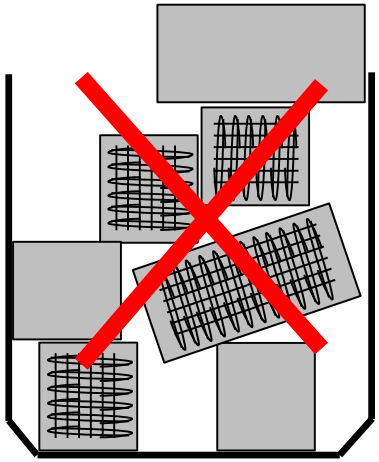




Recommendations for transportation

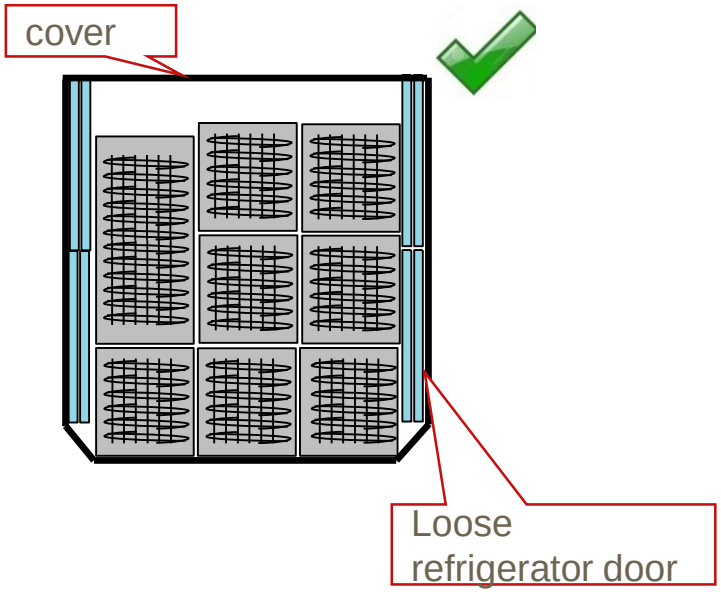
- Refrigerators should be transported in an upright position (not upside down) and shall not be laid on their cooling coils

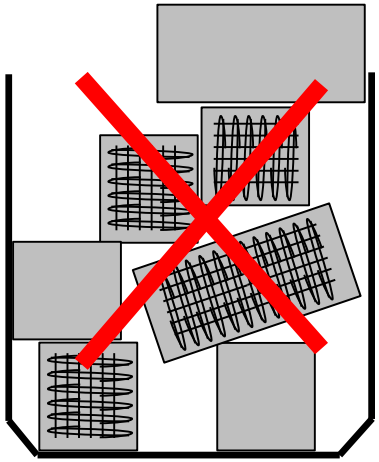




Recommendations for transportation

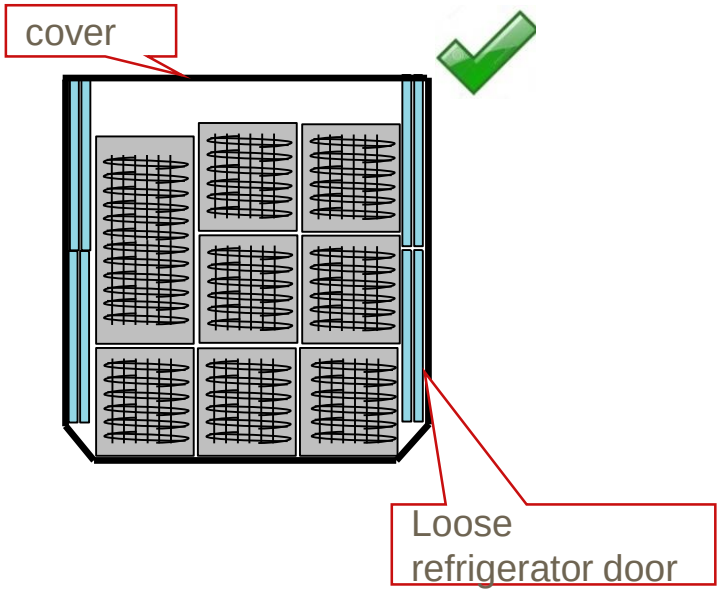
- Heat exchangers of the refrigerators should be directed uniformly at right angles to the same direction of travel

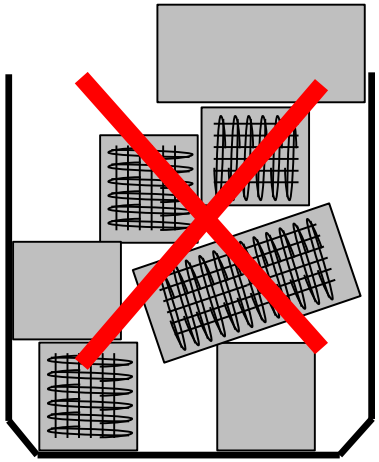




Recommendations for transportation

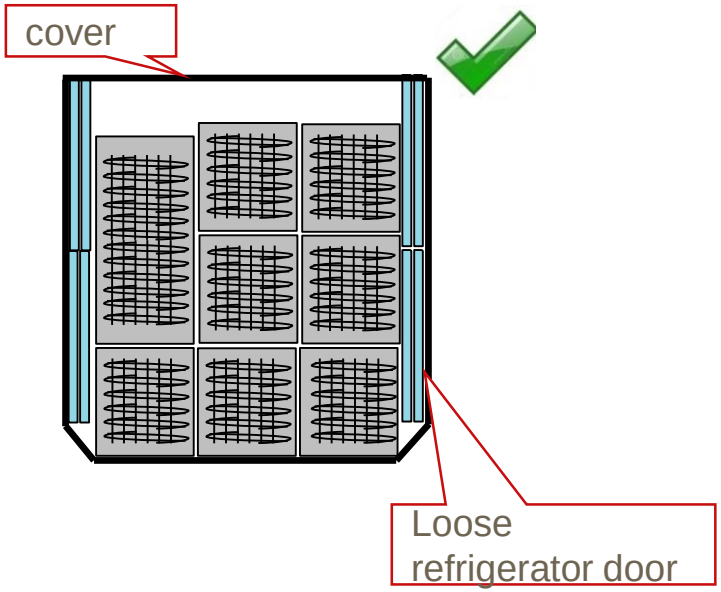
- Avoid reloading from one transportation system to another
- Avoid to pile-up refrigerators randomly

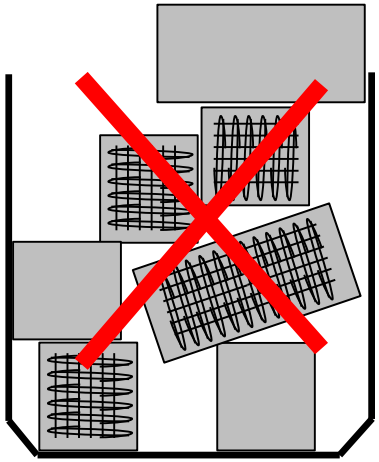




Recommendations for transportation

- Heavy appliances should be placed in the lowest layer, less heavy and smaller items on top of the first layer, etc.
- Roller containers or other transportation containers should be covered (lid) to ensure rain protection





When the appliances arrive WEEE management companies...

- Pre-sorting strongly facilitates later processing of equipment
- Sorted according to different sizes and type of refrigerant

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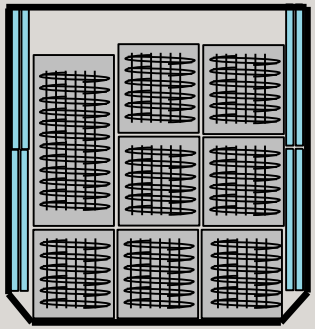
Record keeping

- Every waste management company should have its own monitoring and information system to control:
  1. WEEE input versus output: Tones of WEEE delivered (= input) versus recovered material (= output)
  2. Recovery rates of hazardous substances, in particular refrigerants and blowing agents
- Please note: The WEEE categories depend on national legislation
- In Germany the collection group II of WEEE includes:
  - Appliances for refrigeration and air conditioning (household and small business)
  - Oil radiators
  - Laundry dryer with heat pump technology

Balancing input versus output of WEEE

INPUT: Weight of incoming WEEE



OUTPUT: Weight of recovered materials

- Compressor
- Iron
- Aluminium
- Aluminium-copper heat exchanger
- Copper piping
- Cable
- Glass
- Mixed plastics
- PUR
- PS
- Transformers
- Capacitor
- Oil
- Refrigerant

Categories of refrigerators

- **Type I appliance**
  - ‘Domestic fridges’: These are refrigerators of a typical domestic design with a storage capacity of up to 180 liters. The appliances may or may not be equipped with a separate deep-freeze compartment.

- **Type II appliance**
  - ‘Domestic fridge-freezers’: These are refrigeration appliances of a typical domestic design with a storage capacity ranging from 180 to 350 liters. Generally, these appliances have a separate deep-freeze compartment.

Categories of refrigerators

- **Type III appliance**
  - 'Domestic chest freezers and upright freezers': These are deep-freeze appliances of a typical domestic design with a storage capacity up to 500 liters

- **Commercial refrigerators**
  - 'Commercial refrigerators': These are any appliances whose construction and size differ from those mentioned above and that are predominantly used for commercial purposes

Categories of refrigerators in Colombia

Refrigerator type	Approximate Dimensions (cm)			Approx. weight (kg)
	High	Width	Depth	
Conventional refrigerators or “Frost”	139,8	61,4	69,1	42,2
Frost free refrigerators - “No-Frost”	174,0	69,1	72,1	74,8
Duplex Door Refrigerators “Nevecones” or SBS (side by side)	180,6	92,6	87,5	158,9
Minibar type refrigerators	57,6	49,7	46,5	20,4

Source: RED VERDE

Categories of air conditioners

- Stand-alone

- Split systems

- Country-specific categories might be defined based on size or cooling capacity

Determination of refrigerant recovery rates

- All incoming refrigerators and air conditioners should be recorded
- Advisable to keep a log to record the number of refrigeration and air conditioning including:
  - Type of equipment
  - Type of refrigerant
  - Refrigerant circuit defect or intact
- Hard copy templates might be used during the week an → at the end of week, data should be digitalized (e.g. using an Excel file)

Template for record keeping of refrigerators and air conditioners

CALENDER WEEK:	Total number of units	REFRIGERATORS				AIR CONDITIONERS			
		ODS and F-gases (CFC,HCFC, HFC)		Refrigerants without chlorine and fluorine (Propane, R-600a, hydrocarbon mixtures, etc.)		ODS and F-gases (CFC, HCFC, HFC)		Refrigerants without chlorine and fluorine (Propane, R-600a, hydrocarbon mixtures, etc.)	
		Refrigerant circuit defect, e.g.: • compressor absent • piping damaged	Refrigerant circuit undamaged (i.e. no visible damage)	Refrigerant circuit defect	Refrigerant circuit undamaged	Refrigerant circuit defect	Refrigerant circuit undamaged	Refrigerant circuit defect	Refrigerant circuit undamaged
Monday	8								
Tuesday	4								
Wednesday		𝍸					𝍸		
Thursday			𝍸				𝍸	𝍸	
Friday									

Only the undamaged units with ODS/F-gases are important for recovery rates!

Determination of refrigerant recovery rates

The procedure in detail:

- Recovery rates should be calculated constantly, at least once per week (after data transmission into an electronic version)
- The following formula is used:

$$Recovery\ rate = \frac{amount\ of\ recovered\ refrigerant\ (in\ grams)}{expected\ amount\ of\ refrigerant\ (in\ grams)}$$

Determination of refrigerant recovery rates

Calculation of amount of recoverd refrigerant:

- Note the display value (weight) of pressure vessel in the morning before work
- Extract refrigerant of all units during working time and fill out the hard copy template
- Note the display value (weight) of the pressure vessel at the of working day
- The difference of the display values represents the "amount of recovered refrigerant"

Determination of refrigerant recovery rates

Calculation of amount of recoverd refrigerant:

Determination of refrigerant recovery rates

Calculation of expected amount of refrigerant:

- Multiply number of undamaged units containing ODS or F-gases with the (weighted) average initial charge of units
- Initial charge values can be derived from the product labelling

Control the recovery rate

- This process is done separately for refrigerators and air conditioners
- However, it is not done separately for different (e.g. refrigerator type I, II, etc.)
- It is recommend to control the recovery rate once per year
  - 100 undamaged appliances; 60 type I, 25 type II, 15 type III

Data needed:

- Total weight in kg of refrigerant (ODS/F-gas) and oil recovered
- Total weight of refrigerant according to the information on the rating plates

Important: If recovery rate < 90% → recovery equipment must be checked, repaired or renewed!

Is the refrigeration circuit defect?

- Detect defect circuit:
  - Visual check: components of the systems (e.g. compressor) are missing or piping is obviously damaged

    → defect
  - Check manometer: there is no pressure on the systems?

    → defect
  - Inspection glass: there is no blistering in the inspection glass?

    → defect

  → The defect units are subject to the manual dismantling process as usual

Agenda

- INTRODUCTION AND PRINCIPLES OF RAEE MANAGEMENT
- THE COMPOSITION OF REFRIDGERATORS AND AIR CONDITIONERS
- TRANSPORTATION
- RECORD KEEPING, RECOVERY RATES AND CATEGORIES
- **EQUIPMENT, TOOLS AND JOB SAFETY**
- MANUAL DISMANTLING OF REFRIDGERATORS AND AIR CONDITIONERS
- PROCESSING AND VALORISATION OF EXTRACTED MATERIALS
- CHECKLIST AND OUTLOOK

Job safety: What employees need?

Gloves

Shoes
(steel toe-cap)

Working trousers

Safety
goggles

Dust mask

Earplugs

Earmuffs

Necessary equipment of WEEE management companies

Side cutter

Scraper

Spanner

Hammer

Angle grinder

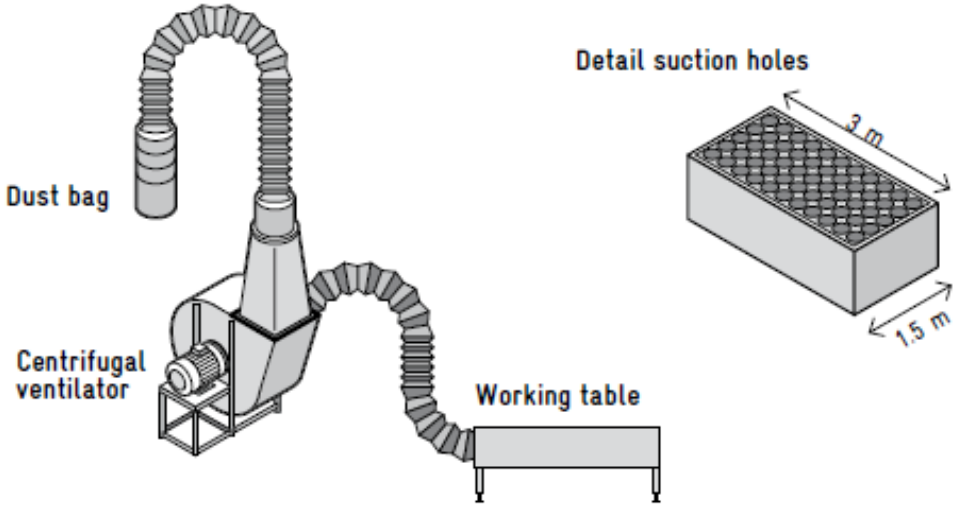
Drilling machine

Hydraulic shears

Cordless screwdriver

Necessary equipment of WEEE management companies

- Dust collection systems to prevent small particles from entering the lungs (filter must effectively capture particles of at least 5 micron)



Necessary equipment of WEEE management companies

- We can distinguish between two different types of **recovery system**:

1. Stationary recovery systems (standard design for around 60 refrigerators per hour)
2. Mobile recovery units

Necessary equipment of WEEE management companies

- Stationary recovery system

Disassembly line for extracting refrigerants using piercing pliers

Piercing pliers

Necessary equipment of WEEE management companies

- Stationary recovery system

Separating refrigerant-oil mix

Pressure vessel and scales

Oil container

Necessary equipment of WEEE management companies

Necessary equipment of WEEE management companies

Storing glass

Storing hazardous components, e.g. capacitors

Storing crushed PUR foam

Site requirements for the WEEE management companies

- To establish a stage I systems including temporary storage of equipment certain requirements are needed:
  1. Construction
  2. Noise and dust protection
  3. Plant safety
  4. Preventive fire protection
  5. Water and soil protection

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Agenda

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- **MANUAL DISMANTLING OF REFRIDGERATORS AND AIR CONDITIONERS**
- PROCESSING AND VALORISATION OF EXTRACTED MATERIALS
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Stage I, II y II for refrigerators

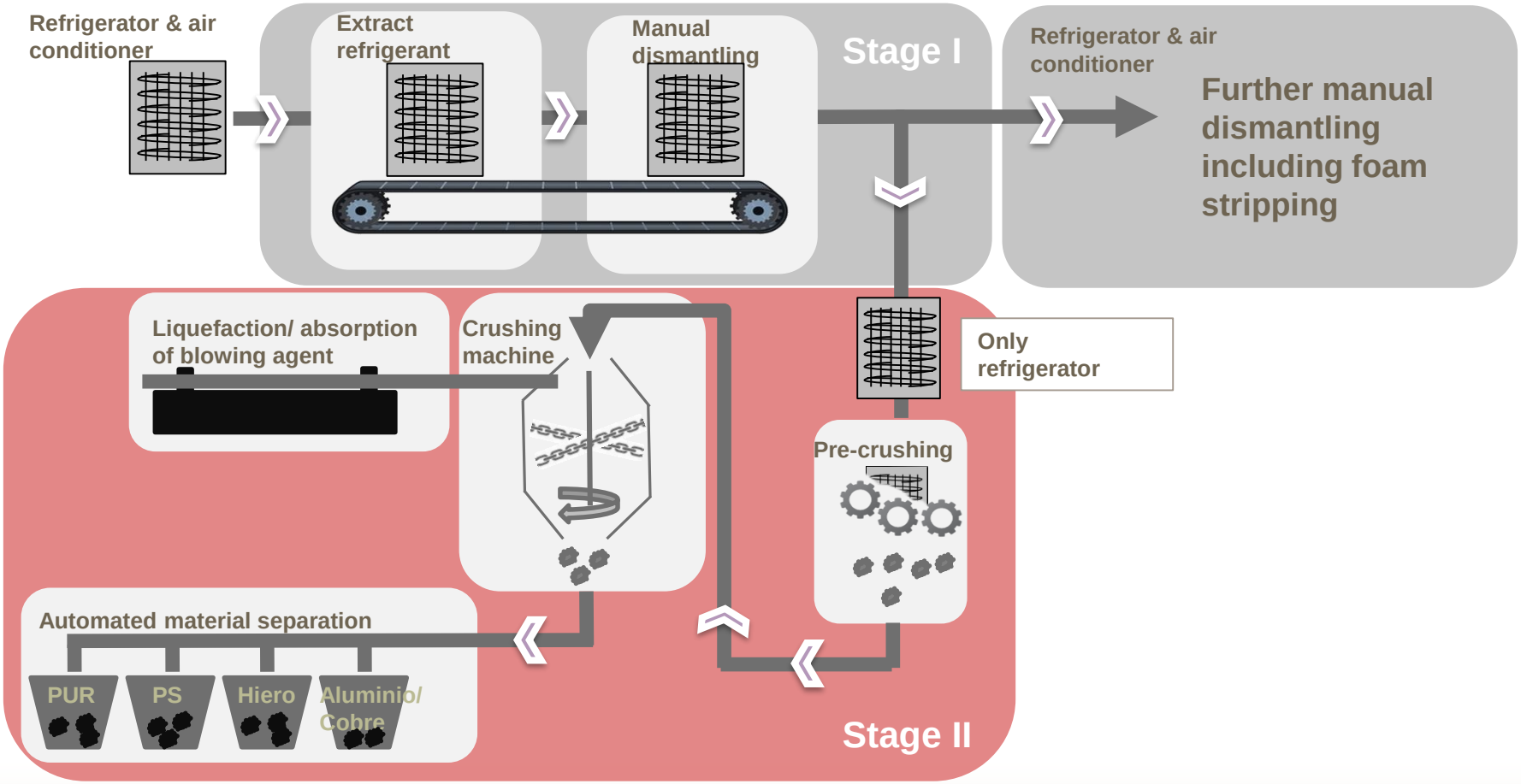
- Stage I:
  - Removal of loose parts
  - Extraction of refrigerant and oil
  - separating oil from refrigerant
  - Removal of hazardous components
  - Removal of the compressor including attached components (and draining the compressor from oil)
  - Removal of condensing unit

→ This presentation and the guideline on manual dismantling focus on stage I

Stage I, II y II for refrigerators

- Stage II:
  - Crushing process in an encapsulated system with the recovery of the blowing agents
  - Recovered blowing agents must be stored in adequate cylinders
  - Stage II systems are relatively expensive with investment costs between EUR 2 and 4 million
- Stage III:
  - Final destruction of ODS that takes place within stage II
  - Destruction of liquefied or gaseous refrigerants and blowing agents by thermal o catalytic treatment

Overview of stage II and stage II processing



Manual dismantling of refrigerators

Removal of all loose parts

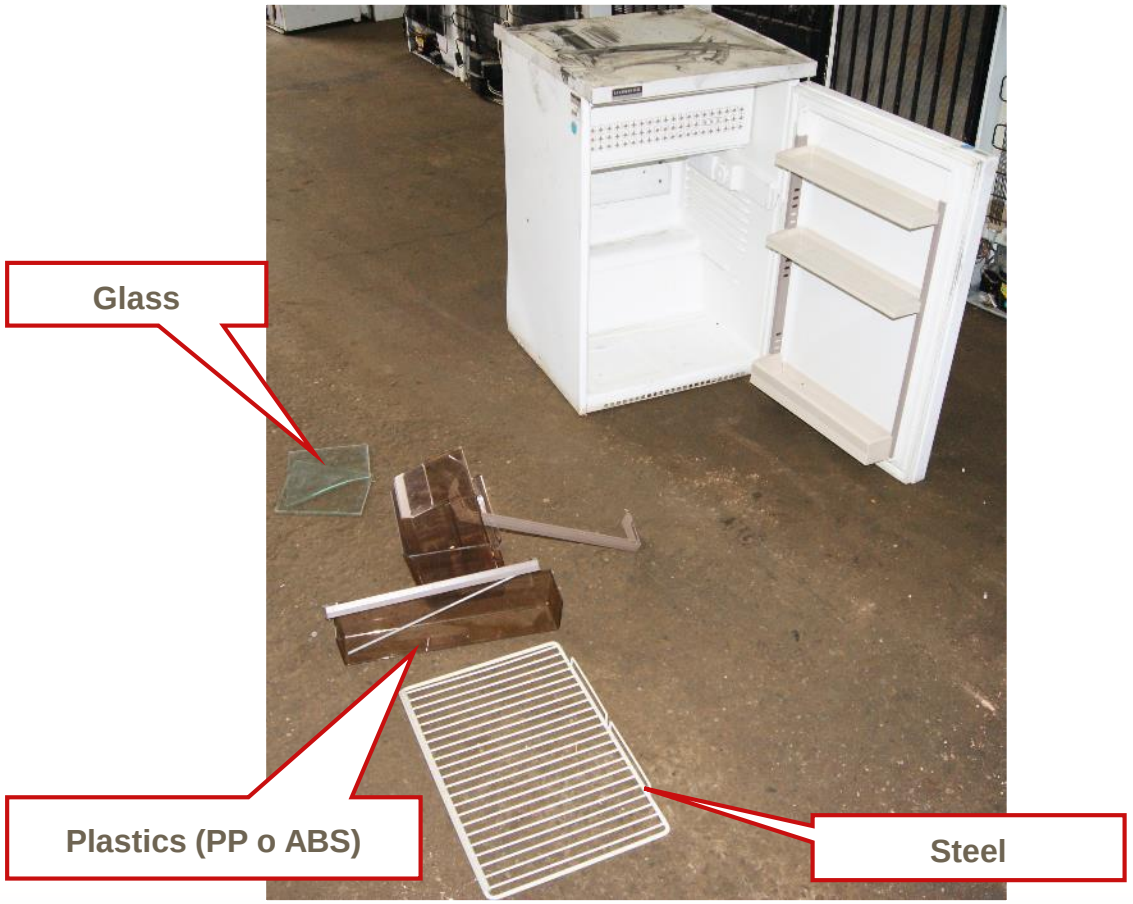
STEP // 01

- The refrigerator is typically delivered with all interior parts

Removal of all loose parts

STEP // 02

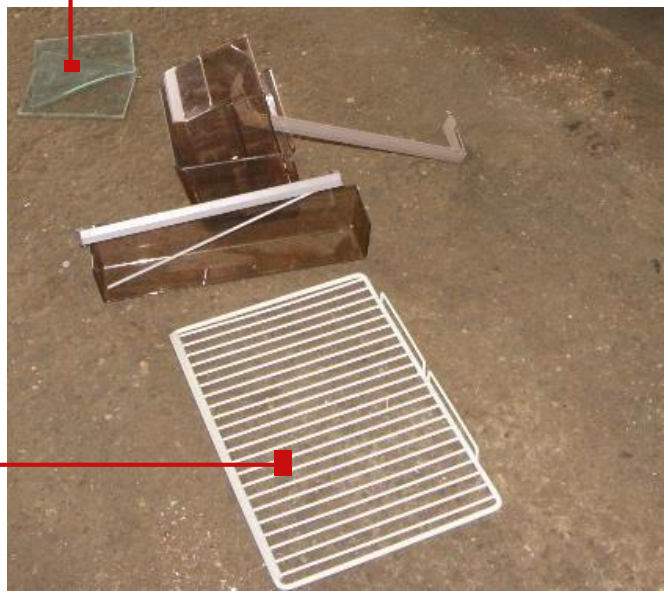
- Remove all loose parts of the fridge:
  - glass
  - plastics
  - steel
- Plastics and Steel are valuable materials



Removal of all loose parts

STEP // 03

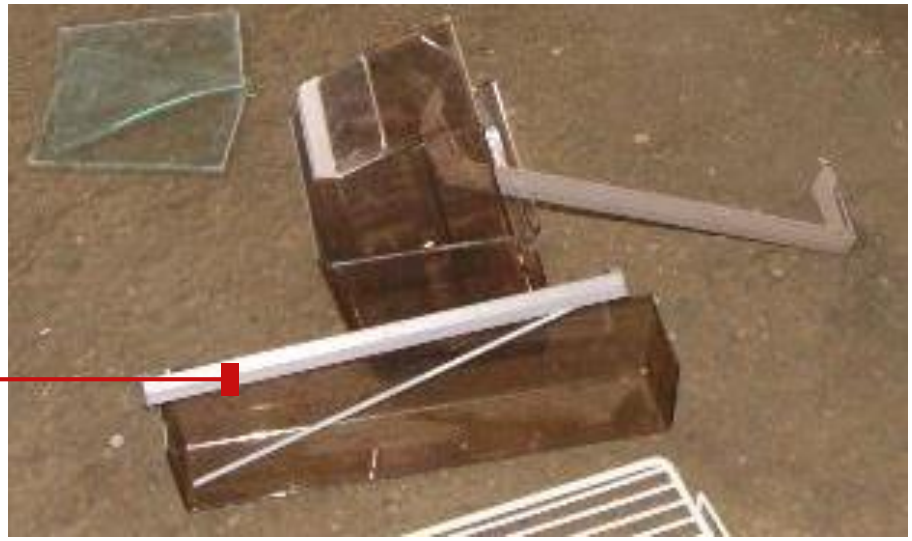
- Store components in separate containers



Removal of all loose parts

STEP // 04

- What to do with the plastics?



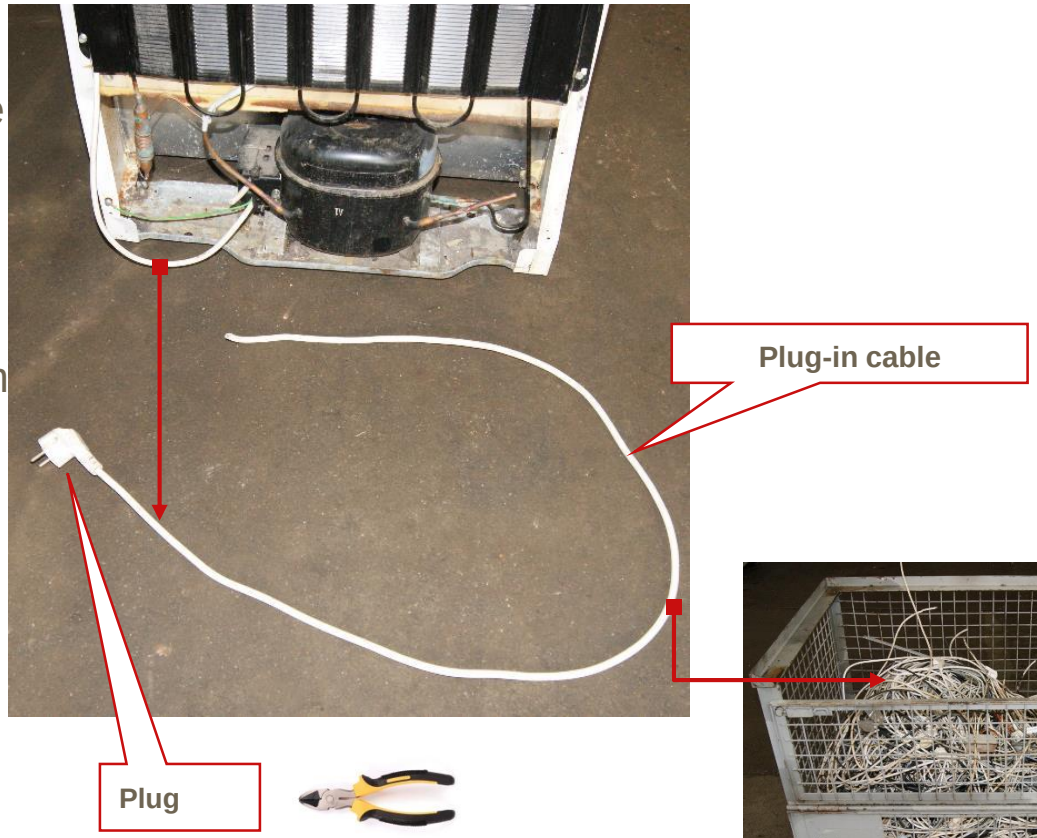
- Symbol on plastic available?
  - Separate plastics according to symbols

- No symbol on plastic available?
  - Store plastic parts as mixed plastics in a container for later separation

Removal of cable

STEP // 05

- Cut the plug-in cable
- Plug-in cables are valuables components
- Cutting the plug from the cable increases the value of the cable



Switches of chest freezers might contain harmful substances!

STEP // 06

- Check the cover plate of the chest freezer fro mercury-containing switches!
- Remove the plastic box at the cap and look for switches

Here, no mercury switch was found.

Switches of chest freezers might contain harmful substances!

STEP // 07

- Store the mercury-containing switches in a separate container.

Here, a mercury switch was found.

Refrigerants are harmful substances! Do not release them into the atmosphere!

Figure A:
Commonly used portable recovery unit for refrigerant extraction.

Figure B:
Mobile recovery unit with integrated oil separator.

Refrigerants are harmful substances! Do not release them into the atmosphere!

Figure C:
Tool to remove oil contaminants and moisture as an attachment for a common recovery unit as shown in figure A.

Figure D:
Cylinder to store the recovered refrigerant.

Refrigerants are harmful substances! Do not release them into the atmosphere!

- Use recovery cylinders with a maximum operating pressure of 400psig → high probability that recovered refrigerants are contaminated (mixed) with other refrigerants

  → The table on the following slide shows the values of different service pressures

- Portable recovery units should generally contain an oil separator → important feature for professional recovery
- For units that are not equipped with an integrated oil separator, a separate tool can be used to remove oil contaminants and moisture
- Depending on the extracted refrigerant type, the refrigerant can be reused after reclamation (e.g. R-134a o R-22) or recovered for final destruction (e.g. R-12)

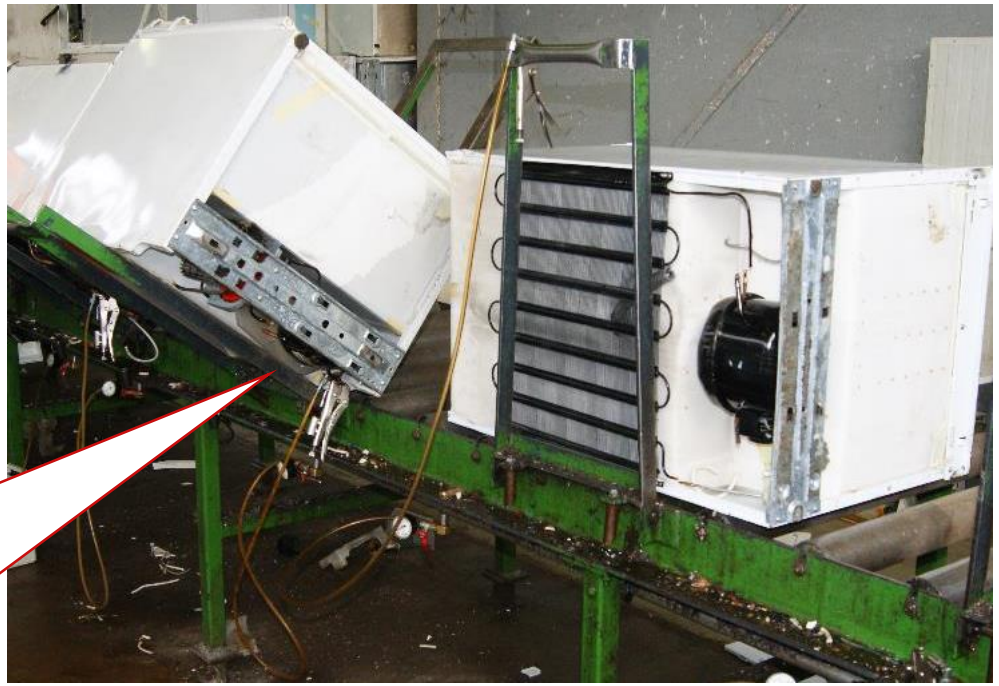
Refrigerant (ASHRAE #)	Class	SG 25 °C (77 °F)	30 or 50 lb. cylinder	125 lb. cylinder	1,000 lb. cylinder
R-22	HCFC	1,2	4BA350	4BA300	4BA260
R-290	HC	0,49	4BA350	4BA300	4BA260
R-438A	HFC	1,15	4BA350	4BA300	4BA260
R-422D	HFC	1,2	4BA350	4BA300	4BA400
R-417A	HFC	1,15	4BA350	4BA300	4BA260
R-422A	HFC	1,14	4BA350	4BA300	4BA400
R-437A	HFC	1,18	4BA350	4BA300	4BA260
R-134a	HFC	1,2	4BA350	4BA300	4BA260

Refrigerant (ASHRAE #)	Class	SG 25 °C (77 °F)	30 or 50 lb. cylinder	125 lb. cylinder	1,000 lb. cylinder
R-401A	HCFC	1,19	4BA350	4BA300	4BA260
R-401B	HCFC	1,19	4BA350	4BA300	4BA260
R-402A	HCFC	1,15	4BA400	4BA400	4BA400
R-402B	HCFC	1,16	4BA400	4BA400	4BA400
R-404 o R-507	HFC	1,05	4BA350	4BA300	4BA400
R-407A o R-407C	HFC	1,15	4BA350	4BA300	4BA400
R-408A	HCFC	1,06	4BA350	4BA300	4BA400
R-409A	HCFC	1,22	4BA350	4BA300	4BA260
R-410A	HFC	1,06	4BA400	4BA400	4BA400

Refrigerants are harmful substances! Do not release into the atmosphere!

STEP // 08

- Extract the refrigerant and the oil at the lowest point using piercing pliers



Piercing pliers

Refrigerants are harmful substances! Do not release into the atmosphere!

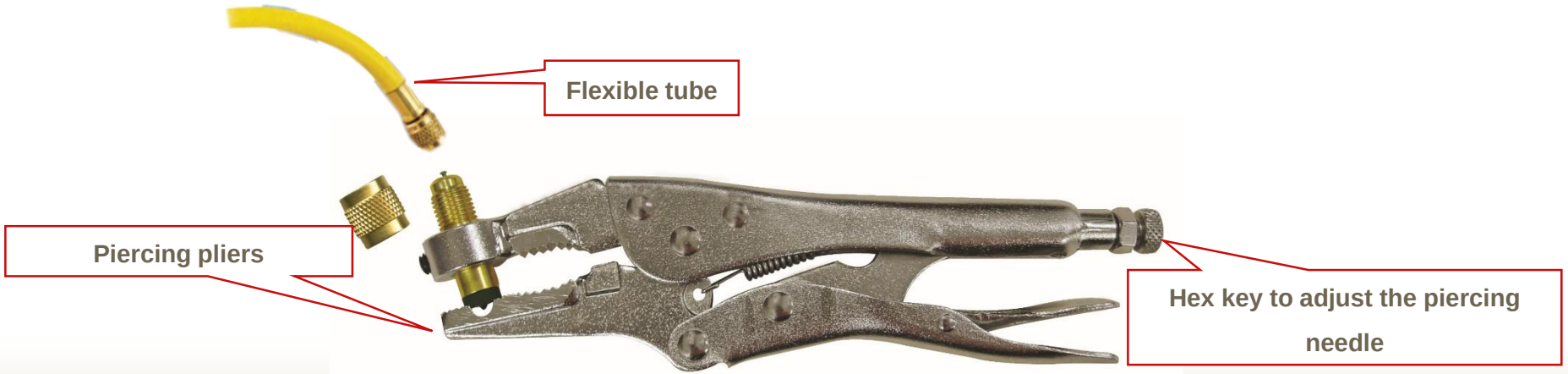
Further information on the piercing pliers

- Piercing pliers are special pliers to extract the refrigerant
- Piercing pliers have a hollow needle and must be places on the refrigerant copper pipe of the refrigeration circuit
- The needle will pierce the copper pipe

Refrigerants are harmful substances! Do not release into the atmosphere!

Further information on the piercing pliers

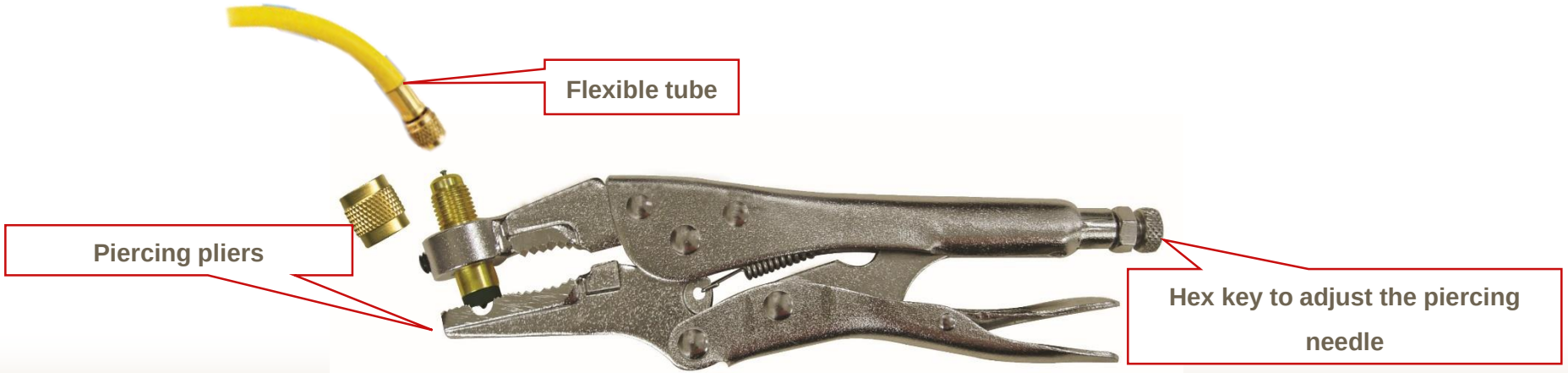
- The refrigerator / air conditioner must be tilted by a certain angle, so that the piercing pliers can be placed at the lowest point of the refrigeration circuit next to the compressor
- A hex key allows the adjustment of a screw which influences the penetration depth of the needle



Refrigerants are harmful substances! Do not release into the atmosphere!

Further information on the piercing pliers

- The pliers have ‘locking function’ that keeps the pliers fixed to the refrigerant copper pipe
- Piercing pliers have to be connected to an industrial extraction system with a heated oil separator or a mobile recovery unit
- Alternatives to piercing pliers are e.g. drill-heads



Separating refrigerant from oil (stationary recovery)

STEP // 09

- Separate refrigerant from oil by using a special heated oil separator

Heated oil separator heats up the refrigerant-oil mix for separation

Separating refrigerant form oil

- The refrigerant-oil mix is heated to at least 100 °C
- Temperature and time of degassing are interdependent, i.e. the higher the temperature, the shorter the degassing process
- It is recommended to do the process overnight, to ensure that all halogenated components evaporate from the oil
- After this process, the CFC/HFC content of the **waste oil should not be more** than 2 g halogenated hydrocarbons/ kg

<2g

- Waste oil recycling to create new oil products (preferred option)
- Oil con be used for co-firing energy plants (thermal utilization)

>2g

- Incinerate for final destruction

Separating refrigerant from oil

STEP // 10

- Weight the amount of refrigerants extracted in a pressure vessel

Separating refrigerant form oil

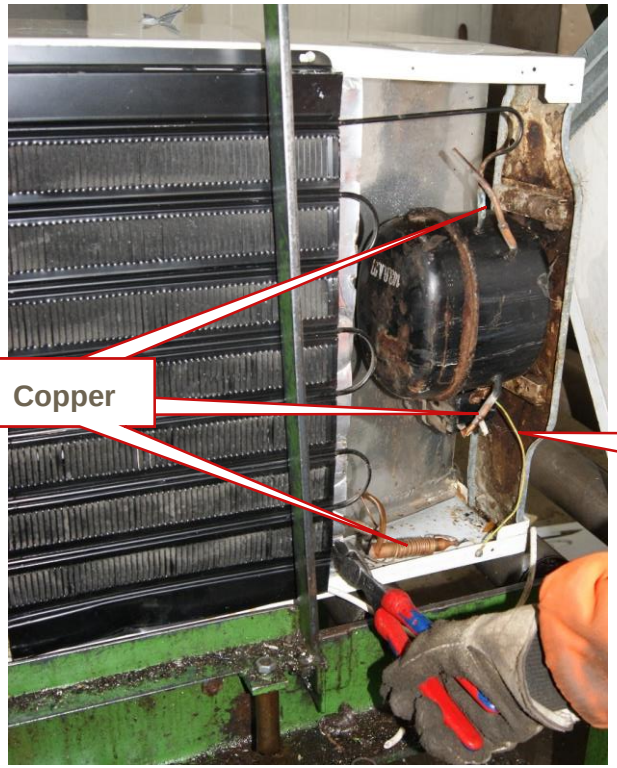
STEP // 11

- Store the oil in extra containers (e.g.: ASF containers)
- Containers should be double-walled with an additional collection tray

Cutting visible parts

STEP // 12

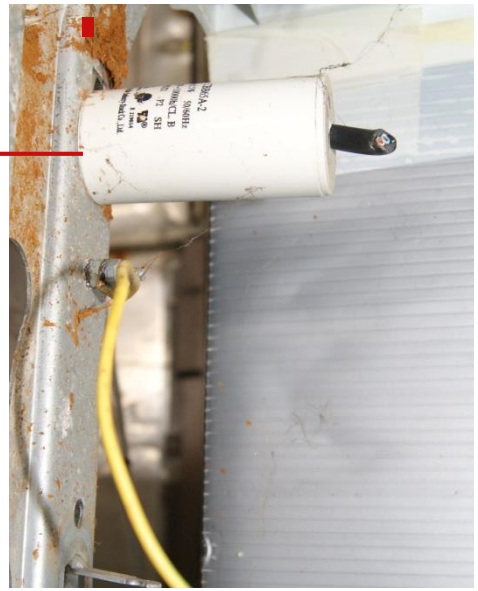
- Cut all visible protruding parts and store them separately
  - Filter dryer and copper piping
  - Cables
- Copper and cables are valuable components



Capacitors might contain harmful substances!

STEP // 13

- Remove the capacitor from the refrigerator
- Attention: the capacitor might contain PCB or other electrolytes of concern
- Store the capacitor in a separate container



Removing the compressor

STEP // 14

- Unscrew the compressor manually with a spanner
- The compressor is a valuable component 

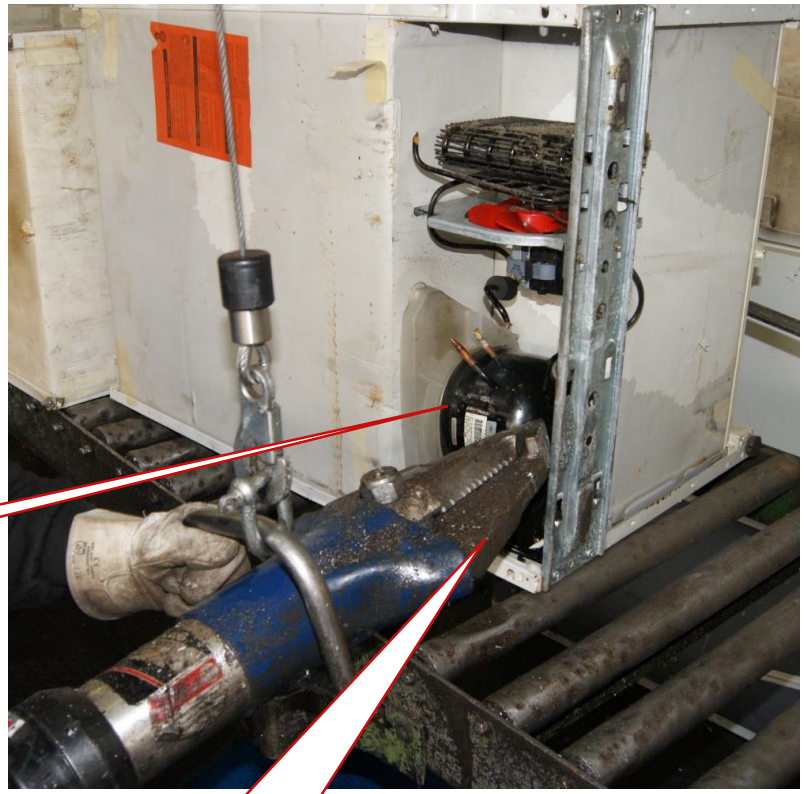
Compressor

Spanner

Removing the compressor

STEP // 15

- Alternatively, use hydraulic shears to remove the compressor



Removing the compressor

STEP // 16

- Remove the compressor from the refrigerator

Removing the compressor

STEP // 17

- Use a drill to bore a hole into the bottom of the compressor housing

Removing the compressor

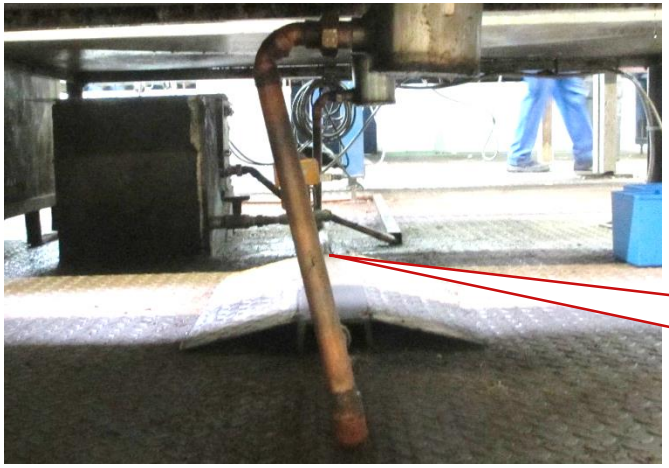
STEP // 18

- Put the compressor upside down on an iron grating (hole pointing down) so that the remaining oil in the compressor drips down
- Below the iron grating, there must be a bottom tray to capture the dripping oil
- Compressors should only be removed from the iron grating once they have stopped dripping
- Oil binders for absorbing should be available in case of spillage

Removing the compressor

STEP // 19

- Put a suitable container below the bottom tray to collect the dripping oil
- Ideally, the dripping oil is directly transferred to the heated oil separator



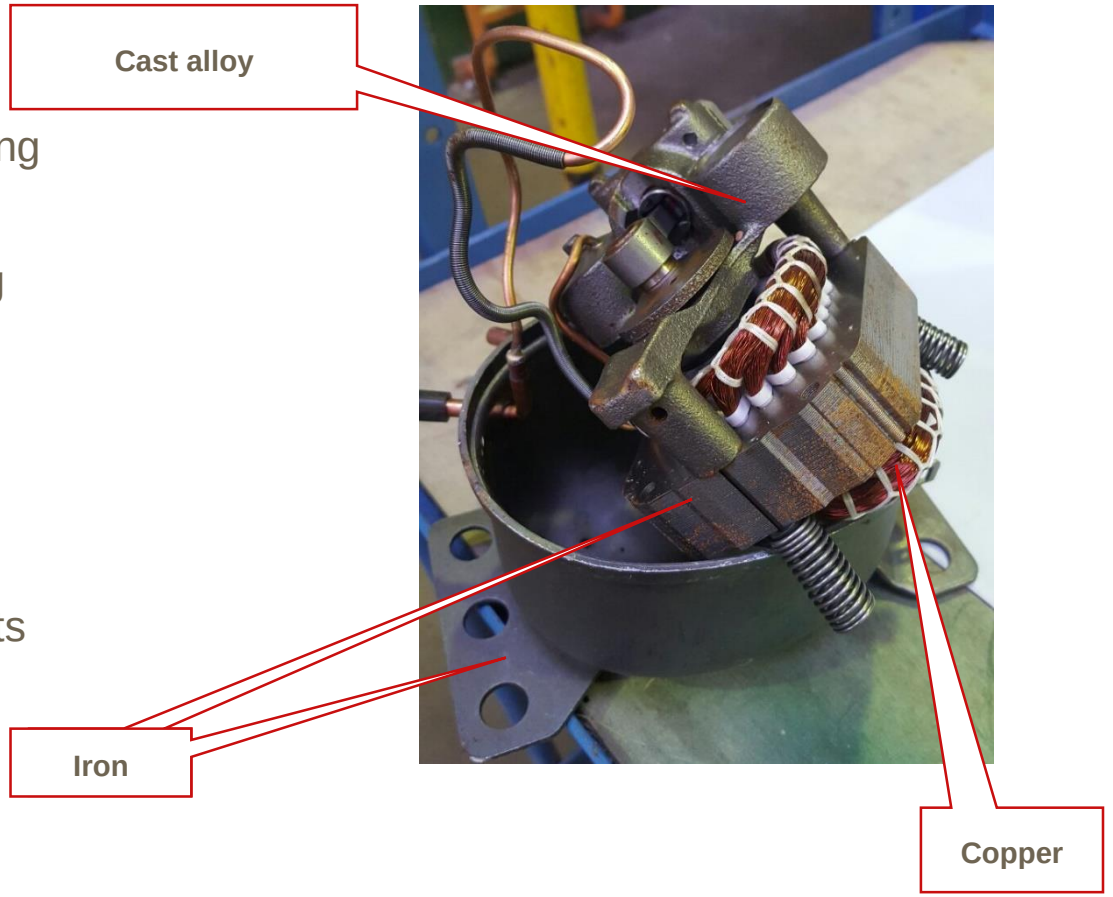
Container for dripping oil

Direct connection with degassing system

Optional: further dismantling of compressor

STEP // 20

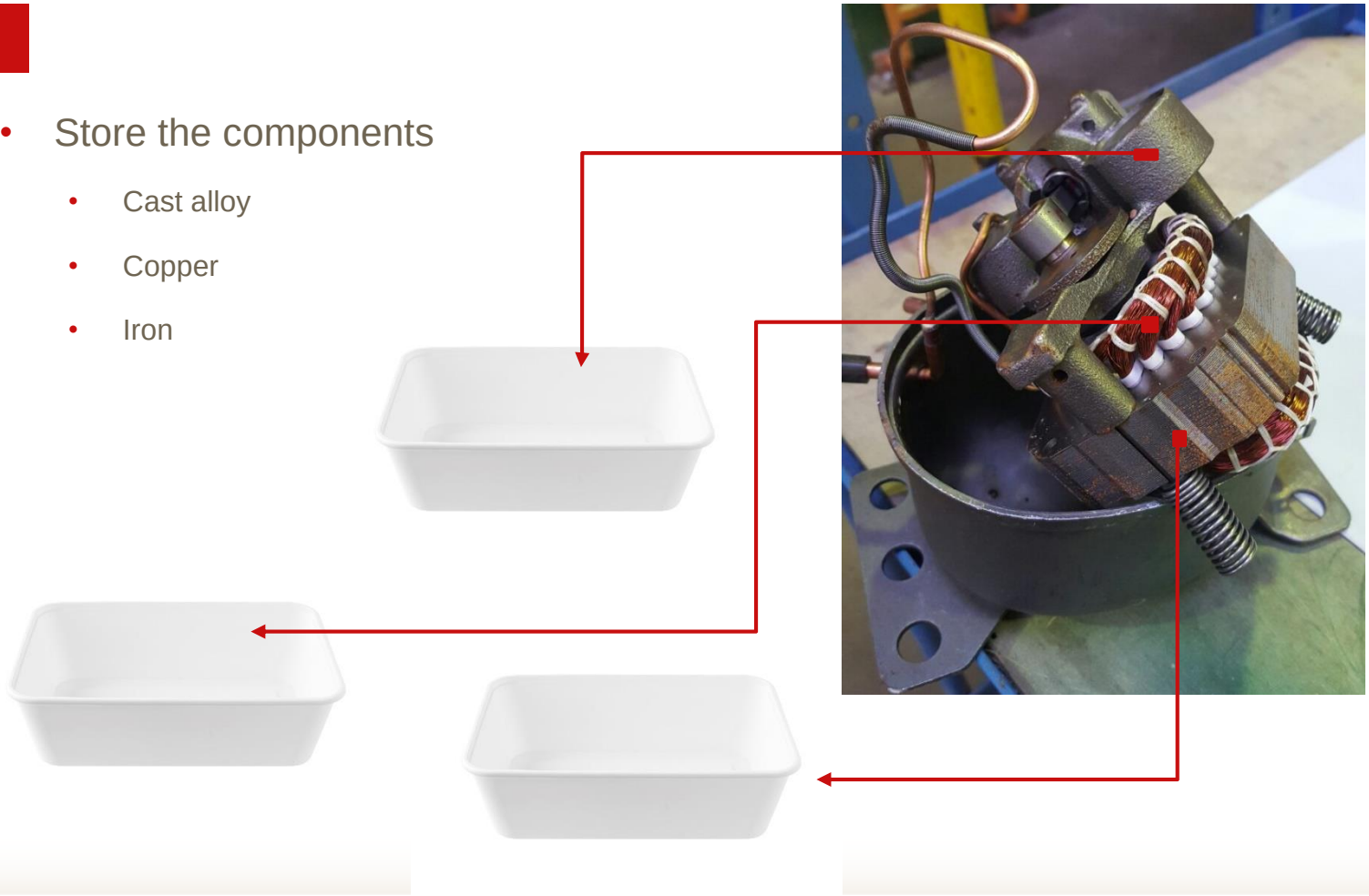
- Cut the compressor using an angle grinder
- Separate the containing components:
  - Cast alloy
  - Copper
  - Iron
- These three components are valuable



Optional: further dismantling of compressor

STEP // 21

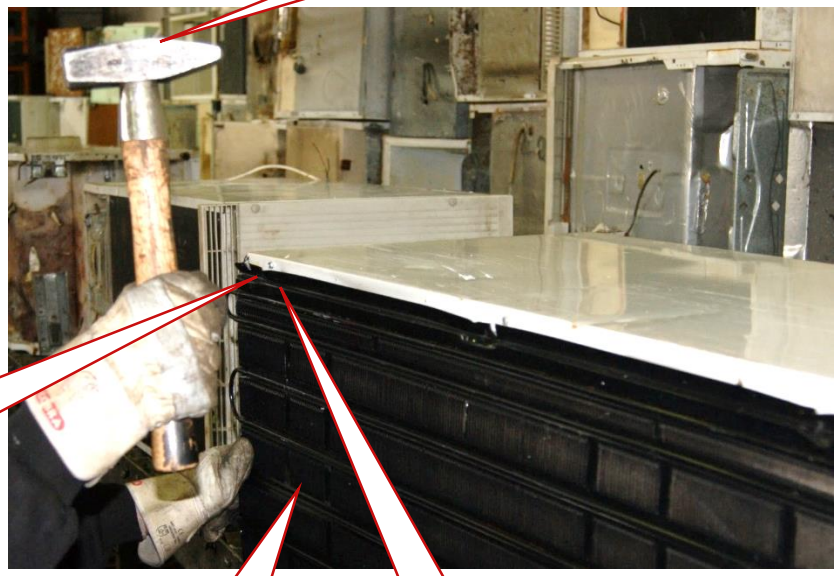
- Store the components
  - Cast alloy
  - Copper
  - Iron



Removing the condensing unit

STEP // 22

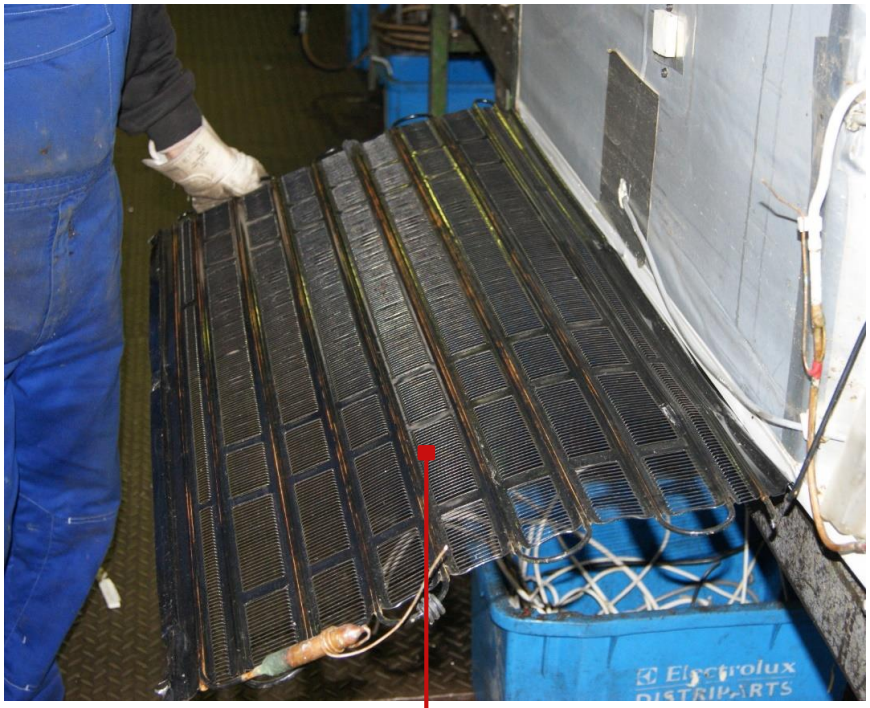
- Remove the condensing unit
- Knock off the mounting brackets with a simple hammer
- The condensing unit as a valuable component

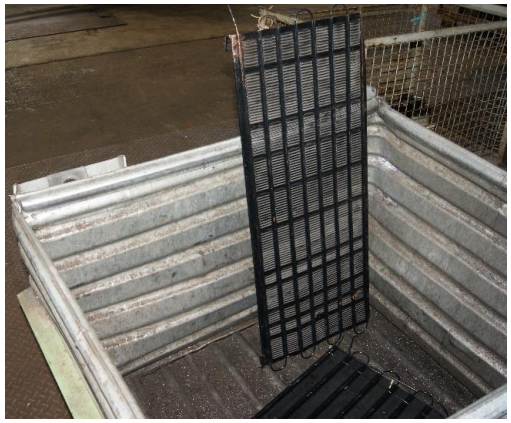


Removing the condensing unit

STEP // 23

- Remove the condensing unit
- Store the condensing unit in a separate container





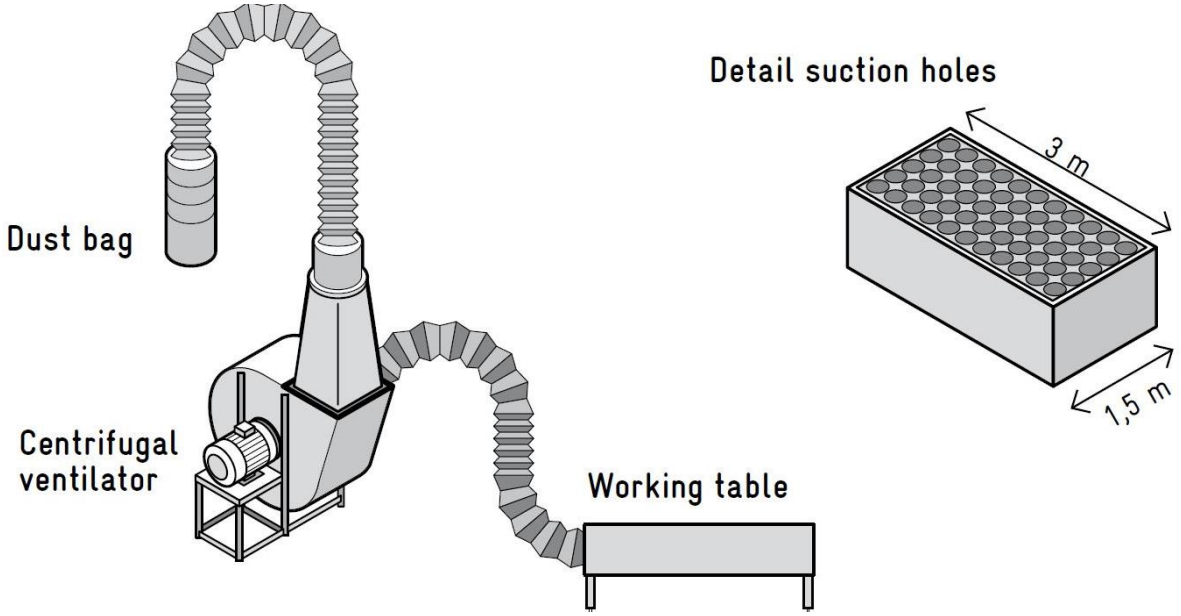
Further information on manual dismantling of foam

If stage II are not available and refrigerators cannot be burnt as entire units in high temperature incinerators, **manual foam stripping** can be considered:

- Remove foam in as large pieces as possible to reduce the release of blowing agents
- Procedure should not take place under hot temperatures, as this greatly increases the release of blowing agents
- Use dust mask and mobile or stationary dust collection systems to avoid small particles from entering the lungs
  - Important that filter can effectively capture particles of at least 5 micron
  - Investment cost ~180€

Further information on manual dismantling of foam

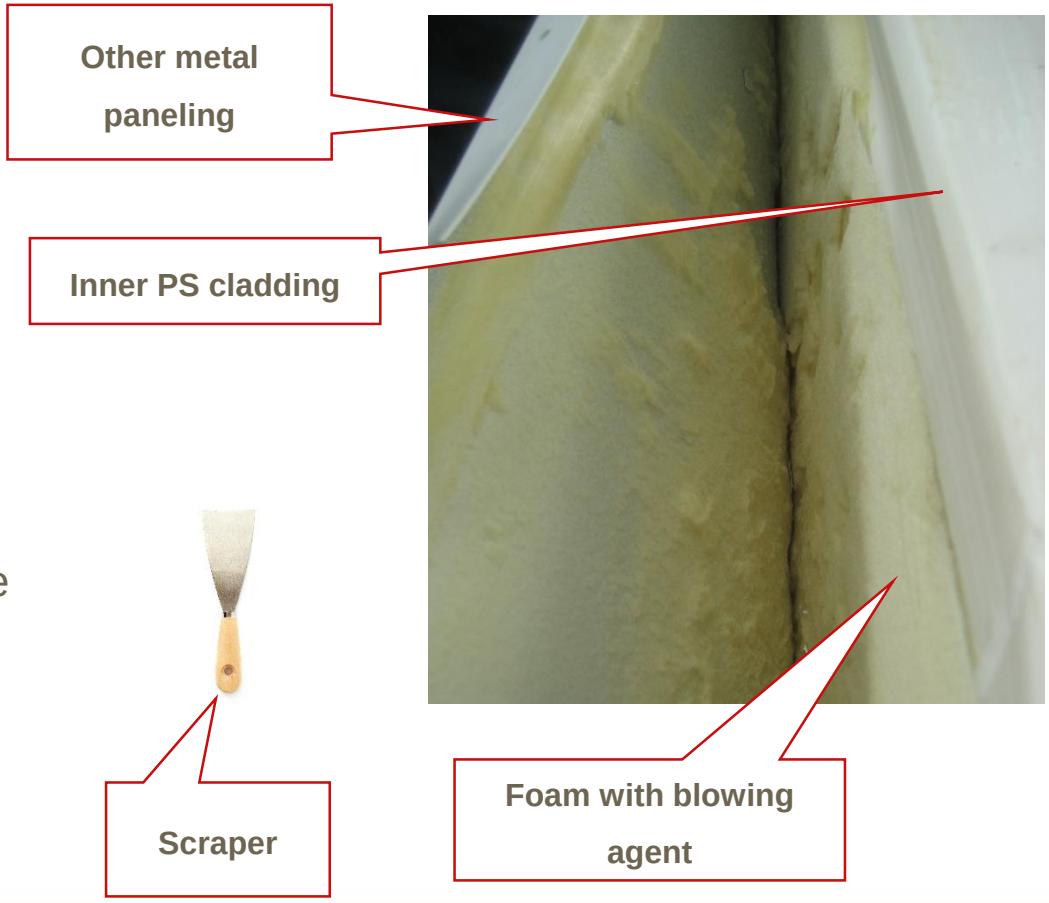
Mobile dust collection system to prevent small particles from entering the lungs



Removal of foam: foam might contain harmful substances!

STEP // 24

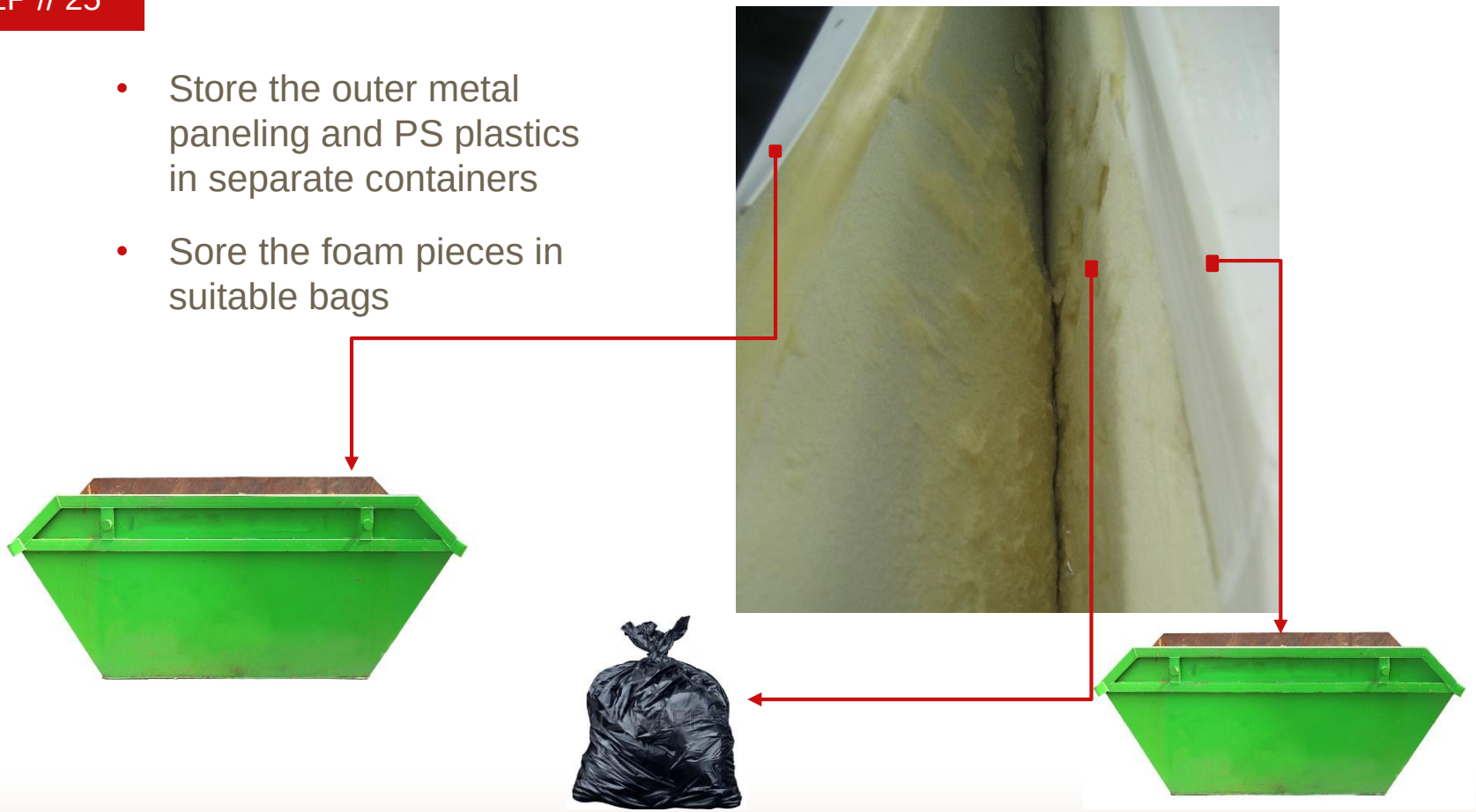
- Remove the outer metal paneling from the side walls. The seals have to be removed upfront
- Remove the foam with a scraper, even small adhesions should be carefully scrapped off
- Remove foam in as large pieces as possible



Removal of foam: foam might contain harmful substances!

STEP // 25

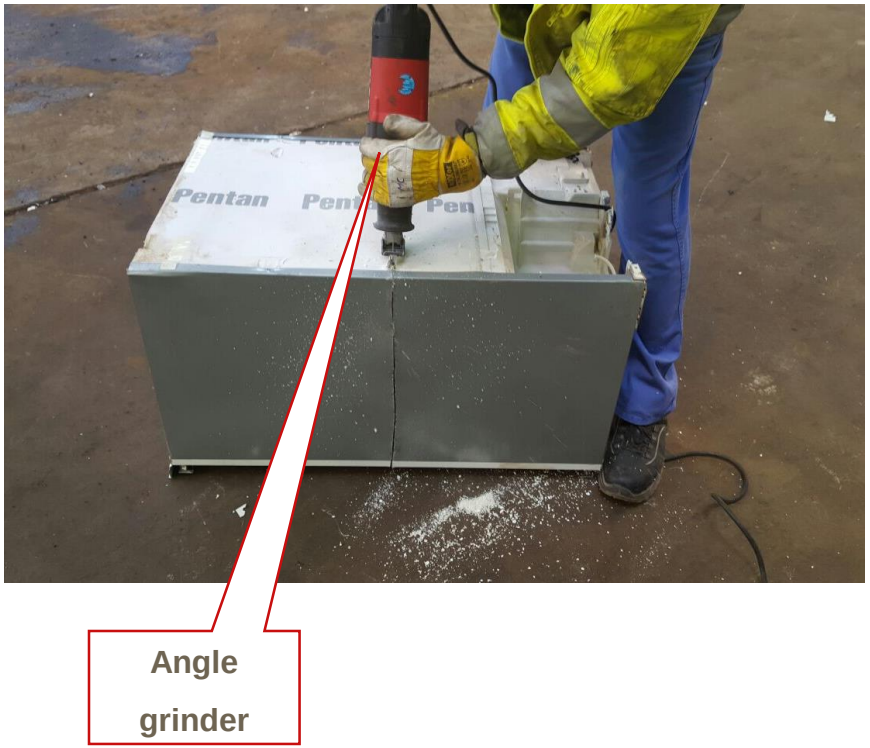
- Store the outer metal paneling and PS plastics in separate containers
- Sore the foam pieces in suitable bags



Removal of foam: foam might contain harmful substances!

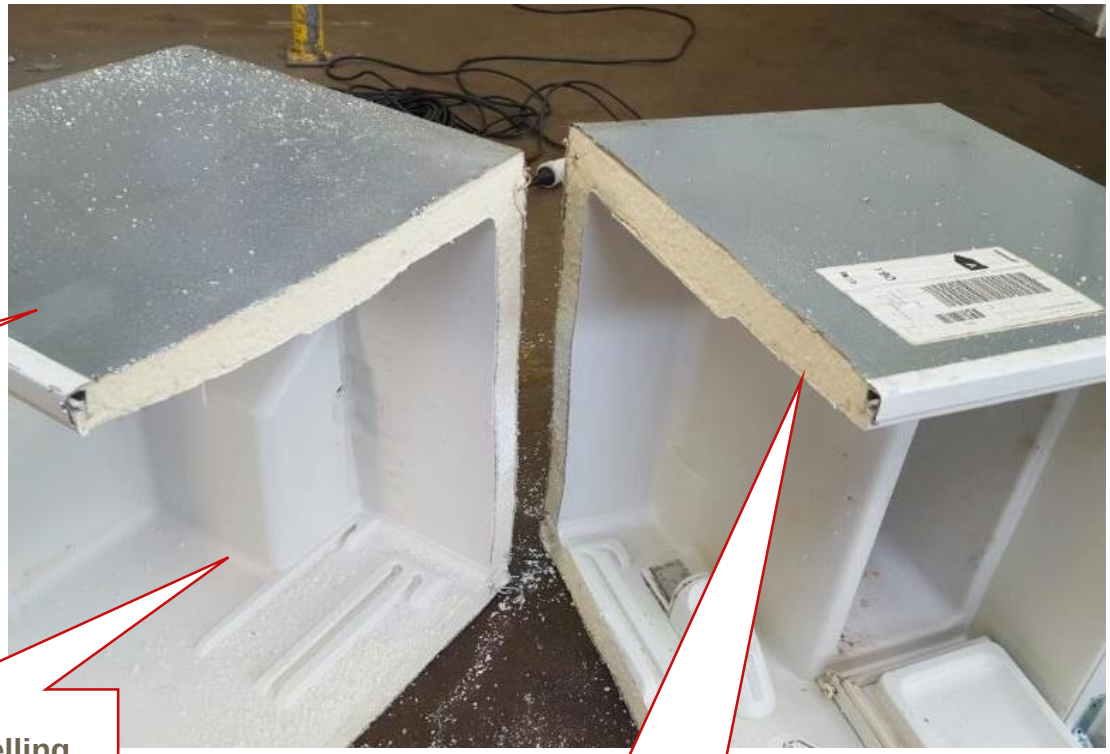
STEP // 26

- If refrigerator are to be cut into smaller pieces, use an angle grinder
- Try to minimize the number of cuts to avoid the release of blowing agents



Removal of foam: foam might contain harmful substances!

STEP // 27



Outer metal paneling

Inner plastic panelling

Foam containing harmful substances

Removal of foam: foam might contain harmful substances!

STEP // 28

- When a refrigerator has been cut into smaller pieces:
  - Remove the Steel enclosure from cut pieces
  - Remove the interior plastic cladding (mostly PS)
  - Store the components in separate containers o plastic bags

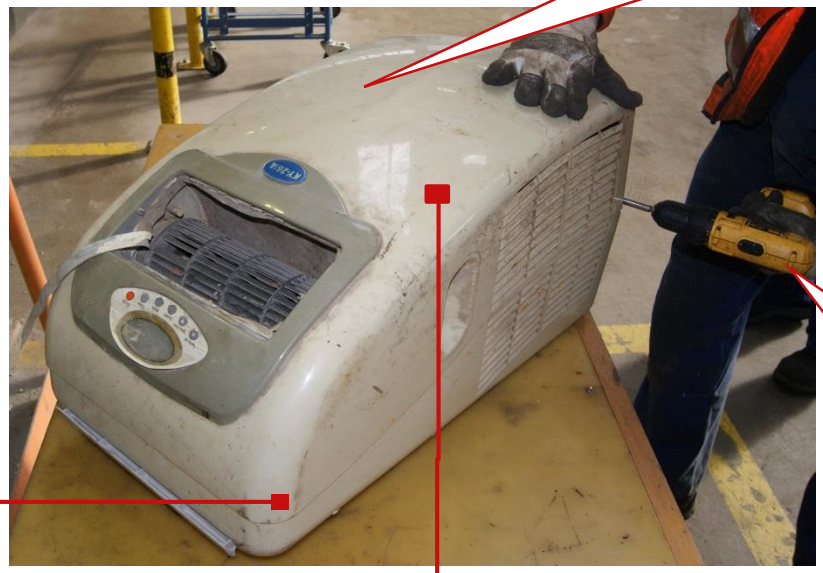
Manual dismantling of air conditioners

Removing outer plastic paneling

STEP // 01

What to do with the plastics?

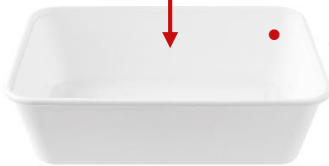
- Remove the outer plastic paneling using a power screwdriver
- Plastics are valuable components



Symbol on plastic available?

- Separate plastics according to symbols

- No symbol on plastic available?
- Store plastic parts as mixed plastics in a container for later separation

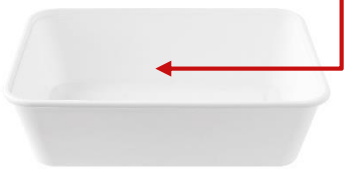


Removing outer plastic paneling

STEP // 02

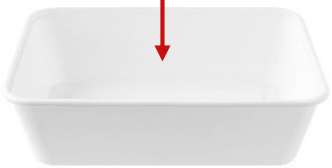
What to do with the plastics?

- Remove the outer plastic paneling



Symbol on plastic available?

- Separate plastics according to symbols

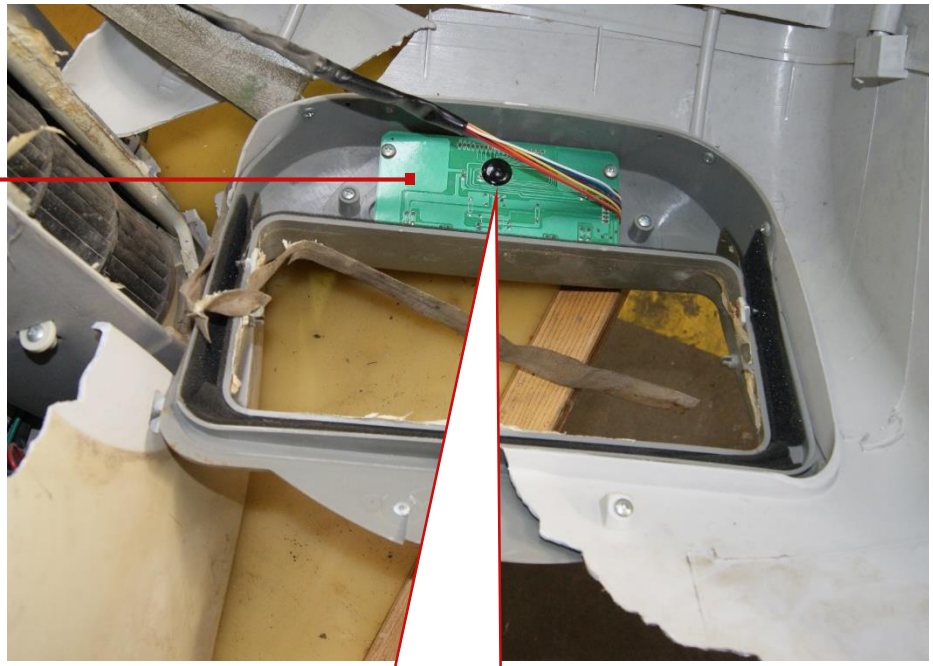


- No symbol on plastic available?
  - Store plastic parts as mixed plastic in a container for later separation

Circuit boards might contain harmful substances!

STEP // 03

- Remove the circuit boards
- Attention: they might contain harmful substances!
- Store the circuit boards in a separate box



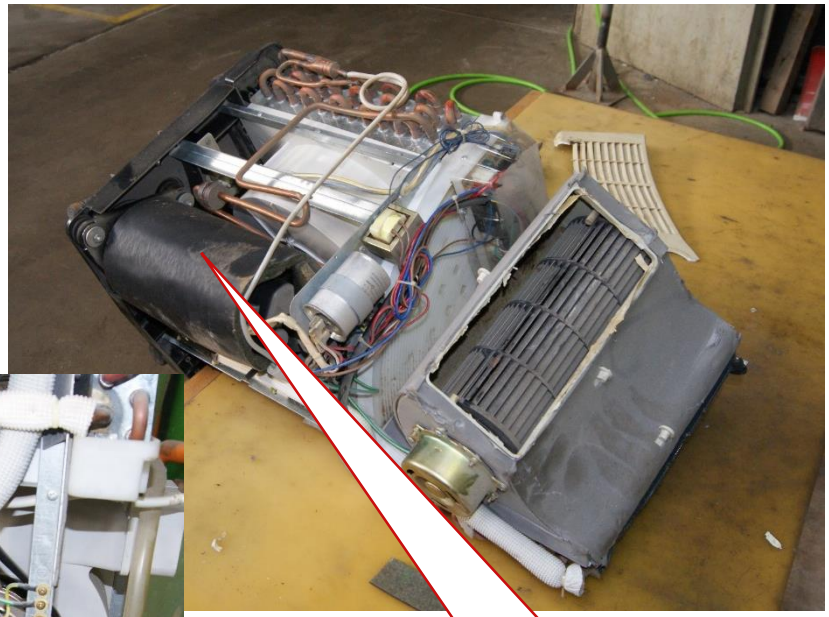
Circuit board attached to plastic paneling

Removing the compressor protection

STEP // 04

- Remove the vibration protection from the compressor
- Put the vibration protection to mixed plastics

Compressor without vibration protection

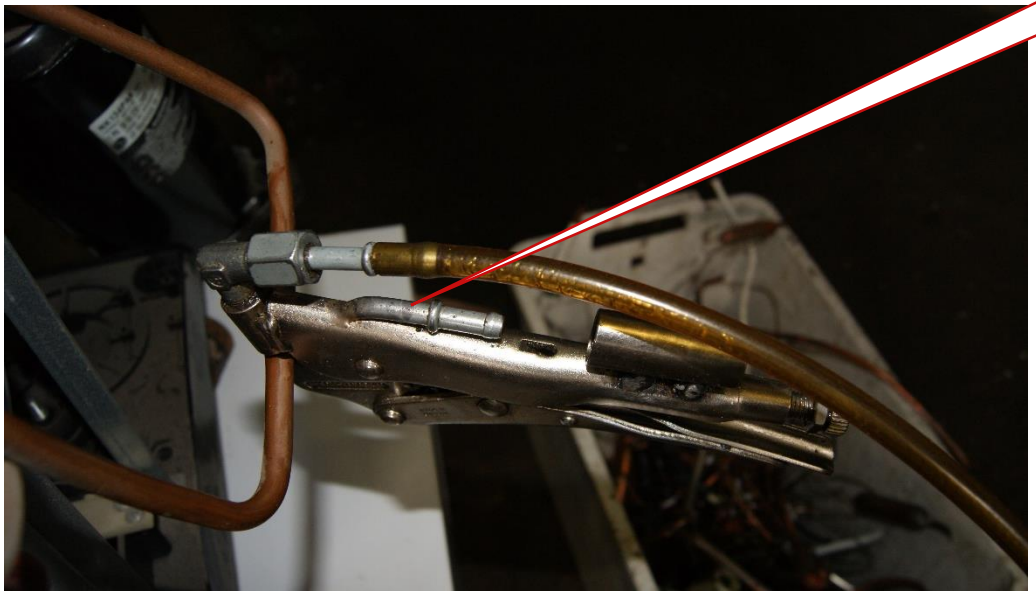


Vibration protection

Refrigerants are harmful substances! Do not release into the atmosphere!

STEP // 05

- Extract the refrigerant and the oil at the lowest point



Remove the compressor

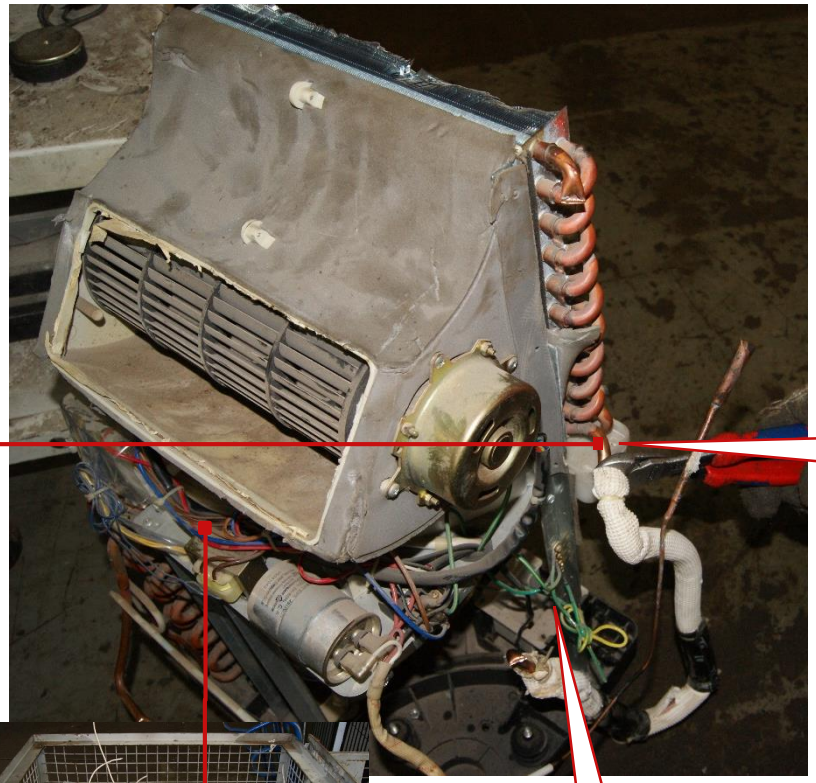
STEP // 06

- Remove the compressor using power screwdriver
- The compressor is a valuable component
- Process the compressor the same way as it was done for refrigerators

Removing visible parts

STEP // 07

- Cut all the visible protruding parts:
  - Filter dryer and copper piping
  - Cables
- Store the components in separate boxes



Removing the heat exchanger

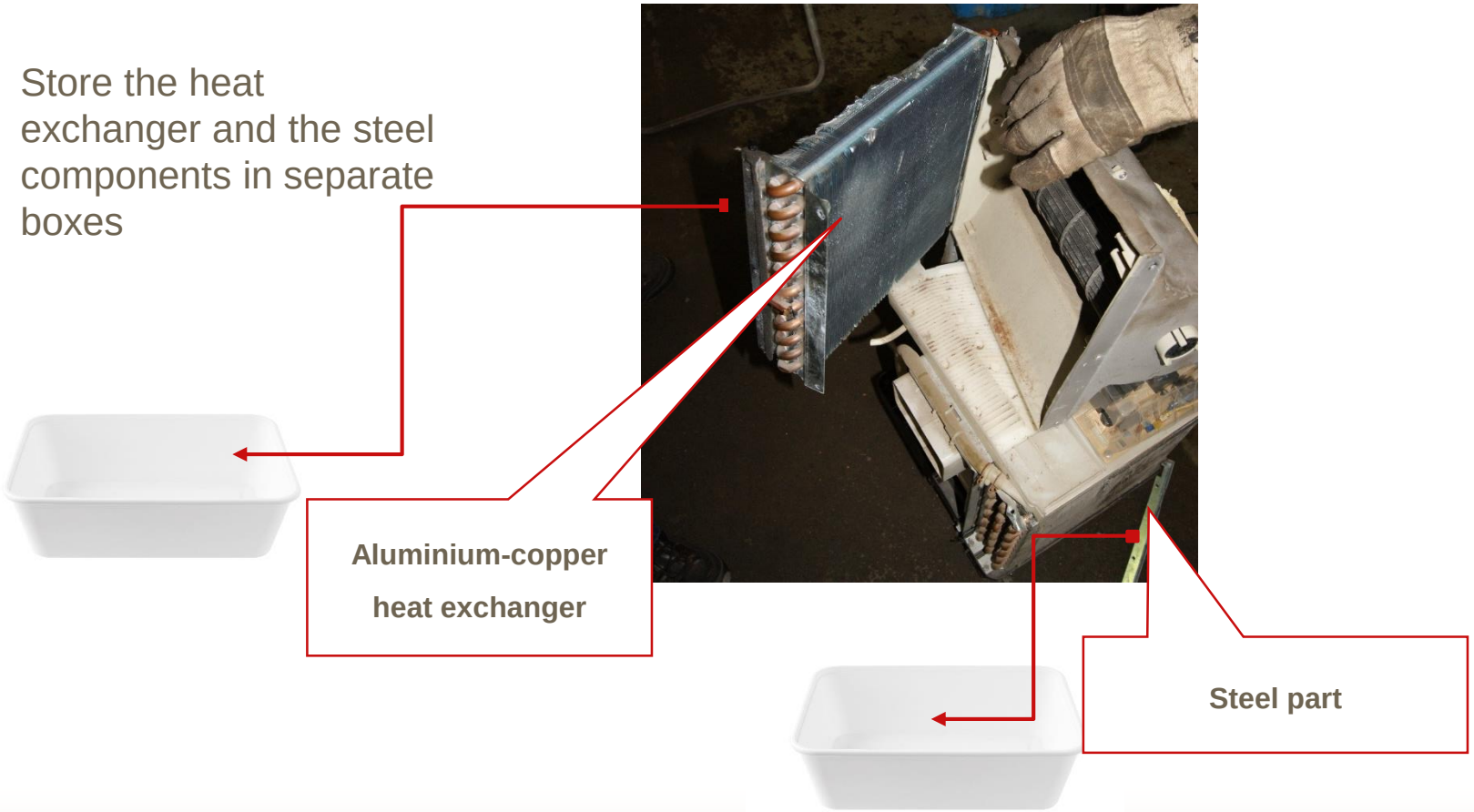
STEP // 08

- Remove the aluminium-copper heat exchanger
- The aluminium-copper heat exchanger is a valuable component

Removing heat exchanger

STEP // 09

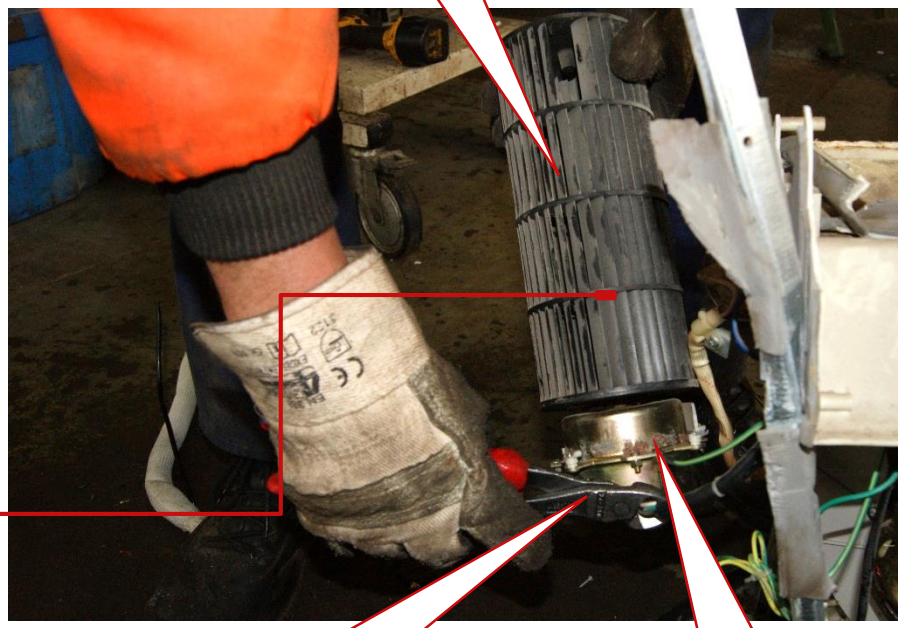
- Store the heat exchanger and the steel components in separate boxes



Removing heat exchanger

STEP // 10

- Remove the fan and the e-motor using pliers
- The e-motor is a valuable component
- Store the e-motor and fan in a separate box



Circuit boards might contain harmful substances!

STEP // 11

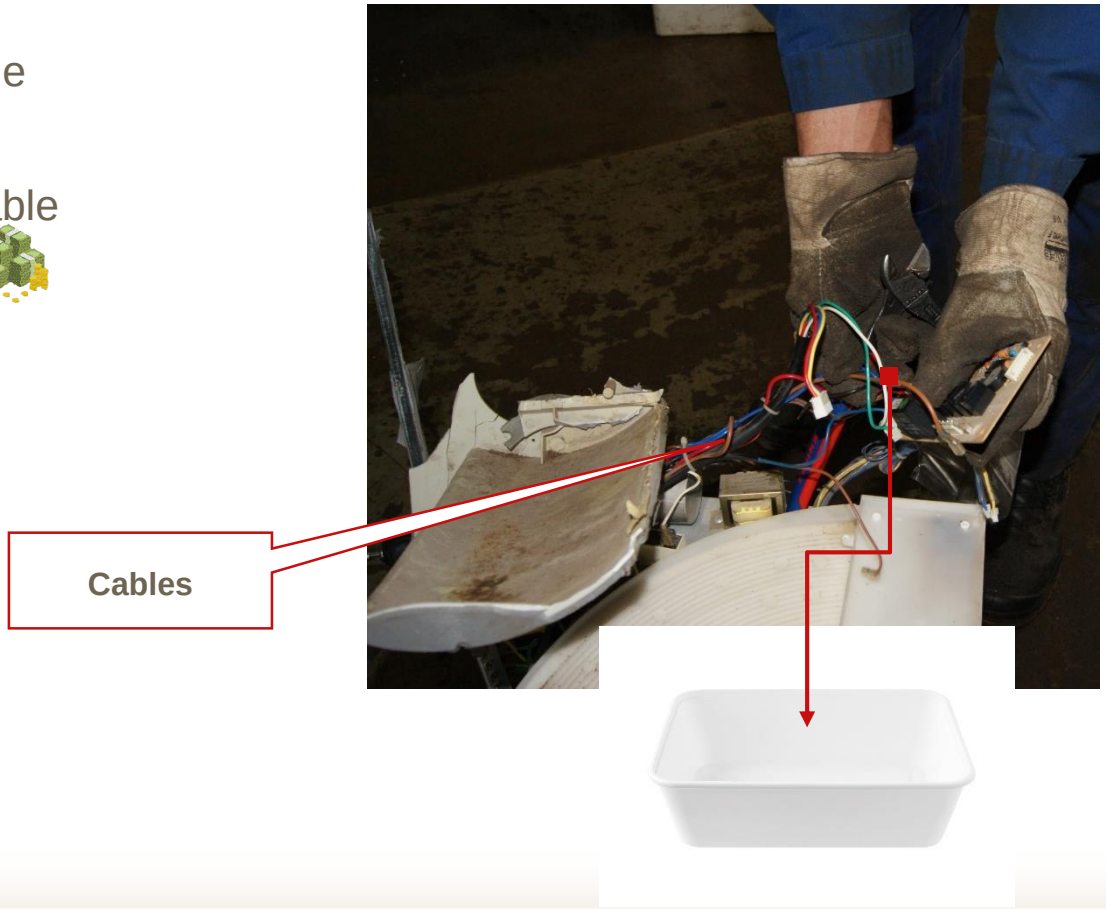
- Remove other visible circuit boards
- Attention: circuit boards might contain harmful substances!
- Store the circuit boards in a separate box

Circuit board

Removing cables

STEP // 12

- Remove all visible cables
- Cables are valuable components
- Store cables in a separate box



Capacitors might contain harmful substances!

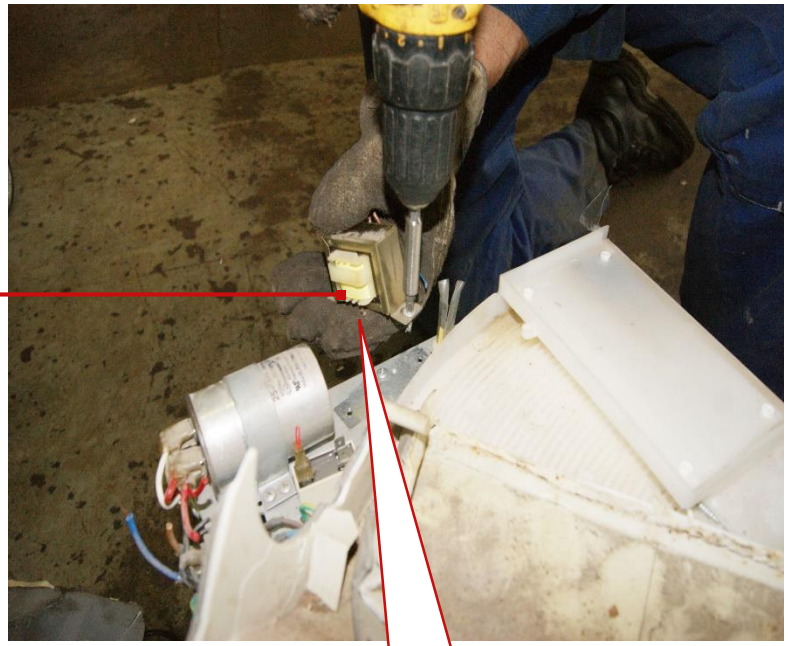
STEP // 13

- Remove the capacitor
- Attention: capacitors might contain harmful substances
- Store the capacitor in a separate box

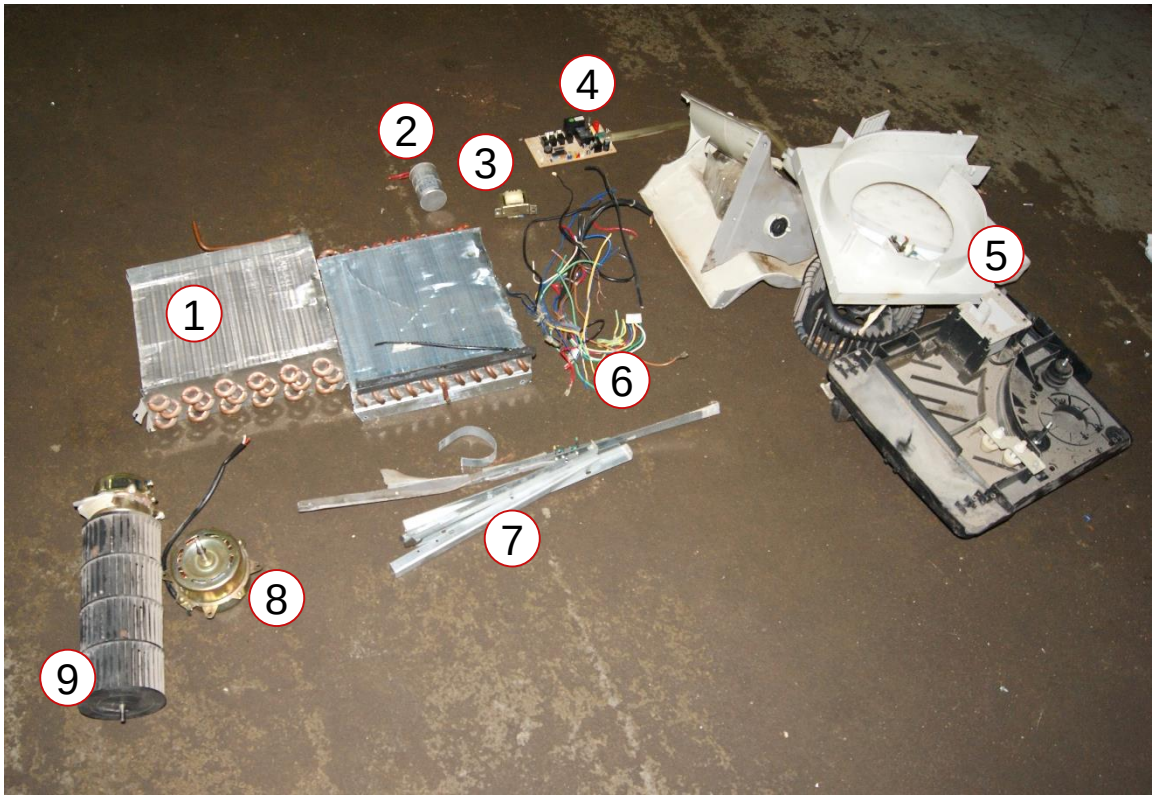
Remove transformer

STEP // 14

- Remove the transformer
- Store the transformer in a separate box
- Transformers are valuable components



Extracted components from a self-contained air conditioning unit



1. Aluminium-copper heat exchanger
2. Capacitor
3. Transformer
4. Circuit board
5. Plastics
6. Cables
7. Steel
8. E-motor
9. Fan with e-motor

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- EQUIPMENT, TOOLS AND JOB SAFETY
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- CHECKLIST AND OUTLOOK

Further processing and separation of extracted components

- Greatest advantage of manual dismantling: high degree to which plastics and materials can be separated → higher selling price 
- Distinguishing metals and plastics

steel
aluminium
Copper
polystyrene (PS)
polypropylene (PP)
Acrylonitrile butadiene styrene (ABS)

- Metals are easier to distinguish than plastics
- Use special detectors for identification of plastics
  - X-Ray fluorescence
  - Near infrared reflectance spectroscopy (NIR) or sliding spark spectrometer (SSS)

Final disposal

The following extracted components are subject to final disposal:

- Capacitors
- Ammonia solutions containing chromium-VI (used as refrigerant)
- CFCs and other critical refrigerants and blowing agents

The following table provides an overview of the different recycling options for materials that are recovered during manual dismantling of refrigerators and air conditioners:

Components	Recycling Options
Aluminium sheets	Smelting
Iron	Smelting
PS granulate	Mechanical recycling
Glass	Smelting
Compressor	Smelting after separation of components
Aluminium-copper heat exchanger	Crushing, separation and smelting
E-motors	Crushing, separation and smelting
Cables without plug	Separation in cable recycling plant
Cables with plug	Separation in cable recycling plant

Components	Recycling option
Aluminium cast	Smelting
Stainless steel	Smelting
Capacitor	Final disposal or first separation and then smelting
Hg switches	Recovery of mercury in special plants (rest: glass)
Plastics	Mechanical recycling, feedstock recycling, energy recovery
Refrigerant	Final disposal
Ammonia	Final disposal
PUR	• Final disposal when PUR contains harmful blowing agent • Degassed PUR to be used as oil binding material • Crushed degassed PUR to be used in cement kilns (co-firing)

The value of extracted components

- The following table shows a qualitative assessment of the net material value of extracted components on the recycling market (European market)
- No absolute values are shown as the prices are subject to high temporal changes and differ depending on the region, demand and oil price
- The colors indicate:
  - red = negative cost (WEEE managers have to pay for further processing)
  - yellow = net values up to 300 € per ton
  - green = net values up to 1,500 € per ton

Components	Air Conditioner	Refrigerator
Aluminium sheets		Paneling of the freezing compartment
Iron	Little pieces for cover panels	Condensing unit, outer panelling
PS granulate	Not available without crushing technique	Not available without crushing technique
Glass		Shelves
Compressor	X	X
Aluminium-copper heat exchanger	X	
Electro motors	X	
Cables without plug	X	X

Components	Air Conditioner	Refrigerator
Cables with plug	X	X
Aluminium cast	Part of compressor	Part of compressor
Stainless Steel		Little parts in comercial refrigerators
Capacitor	X	X
Transformer	X	
Refrigerant	X	X
Mixed plastics	X	X

Cost balancing for a domestic refrigerator – Example from Germany

Component	Weight (kg)	Revenue/ kg	Net material value
Iron fraction	19.8	0.13	2.57
Compressor	9.2	0.31	2.85
PS	8.3	0.12	0.99
PUR	4.6	-0.07	-0.32
Aluminium	1.8	0.86	1.58
CFC-11	0.2	0.00	0.00
Glass	0.2	-0.02	0.00
Oil	0.1	0.00	0.00
Cables	0.2	1.50	0.35
CFC-12	0.1	2.25	-0.23
Rest	1.3	-0.12	-0.16
Total	**46.0**		**7.63**

Cost balancing for an air conditioner – Example from Germany (analysis of 28 units)

Component	Weight (kg)	Revenue (€/kg)	Revenue (€)	Percentage (%)
Compressor	216.00	0.31	66.96	39.85
Aluminium-copper heat exchanger	87.00	1.70	147.90	16.05
Cable	7.00	1.50	10.50	1.29
Iron	22.00	0.90	19.80	4.06
Plastics	145.00	-0.08	-11.60	26.75
Copper piping	18.00	2.20	39.60	3.32
E-moter	45.00	0.40	18.00	8.30
Capacitor	2.00	-0.60	-1.20	0.37
Total	**542.00**		**289.96**	**100.00**

The revenue for 1 tonne = 535 € (10.40 € per unit)

The value of extracted components

- The most valuable components are aluminium-copper heat exchangers and cables without plugs → cut the plugs if possible
- Higher degree of dismantling results in higher returns
  - Dismantle compressors if possible, because higher prices are achieved when selling single components
  - Properly sorted plastics achieve higher prices than mixed plastics
  - Price balancing is positive for both refrigerators and air conditioners, the revenue is between 5 to 15 € per appliance

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Checklist

Are all relevant environmental licenses available?

Are all the necessary pieces of equipment and tools in place at the WEEE management company?

Are the employees adequately equipped regarding job safety and trained to handle component containing hazardous waste?

Checklist

Were all hazardous components removed from the appliances?

- Refrigerant and foam parts with the blowing agent
- Mercury (only chest freezers)
- Printed circuit board components (in air conditioners and refrigerators)
- PCB in capacitators (refrigerators and air conditioners)
- PBB and PBDE in plastics as flame retardants (higher probability to find these substances in air conditioners than in refrigerators)

Do I have a market for all valuable recovered components?

Outlook: Towards stage II

- **Stage II systems are recommended**, where the foam is crushed in encapsulated systems with recovery of the blowing agent
- However, **transitional options** appear reasonable when the waste stream of refrigerators is still low (< 100,000 refrigerators per year)
  - Conduct stage I as described before
  - For crushing the foam, we recommend to use a "*Querstromzerspaner*"
  - Attention: ensure inert atmosphere to avoid the creation of explosive atmospheres and the recovery of the blowing agent
  - There are various options to recover the blowing agent from the process air:

Outlook: Towards stage II

1. Cryocondensation:
   - Escaped blowing agents are liquefied by cooling down the process air, using liquid nitrogen
   - Increasingly less applied: complexity of technology and high operational costs
2. Activated carbon - incineration:
   - Water and humidity is recovered from the process air and the stream is passed over extruded activated carbon
   - Adsorption process is exothermic, so that desorption requires a heat source
   - Further safety requirements when foam was blown with pentane
     → Special detectors to identify the blowing agents

Outlook: Towards stage II

3. Activated carbon – reusable:
   - Process is similar to the process described under option 2.
   - However, the blowing agent is desorbed to reuse the activated carbon
   - This option is increasingly applied

- Besides foam, entire refrigerators and small WEEE can be processed in crushing machine → additional components are necessary
  - Airflow separator (filter, cyclones)
  - Overbelt magnet
  - Conveybor belt

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Guideline on the Manual dismantling of Refrigerators and Air Conditioners:

https://www.giz.de/expertise/downloads/giz2017-en-weee.pdf

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry
for the Environment, Nature Conservation,
Building and Nuclear Safety

of the Federal Republic of Germany

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Thanks!

Any questions?

Contact:

GIZ Proklima International

www.giz.de/proklima

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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