

Ecodesign Preparatory Study on

Electric motor systems / **Compressors**

ENER Lot 31

FINAL Report of Task 1, 2, 3, 4, & 5



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Ecodesign Preparatory Study on

Electric motor systems / **Compressors**

ENER Lot 31

FINAL Report Task 1

Product Definition, Standards and Legislation



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Final Report Lot 31 Task 1

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1 Introduction to Task 1

1.1 Scope

This is the final Task 1 report of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **‘ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives’**.

The aim of Task 1, in accordance with the tender specifications¹, is to *“classify and define the energy-using products covered by the lot and [provide a] “level playing field” for ecodesign. The product classification and definition should be relevant from a technical, functional, economic and environmental point of view, so that it can be used as a basis for the whole study. It is important to define the products as placed on the Community market. The product classification and definition have to be agreed with the Commission, after having consulted the stakeholders, and should be confirmed throughout the other tasks of the study. Standards and existing legislation for the defined energy-using products should be investigated.”*

1.2 Subtasks

The technical tender specifications for the Task 1 subtasks are:

Subtask 1.1 - Product category and performance assessment

The classification and definition of the products should be based notably on the following categorisations:

- Prodcom category or categories (Eurostat);
- Categories according to EN- or ISO-standard(s);
- Other product-specific categories (e.g. labelling, sector-specific categories), if not defined by
- the above.

Prodcom should be the first basis for defining the products (see also subtask 2.1).

If the product classification and definition relevant from a technical, economic and environmental point of view does not match directly with one or several Prodcom categories, the study should detail how it is translated into parts of Prodcom categories or the other categories mentioned above.

If products do not match with Prodcom categories, the standalone or packaged products placed on the European internal market², to which a CE mark is/could be affixed, should be defined. This may result in several Prodcom or otherwise categorised products relevant for the lot.

The above existing categorisations are a starting point for classifying and defining the products and can be completed by other relevant criteria, according notably to the functionality of the product, its environmental characteristics and the structure of the market where the product is placed. In particular, the classification and definition of the products should be linked to the assessment of primary product performance parameter (the "functional unit").³

¹ European Commission, Tender specifications ENER/C3/410-2010, which are the basis for the study.

² A product is placed on the Community market when it is made available for the first time. This is considered to take place when a product is transferred from the stage of manufacture with the intention of distribution or use on the Community market.

³ The functional unit is the quantified performance of a product for use as a reference unit.

If needed, on the basis of functional performance characteristics and not on the basis of technology, a further segmentation can be applied on the basis of secondary product performance parameters.

Subtask 1.2 – Test standards

This task should identify the relevant test standards for the products in the scope of the study.

Identify and shortly describe:

- the harmonised measurement standards;
- and additional sector-specific directions for product-measurement.

Regarding the measurement procedures for:

- the primary and secondary functional performance parameters mentioned above;
- resources use and emissions during product-life;
- safety (gas, oil, electricity, EMC, stability of the product, etc.);
- product quality;
- noise and vibrations (if applicable).

Identify and shortly describe:

- any other standard relevant for the products regarding the technical, economic, environmental and ecodesign analysis carried out in this study.

Subtask 1.3 - Existing legislation

This subtask should identify and analyse the relevant legislation for the products. It can be subdivided in three parts:

Subtask 1.3.1 - Legislation and Agreements at European Union level

Apart from the obvious environmental legislation (such as the RoHS, WEEE, Packaging directive), this could be building regulations (EPBD), regulations on health and labour conditions, labelling directives, minimum efficiency directive, product safety, EMC etc., including relevant standards interpreting such instruments. Also EU Voluntary Agreements and already existing ecodesign regulations for the sector's products or related products need to be identified.

Subtask 1.3.2 - Legislation at Member State level

This section deals with the subjects as above, but now for legislation that has been indicated by stakeholders as being relevant for the products at Member State level.

Subtask 1.3.3 - Third Country Legislation

This section again deals with the subjects as above, but now for legislation and measures in Third Countries (extra-EU) that have been indicated by stakeholders as being relevant for the product group.

2 Product category and performance assessment

2.1 Introduction

This subtask aims to present possible definitions of products in the overall scope taking into account existing categorisations. The idea is to identify the parameters to be used to define the product group and/or narrow down the product scope.

The tasks involve three main elements:

1. describing possible categorisations of products, and related product definitions;
2. presenting relevant technical standards, for possible definitions of products and scope and to identify primary and secondary product performance parameters;
3. presenting an overview of relevant existing legislation, within the EU and outside.

This section first presents a generic definition of the product group, and then proceeds to present possible categorisations of compressors. Some categorisations (according Prodcom, EN/ISO standards, measures) are obligatory elements of the methodology.

2.2 Generic definition of compressors

In order to understand better the scope of the study and the technical terms used throughout this report, this section starts with a very generic explanation of the differences between compressors, fans, blowers and pumps.

COMPRESSORS The technical term 'compressor' in this study is reserved for equipment for transport and/or pressure increase of **gaseous media** with a minimum pressure ratio.

In ISO/TR 12942:2011 the compressor is defined as "a machine or apparatus converting different types of energy into the potential energy of gas pressure for displacement and compression of gaseous media to any higher pressure values **above atmospheric pressure** with pressure-increase ratios **exceeding 1.1**".

The above definition is not to be understood as the final definition of a compressor within the study scope: A.o. it needs to be amended to restrict the scope to compressors using electric motors only (not 'different types of energy'). Furthermore the possible coverage/inclusion of vacuum pumps shall be discussed (vacuum pumps do not meet the generic definition above as they do not increase pressure 'above atmospheric pressure').

For the purpose of clarifying figure 1 below (next page) the low pressure compressor is to be understood as a compressor for absolute outlet pressure of approximately 1.1 to 5 bar (exact limits may vary - are not defined). Compressors used in industrial settings may have an absolute outlet pressure of between 7-15 bar. Compressors for process gas applications may exceed these limits. See also section 2.4 on categorisation by application.

The definition does set a clear boundary between compressors and fans - see figure below.

FANS Fans, like compressors, are used for transport or increase of the pressure of **gaseous media** and in specific cases (turbocompressors versus centrifugal and/or axial fans) the very basic working principle is similar. The main difference is the minimum pressure increase: According ISO/TR 12942 equipment with pressure-increase ratio of **up to 1.1** is regarded as a "ventilator (fan)".

In Regulation 327/2011 'Fan' means "a rotary bladed machine that is used to maintain a continuous flow of gas, typically air, passing through it and whose work per unit mass does not exceed 25 kJ/kg" (and then continues to limit the scope to axial, centrifugal, cross flow or mixed flow fans, designed for use with an electric motor > 125 W). This definition of fans is limited to rotary equipment only, whereas compressors may use much more diverse working principles. The limit value of 25 kJ/kg (fans) and the pressure increase ratio of 1.1 (compressors) are more or less comparable thresholds.

BLOWERS

The term "blowers" is **confusing** as the type of equipment meant, varies according to the context: For the average layperson a 'blower' may be equipment used for cleaning up fallen leaves from lawns, or equipment in lavatories to dry hands. In many industrial settings the term 'blowers' refers to centrifugal (forward curved) 'fans' with a housing, used for high volume air flows (e.g. in cooling applications).

In this study, with compressors as context, 'blowers' are regarded as a special type of positive displacement compressor, namely a rotary compressor with a double-rotor composed of straight lobes (a.k.a. 'Roots' blower). To avoid confusion, the term 'blower' will be avoided in the remainder of the study (unless it helps to explain certain aspects).

PUMPS

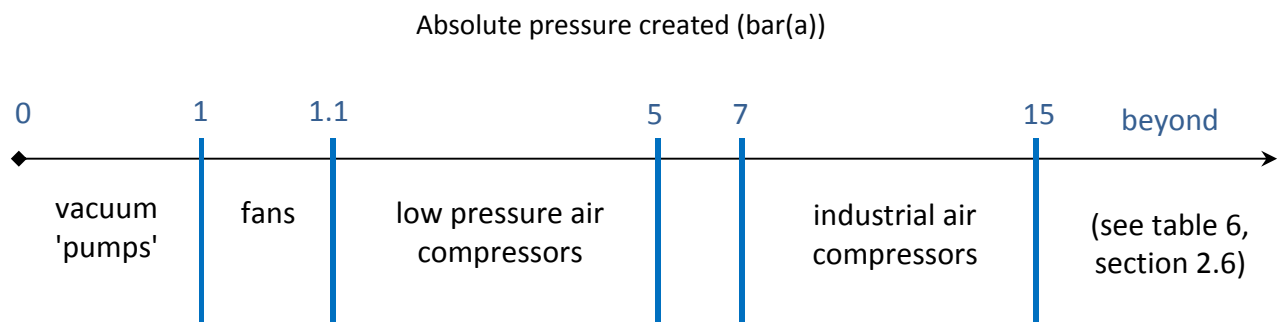
In this study the term 'pump' is generally reserved for equipment for transport and/or pressure increase of **liquid media** only (water, slurries, etc.) although the technical working principles of certain compressors and pumps may be very similar (positive displacement, or rotodynamic principles).

VACUUM PUMPS

An exception to this rule is the term 'vacuum pump', as this refers to products that handle gaseous media, not liquid media. Vacuum pumps compress gas as single stage or multi-stage machines from nearly zero bar absolute pressure to 1 bar (absolute pressure) which is the average ambient gas pressure. This study will use the term 'vacuum pumps' as this term is widely adopted/in use by the relevant industries.

In the figure below the position of compressors, fans and vacuum pumps on a scale of absolute pressure is given.

Figure 1: Typical product type by absolute pressure created (bar(a))



ISO/TR 12942 (see section 3.2) provides compressor categorisation and classification based on many approaches, many of which may be related to an application range of which a wide spectrum and diversity exists. This results in a great number of applicability and performance criteria, such as:

- compression principles;

- basic design features;
- media;
- energy forms used (electricity, fuel heat, etc.) and driver types;
- cooling agents (air, water, etc.) and methods;
- lubrication conditions (oil-free or oil-injected, oil-lubricated);
- mobility, transportability;
- prefabrication level (packaged and factory-assembled compressor, compressor plant, etc.);
- operation modes and service parameters;
- range of functions (compression, energy conversion, cooling, drying, etc.) and appropriate structural composition of the equipment.

Neither identification of the compressor equipment and its application fields nor selection of compressors for specific services and comparison of their technical and economical parameters are possible without knowledge of this information. That is why it is intended that the attributes listed in ISO/TR 12942 serve as a basis for the practical multi-dimensional classification system of compressor equipment.

2.3 Categories according Prodcom

Eurostat provides data regarding European business statistics of manufactured goods under the heading 'Prodcom'. International trade statistics are structured using the Combined Nomenclature (CN). Prodcom and CN categories are to a large extent similar, but not to the full 100%.

The table below shows the categories that list "compressors" according Prodcom nomenclature year 2010 and the corresponding international Combined Nomenclature (CN). The table includes a column for comments regarding the categorisation applied by Prodcom.

Table 1 Prodcom 2010 categories that list compressors

PRODCOM	Combined Nomenclature	Description	Remarks
28 13 23 00		Compressors for refrigeration equipment	Refrigeration (cooling and freezing)
28 13 24 00	84144010 84144090	Air compressors mounted on a wheeled chassis for towing	These are often reciprocating compressors, but screw and vane compressors can also be applied. This category is very diverse as it ranges from small electrically driven piston compressors with two wheels, up to diesel engine driven compressors, to be towed behind vehicles. This means that part of this category is within scope (electric motor driven) and part will be outside scope (diesel engine driven).
28 13 25 30	84148011	Turbo-compressors, single stage	These are centrifugal compressors as axial compressors are always multi stage. This group may also include "turbochargers" included in "Trade statistics No. 84148011, PRODCOM No. 28132530 - Turbo-compressors, single stage" according to EU Commission EXPLANATORY NOTES TO THE COMBINED NOMENCLATURE OF THE EUROPEAN COMMUNITIES (2008/C 133/01) ⁴ . A typical application for compressors for transport is the production of compressed air for braking systems (transport

⁴ see also <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2008:133:0001:0402:EN:PDF>

			equipment). This means that part of this category is outside scope if designed for use in 'means of transport'.
28 13 25 50	84148019	Turbo-compressors, multistage	This group can be both centrifugal and axial compressors. As above, part of this category is outside scope if designed for use in 'means of transport'
28 13 26 30	84148022	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow ≤ 60 m ³ /hour	These groups may include mini- compressors used as tyre-repair-kit, a household application inflating toys, balls, air mattresses or other inflatable objects (reciprocating compressors (excluding reciprocating compressor pumps), giving a flow not exceeding 2 cubic metres per minute); according COUNCIL IMPLEMENTING REGULATION (EU) No 1306/2011 of 12 December 2011. (concerning CN codes ex 8414 40 10, ex 8414 80 22, ex 8414 80 28 and ex 8414 80 51)
28 13 26 50	8414 80 28	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow per hour > 60 m ³	
28 13 26 70	8414 80 51	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour ≤ 120 m ³	
28 13 26 90	84148059	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m ³	
28 13 27 30	84148073	Rotary displacement compressors, single-shaft	
28 13 27 53	84148075	Multi-shaft screw compressors	Typical rotary compressors with a single shaft are vane, scroll and liquid ring type compressors. These are mainly screw compressors
28 13 27 55	84148078	Multi-shaft compressors (excluding screw compressors)	These are e.g. lobe type compressors and single screw compressors (with two additional gate rotors).
28 13 28 00	84148080	Air/gas compressors excluding air/vacuum pumps used in refrigeration, air compressors mounted on wheeled chassis, turbo compressors, reciprocating and rotary displacement compressors	According Nomenclature of Trade statistics HS 84148080 this category includes air pumps and ventilating or recycling hoods incorporating a fan, whether or not fitted with filters, with a maximum horizontal side > 120 cm (excl. vacuum pumps, hand- or foot-operated air pumps and compressors). This means that part of this category is outside the scope if they are considered to be 'fans' or other non-compressor equipment ⁵ .

Table 2 Vacuum pumps

PRODCOM	Combined Nomenclature	Description	Main application areas
28 13 21 70	84141089	Rotary piston vacuum pumps, sliding vane rotary pumps, molecular drag pumps, Roots pumps, diffusion pumps, cryopumps and adsorption pumps	According Nomenclature of Trade statistics HS 84141089 this category excludes sliding vane rotary pumps while PRODCOM includes them
28 13 21 90		Liquid ring pumps	
28 13 21	84141020	Vacuum pumps for use in semiconductor production	

⁵ see also http://www.zolltarifnummern.de/2012_en/84148080.html

84141025	Rotary piston vacuum pumps, sliding vane rotary pumps, molecular drag pumps and Roots pumps	
84141081	Diffusion pumps, cryopumps and adsorption pumps	

The overall conclusion on the categorisation as applied in Prodcom is that there is only a partial 'match' with the categorisation according working principles and the category description does not provide in a technical definition of the product, allowing differentiation from other principles. Also, the Prodcom categories may combine in single category compressors that are inside or outside scope.

Concluding: Prodcom categorisation is unsuitable for product group definitions, or scope, for the possible purpose of legislative measures.

As regards the actual unit sales and value trade statistics by Prodcom: these will be covered under Task 2: economic and market analysis.

2.4 Categories by working principle

The first categorisation of compressor machines can be made on the basis of the technical working principle. Essentially there are two ways to increase the pressure of a gas: Either by "positive displacement", or by a "dynamic" transfer of energy between a moving rotor and the fluid, also known as "turbocompressors". The ISO/TR 12942 definitions are provided below:

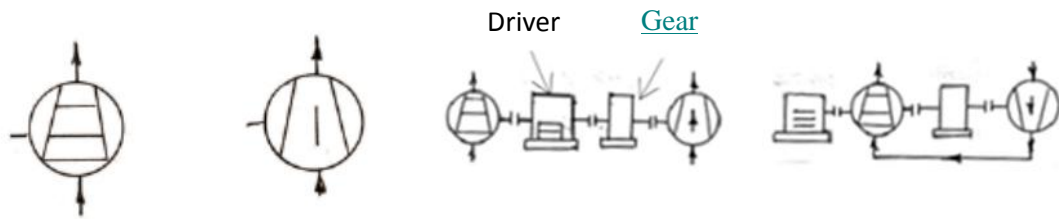
1. **Positive-displacement compressor:** a compressor machine in which the admission and compression of successive volumes of the gaseous medium are performed periodically by forced expansion and diminution of a closed space(s) in a working chambers(s) by means of displacement of a moving member(s) or by displacement and forced discharge of the gaseous medium into the high-pressure area.

NOTE The closed spaces with variable or displaceable volumes represent compression chambers. In one working chamber, there can be one or several variable-volume compression chambers.
2. **Dynamic compressor ('turbo compressors'):** a compressor machine in which the gas pressure increase is achieved in continuous flow essentially by increasing its kinetic energy in the flow path of the machine due to acceleration to the high velocities by mechanical action of blades placed on a rapid rotating wheel and further transformation of the kinetic energy into the potential energy of the elevated pressure by successive deceleration of the said flow.

A third option is the combined use of displacement and dynamic action, the 'combined compressor machine':

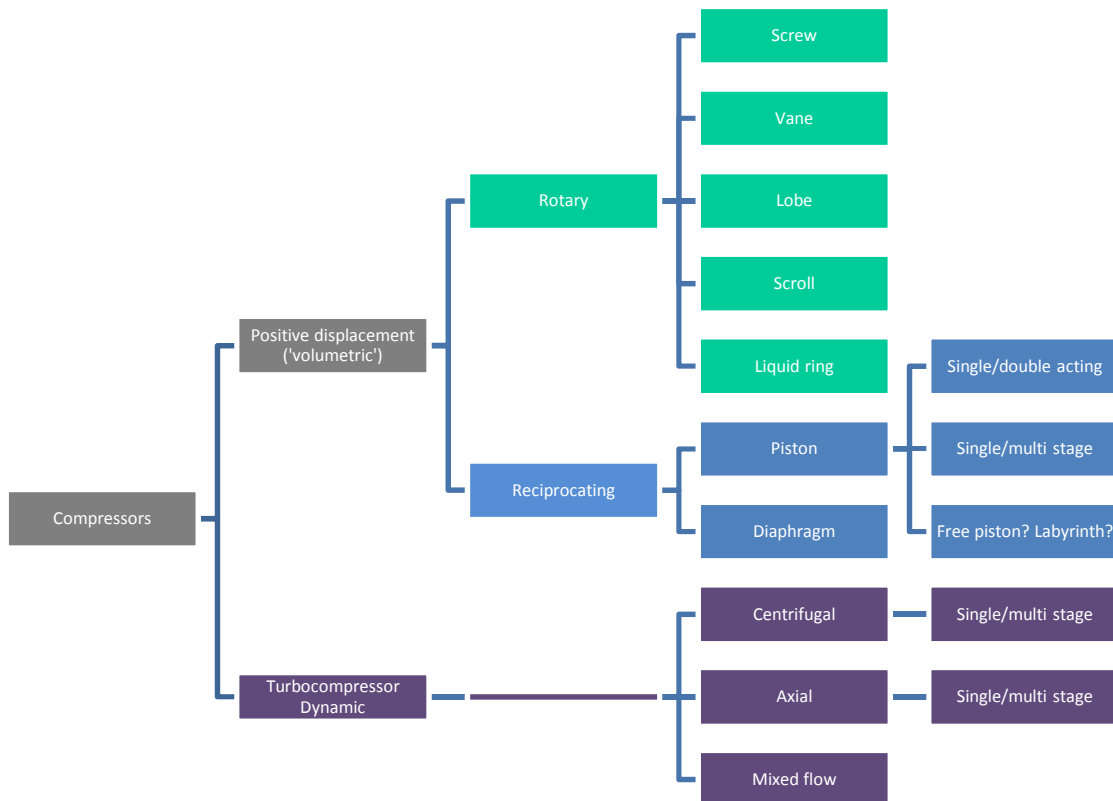
3. **Combined compressor machine:** a compressor machine in which the compression of gaseous medium or media is performed simultaneously or successively by dynamic and positive-displacement compressors driven by a common prime mover.

Figure 2: Schematic notification: positive displacement compressor (left), dynamic compressor (left middle) combined compressor machine (two pictures on the right)⁶



Within these main groups, positive displacement and dynamic, there is a wide variety of working principles. The figure below gives an overview of the main working principles (non-exhaustive).

Figure 3: Categorisation by working principle



The main types of compressor principles are described below (all descriptions based in ISO/TR 12942:2011).

2.4.1 Positive displacement compressors

Within the group of positive displacement compressors one can distinguish the following types:

Rotary compressor: A displacement compressor in which gas admission and diminution of its successive volumes or its forced discharge are performed cyclically by rotation of one or several rotors in a compressor casing.

NOTE 1 The rotor-number subclass are:

⁶ ISO/TR 12942:2011

- Single-rotor compressor: such as 'liquid ring', 'sliding vane' and 'swing vane' and 'rolling rotor' compressors and the 'single screw' compressor.
- Double-rotor compressor: such as 'internally meshing double rotor', 'straight-lobe' (this comprises 'Roots compressors, also known as 'blowers'), 'stepped-lobe', 'screw (helical lobe)' compressor;
- Multi-rotor compressor.

Reciprocating compressor: A displacement compressor in which gas admission and diminution of its successive volumes are performed cyclically by straight-line alternating movement of a moving member(s) in a compression chamber(s).

NOTE 2 Design subclasses of reciprocating compressors are:

- Piston compressor, a reciprocating compressor in which the moving member constitutes a piston reciprocating in a cylinder. Sub-classes can be defined according energy-supply methods to the piston: 'free-piston', 'shaft driven' (can be 'crankshaft', 'link-mechanism', 'swash-plate', 'cam-and-spring', 'slot-and-crank', 'rocking cylinder' or 'eccentric' driven), labyrinth-piston, piston-ring, plunger, rolling diaphragm; In addition there is a subdivision according cooling method (non-cooled, air-cooled, water-cooled, water-air cooled, water-injection cooled).
- Diaphragm (membrane) compressor; a reciprocating compressor in which the moving member constitutes a peripherally clamped and sealed flexible membrane or diaphragm in essentially concavo-concave compression chamber.
- Bellows-type compressor: a reciprocating compressor in which the moving member constitutes one of two opposite solid walls connected by flexible bellows-type folding walls, volumes of the compression chamber being decreased and increased by cyclical movement of one solid wall back and forward.

Peristaltic compressor: A displacement compressor in which admission of the gas volumes and their forced discharge are performed cyclically by local squeezing of sections of a flexible pipe rested on arc-shaped support by rollers of an external rotor and by displacing the trapped gas volumes from low-pressure side to high-pressure area.

NOTE 3 The inner flexible-pipe surface driven by the rollers represents the working member in the peristaltic compressors.

Orbital compressor: A displacement compressor in which gas admission and diminution of their successive volumes are performed cyclically by plain-parallel non-rotating orbital motion of the working member along the circular or other closed-curve path in the working chamber.

Subclass: scroll compressor: An orbital compressor in which closed-space compression chambers are formed between two identical spiral bands inserted eccentrically in each other and their flat end cover plates, the volumes of said spaces being cyclically decreased and increased from periphery to the centre by orbital non-rotating plane-parallel motion of one spiral band inside the fixed one along the circular path.

Swing-lobe compressor (oscillating lobe compressor): A displacement compressor in which gas admission and diminution of its successive volumes are performed by angular swinging (rocking) motion of one or several lobes around their axes in a cylindrical or partly cylindrical casing.

And again combined positive displacement compressor where the different types of positive displacement compressors are combined.

Generally speaking a subdivision into these three main types is specific enough and covers an overwhelming majority of compressor applications:

1. rotary displacement compressors;
2. reciprocating displacement compressors;

3. turbocompressors.

In the event that the text applies to a subclass within one of these three main classes, it is indicated in the text.

The categorisation chosen will in practice be influenced by application, pressure, sizes and technology which are quite often closely related.

2.4.2 Turbocompressors

The group of turbocompressors can be subdivided into:

Radial turbocompressor (Radial-flow turbocompressor): A turbo compressor in which the acceleration of the gas stream in the meridional plane is performed in radial direction with respect to the axis of rotation of the bladed wheel.

NOTE 1 The subclasses of radial compressors are:

- Radial centrifugal compressor: a radial turbo compressor in which the acceleration of the gas stream is caused essentially by centrifugal forces and performed from the centre of the rotating wheel to its periphery;
- Radial centripetal compressor: A radial turbo compressor in which the gas stream is accelerated essentially by centripetal forces induced by mechanical action of blades placed circumpherentially on the rotating wheel and moves from its periphery to the centre.⁷

NOTE 2 The broader term “radial compressor” can be used instead of “centrifugal compressor” if there is no possibility of confusion with centripetal radial compressors.

Figure 4: Illustration example of a centripetal compressor (left) and centrifugal compressor (right)⁸



In the Fan Regulation 327/2011 the centrifugal fans are divided by blade curvature which can be applied to this type of compressor also. The applicable blade curvatures in the Fan regulation are:

- ‘Centrifugal fan’ means a fan in which the gas enters the impeller(s) in an essentially axial direction and leaves it in a direction perpendicular to that axis. The impeller may have one or two inlets and may or may not have a housing;
- ‘Centrifugal radial bladed fan’ means a centrifugal fan where the outward direction of the blades of the impeller(s) at the periphery is radial relative to the axis of rotation;
- ‘Centrifugal forward curved fan’ means a centrifugal fan where the outward direction of the blades of the impeller(s) at the periphery is forward relative to the direction of rotation;

⁷ This specific type of compressor is rare in applications

⁸ ISO/TR 12942:2011

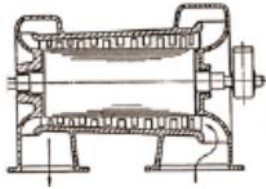
- 'Centrifugal backward curved fan without housing' means a centrifugal fan where the outward direction of the blades of the impeller(s) at the periphery is backward relative to the direction of rotation and which does not have a housing;
- 'Centrifugal backward curved fan with housing' means a centrifugal fan with an impeller where the outward direction of the blades at the periphery is backward relative to the direction of rotation and which has a housing;

Axial compressor (axial-flow compressor): A turbo compressor in which the acceleration of the gas stream in the meridional plane is performed in the direction parallel to the axis of rotation of the bladed wheel.

NOTE 5 The basic design subclasses of axial compressor are:

- compressors with fixed stator blading;
- compressor with variable stator blading.

Figure 5 Axial compressor



Other dynamic turbocompressors types are: peripheral flow compressor (also referred to as periflow, vortex, regenerative, drag or tangential compressor), diagonal or mixed-flow compressor, cross-flow compressor and combined turbocompressors. These types are however more niche applications and are not as abundant as centrifugal or axial flow compressors.

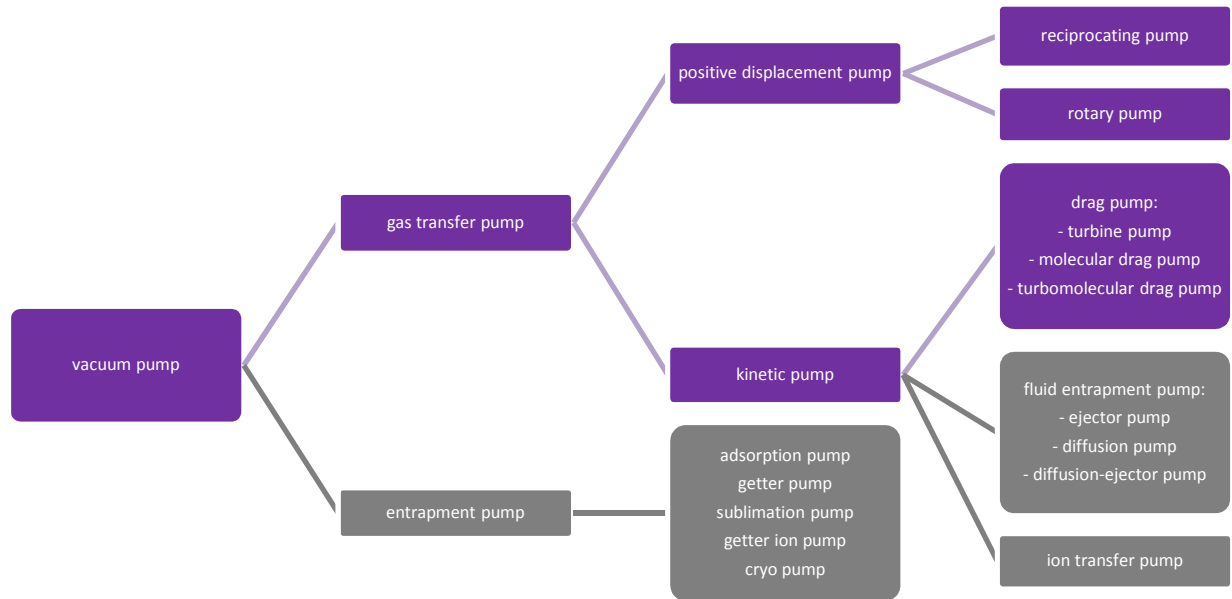
2.4.3 Vacuum pumps

The working group of the international statistics on vacuum technology program (ISVT) has proposed a classification of pumps into 13 categories:

1. Liquid ring;
2. Side channel;
3. Oil-sealed rotary vane/piston pumps;
4. Roots pumps;
5. Radial blowers;
6. Ejector pumps;
7. Dry pumps;
8. Turbomolecular pumps;
9. Diffusion pumps;
10. Ion getter pumps;
11. Sublimation/sorption/getter pumps;
12. Cryo pumps < -160°C;
13. Cryo water pumps > -160°C.

In ISO 3529-2 (under revision by ISO/TC 112 "Vacuum technology") a classification of vacuum pumps is presented.

Figure 6: Vacuum technology according ISO 3529-2



2.4.4 Examples of various compressor / principles

Examples of the various compressors types, both positive displacement and turbo, are presented below.

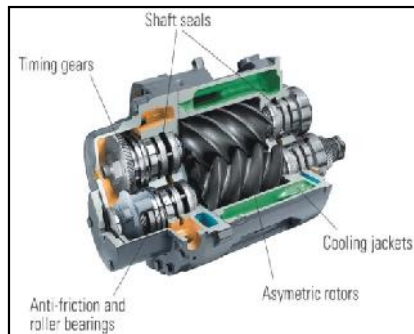


Figure 7: Rotary screw compressor⁹

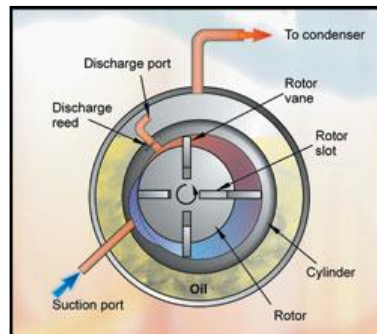


Figure 8: Rotary vane compressor¹⁰

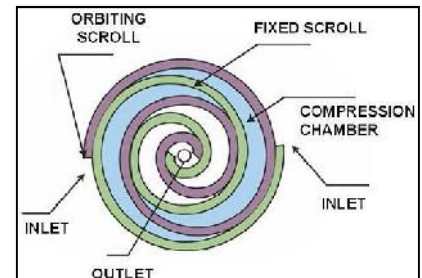


Figure 9: Rotary scroll compressor¹¹

⁹ http://www.classzero.com/press_room-image_downloads-compressors.html

¹⁰ <http://www.china-aircon.com/detail-10001893/masterclass-compressors-part-7.html>

¹¹ http://www.gentecsys.com/Knowledge/KB04_comp_tech.htm

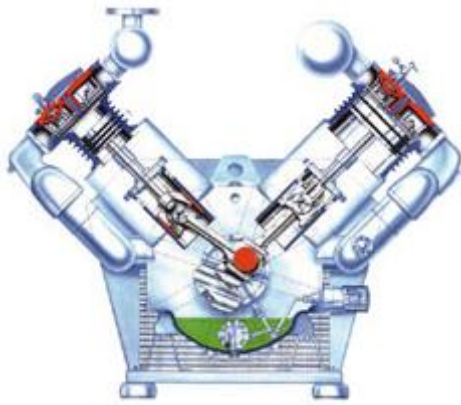


Figure 10: Piston compressor¹²

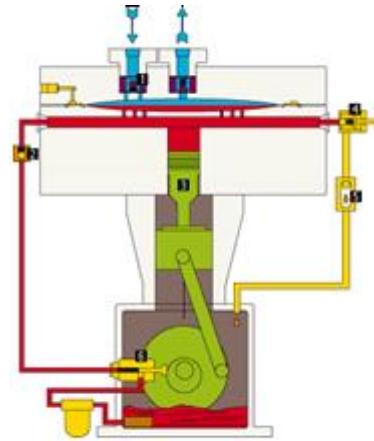


Figure 11: Diaphragm compressor¹³

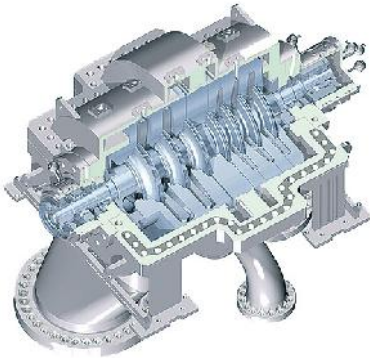


Figure 12: Centrifugal compressor¹⁴



Figure 13: Axial compressor¹⁵

2.5 Other categorisations

ISO/TR 12492 presents several other ways for classifying, categorising compressors, compressor machines and compressor equipment on their technical characteristics, other than working principles. The section below presents some of the more prominent categorisations.

2.5.1 by lubrication/cooling principle

Lubrication, sealing and cooling can be based on the use of oil, or by other principles.

Positive displacement compressors / oil-free

Certain types of positive displacement compressor designs rely on the use of oil for lubrication of bearings, gears and seals, for sealing compression elements and chamber(s), for removal of excess heat produced by the compression process.

Other reasons for use of oil are to catch contaminants and to keep internal surfaces clean and rust-free among others. The prime mover is mostly lubricated by grease instead of oil.

¹² http://www.compair.com/Products/Low_and_Medium_Pressure_Pistons.aspx

¹³ <http://www.pressureproductsindustries.com/compressors/explained.html>

¹⁴ http://www.siemens.com/press/en/presspicture/?press=/en/presspicture/2009/fossil_power_generation/efpg20070701-04.htm

¹⁵ http://dacworldwide.com/products/product_display.cfm?the_cat=11&the_id=714

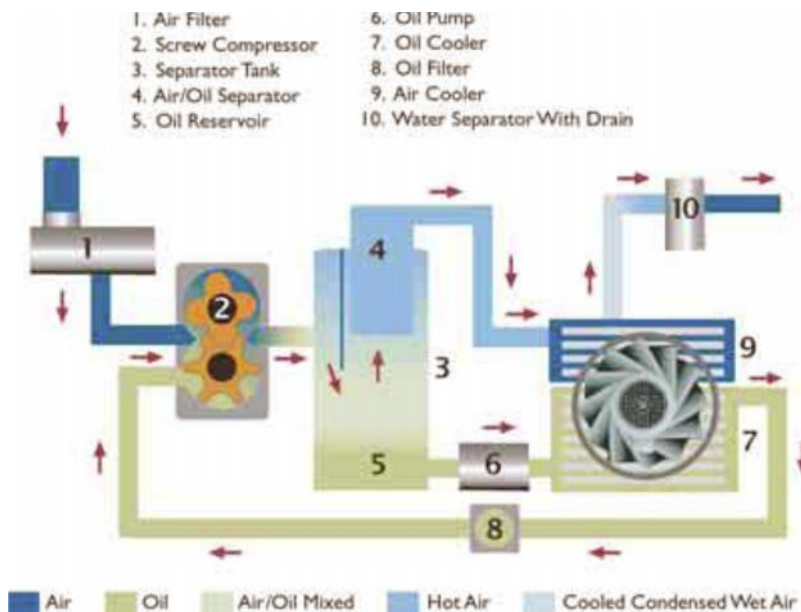
A drawback of using oil for the above reasons is that oil may be present in the gas delivery. This can be resolved by after treatment of the gas with oil-separators, but has also led to development of compressors that are 'oil-free': No oil is present in the compression chamber(s)), although oil may still be used for heat removal and/or lubrication of bearings, gears and seals outside the compression chamber(s).

Oil-free compressors exist for different working principles: There are oil-free piston compressors with PTFE (Teflon) sealing's, oil-free (twin) screw compressors where the compression chamber is separated from oil-lubricated gears and bearings by shaft seals, oil-free rotary (scroll) compressors, and twin-lobe without internal compression.

A fairly recent development is the use of water, injected into the compression element, providing lubrication, sealing and cooling. These compressors are also considered to be oil-free. A reverse osmosis system keeps the water 'clean'. Screw compressors with water injection cooling become more and more accepted for the generation of absolutely oil-free compressed air, whereas the function of oil is mostly taken over by water.

The figure below shows an oil-injected screw compressor where oil is used for lubrication, sealing of compression elements and chamber and removal of the heat of the compression.

Figure 14: Schematic of lubrication in typical compressor



Source: www.rv-synlube.com/whitepaper7.pdf

Certain compressor designs, such as vane compressors, usually operate with oil.

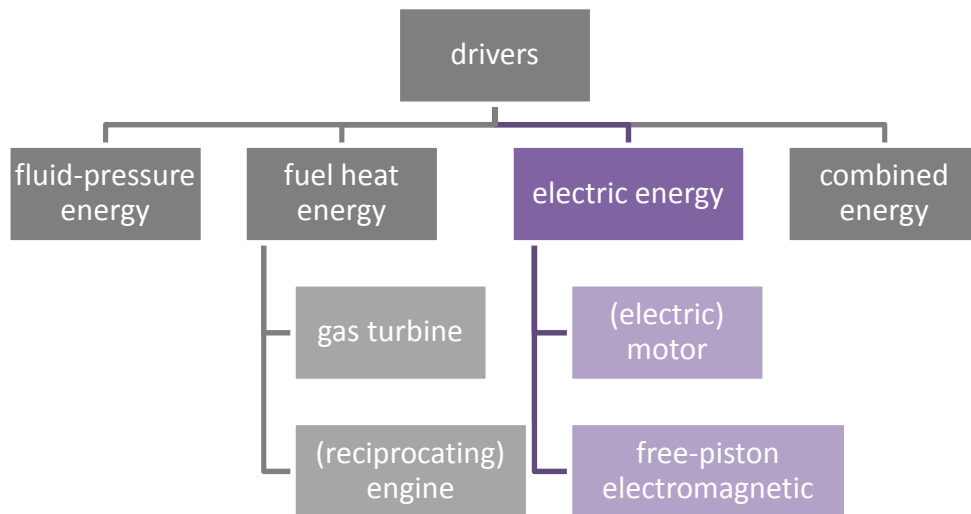
Turbo compressors

Centrifugal turbocompressors are generally considered to be 'oil-free' but may rely on use of oil for journaling (oil film bearings), but there are designs that are completely oil-free (with magnetic or air film bearings).

2.5.2 by drive train

Compressors may be driven by a variety of drives and forms of energy as shown in the figure below.

Figure 15: Possible compressor drivers ¹⁶



Electric

Electric motor driven compressors, are classified in two groups: the (electric) motor compressors and the free piston electromagnetic compressors. Both can be integral or separable.

The free piston electromagnetic compressor is not widespread in application. The principle is used in some refrigerating compressors (linear motor compressors¹⁷), some Rankine applications and Stirling engine type applications. Its relevance for the study is considered to be minimal.

Fuel heat / fluid-pressure

The fuel-heat energy powered compressors are either driven by a reciprocating internal combustion engine or a gas turbine. The internal combustion engine is the predominant drive for "portable compressors" (non-road mobile machinery), but such diesel engine drives can also be found on some compressors for pneumatic conveying, e.g. on trucks and mobile units in harbours etc.

Figure 16: Towable diesel engine powered compressor



(Source: www.kaeser.com)

Turbocompressors can also be driven by gas-turbines systems (fuel-heat energy powered or steam-turbines). Such compressor drives are usually found in large process gas compressors. Note: Steam turbines are different from gas turbines as they have no internal combustion.

¹⁶ ISO/TR 12942:2011

¹⁷ As applied by LG Electronics in many of their refrigerating products.

Figure 17: Turbocompressor driven by a turbine



(Source: <http://www.barber-nichols.com>)

An example of a fluid-pressure energy powered compressor is a turbocompressor driven by steam. Some fifty per cent of the compressors used in cracking and refining processes are driven by steam turbines.

2.5.3 by power range of the electric motor

Compressors can be categorised by the capacity of the (electric) motor driving the compressor or the required shaft input power. This power may range from < 100 W to up to 100 MW¹⁸. The range in minimum and maximum power of 10⁶ of (electric) driven compressors is unusual for ecodesign product groups under study.

Motors driving a compressor can be single phase (up to 230 V AC) or three phase (above 400 V AC). Three-phase motors are typical for industrial applications, as motors for single-phase exceeding 10 kW are rare and most industrial applications exceed that power requirement.

There appears to be a 'natural threshold' at about 375 kW where the voltage supply changes from low voltage (maximum 1 kV AC, 1.5 kV DC) to medium voltage¹⁹. The current applied in Low Voltage applications may still exceed 1 000 Amperes. There are examples of motors at low voltage (1.1 kV) that provide some 1 000 kW (1 MW) power. Motors in the medium voltage range may require up to 10 kV, but most applications for medium voltage are at maximum 6.6 kV.

In the context of the ENER Lot 30 Ecodesign preparatory study on electric motors the revision of IEC 60034-30-1 which considers only low voltage motors (up to 1 kV) was discussed. The importance of including higher voltage motors (up to 6.6 kV) in the present study was discussed since the USA has a voluntary labelling scheme for High Voltage motors and China is also preparing one. At the moment there is very little data on the split up of the market between 1.1 kV and 6.6 kV.

All experts (of both ENER Lot 30 on electric motors as well as ENER Lot 31 on compressors) agree that equipment operating on medium or high voltage is very energy intensive and energy efficiency is therefore a prime parameter in buyer's specifications. Furthermore the possible relative savings in motor efficiency are smaller when motor capacity increases.

The smallest compressors may be typical for portable (battery driven) applications at for example 12 V DC, the larger capacities are typical for process gas compressor applications.

¹⁸ <http://www.energy.siemens.com/nl/en/compression-expansion/turbocompressors/integrally-geared-compressors/#content=Mega%20Test%20Center>

¹⁹ The definition of medium voltage varies per location but is usually maximum 35 kV in Europe. From 35 kV and more we speak of high voltage.

Electric motors of a capacity beyond 375 kW may be applied in oil injected screw applications, oil free screw applications and turbocompressors.

Some examples are provided below.

Figure 18: Simple 12 V battery operated air compressor



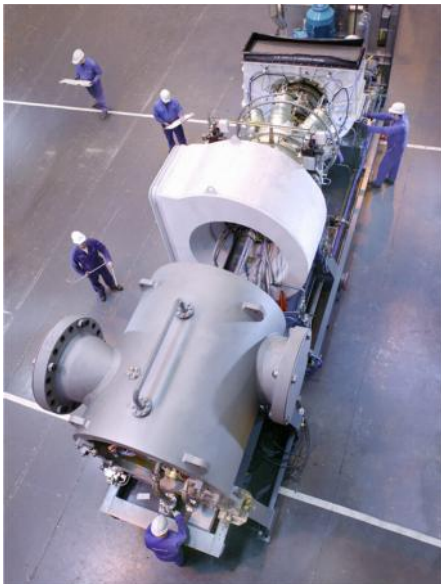
Source: cnfms.com

The LNG (Liquid Natural Gas) industries normally use compressors with electric motors as drive system in the power range of 20-100 MW per compressor, but motors of 250 MW are considered a possibility²⁰. The ConocoPhillips Liquid Natural Gas (LNG) plant uses compressors with electric motors in the range of 95-100 MW²¹.

For transport and distribution of natural gas through pipeline networks compressors of 5-30 MW are applied: gas turbine driven compressors are preferred for transport of gas and electric motors for distribution nodes²². Offshore platforms use compressors with electric motor drives up to 40MW²³.

The largest compressors of up to 400 MW are used in gas turbine power plants and are driven by the gas turbine and compress only atmospheric air.

Figure 19: 15 MW pipeline turbocompressor package



(Source: Siemens.com / SPCP-400 package)

²⁰ http://www.tmeic-ge.com/upload/library_docs/english/Turbomachinery_LNG_Article_1274973041.pdf

²¹ <http://inglicensing.conocophillips.com/EN/publications/documents/GastechElectricMotorPaper.pdf>

²² <http://pipelineandgasjournal.com/high-efficiency-pipeline-compressor-packages-efficient-dependable-and-shelf>

²³ [http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/18a4d26572c7d980c12570c70026f2be/\\$file/offshore%20platform%20powered%20with%20new%20electrical%20motor%20drive%20system_presentation%201.pdf](http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/18a4d26572c7d980c12570c70026f2be/$file/offshore%20platform%20powered%20with%20new%20electrical%20motor%20drive%20system_presentation%201.pdf)

A modern 6–8 MTPA (million tons per annum) LNG liquefaction plant typically requires four large compressors with 60–80 MW of rotating shaft power. This power can be provided by either gas turbines or electric drives.

Figure 20: Siemens SPCP-100, a 5 MW turbocompressor package for pipeline stations

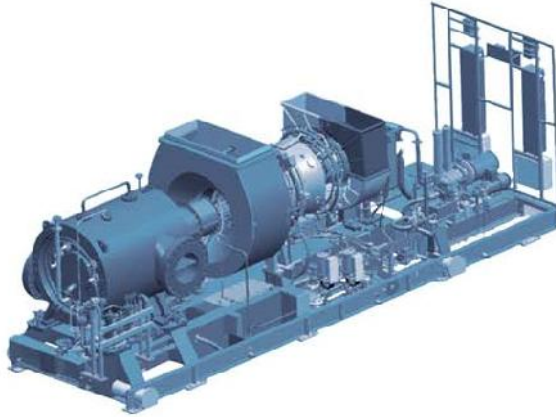


Table 3: Electric motor drive features for LNG plant²⁴

Driver type	Power (MW)	Electric motor efficiency %	Speed RPM
Electric motor, VF drive, and input transformer	25	95.3 (electrical to shaft hp)	3 600
Electric motor, two VF drives and input transformer	50	95.3 (electrical to shaft hp)	Up to 4 200

Such large electric motors are currently not regulated by existing Ecodesign measures, or by the Low Voltage Directive.

The Low Voltage Directive (LVD) 2006/95/EC covers electrical equipment with a voltage between 50 and 1 000 V for alternating current and between 75 and 1 500 V for direct current. It should be noted that these voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment.

The Electric Motor Regulation 640/2009 applies to asynchronous electric motors that:

- has 2 to 6 poles,
- has a rated voltage of U_N up to 1 000 V,
- has a rated output P_N between 0.75 kW and 375 kW,
- is rated on the basis of continuous duty operation.

The Fan Regulation 327/2011 applies to driven fans of

- is designed for use with or equipped with an electrical motor with an electric input power between 125 W and 500 kW (≥ 125 W and ≤ 500 kW) to drive the impeller at its optimum energy efficiency point.

The Fan Regulation did not specify a voltage limit for the electric motors that drive the fans.

For most electrical equipment, the health aspects of emissions of electromagnetic fields are also under the domain of the Low Voltage Directive.

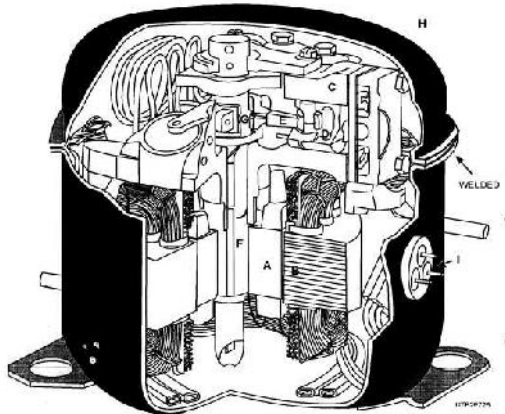
²⁴ http://www.tmeic-ge.com/upload/library_docs/english/Turbomachinery_LNG_Article_1274973041.pdf

2.5.4 by type of enclosure

The enclosure of compressors may be hermetically sealed, semi-hermetic or open which refers to the position of the bare compressor in relation to the driver (motor).

Hermetic compressor: the compressor and motor are “sealed” (welded) in an enclosed casing, immune to outside interference or influence. The figure below presents a typical hermetic sealed compressor mostly used in refrigerating equipment.

Figure 21: Hermetic compressor, reciprocating piston ²⁵

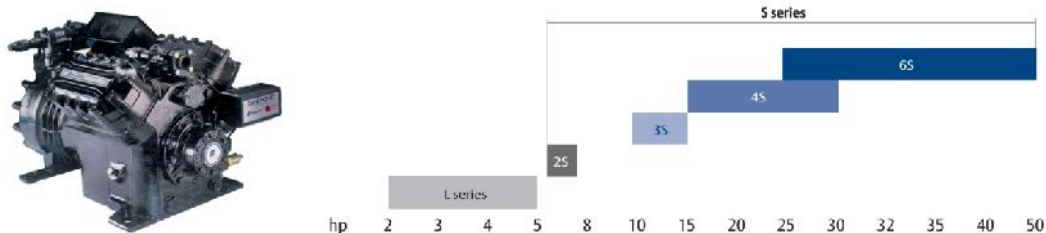


Legend:

- (A) Motor rotor;
- (B) Motor stator;
- (C) Compressor cylinder;
- (D) Compressor piston;
- (E) Connecting rod;
- (F) crankshaft;
- (G) Crank throw;
- (H) Compressor shell
- (I) Glass sealed electrical connection

Semi-hermetic compressor: compressors that have a casing that can be opened to replace motor and pump components. The figure below shows a semi-hermetic compressor and an overview of power ranges of these compressors.

Figure 22: Semi-hermetic compressor ²⁶ and power ranges semi hermetic compressors ²⁷



Open type compressor: one end of the crankshaft sticks out of the crankcase (the casing that contains the pistons and the mechanisms inside the compressor)

Figure 23 Open compressor ²⁸

²⁵ http://constructionmanuals.tpub.com/14279/css/14279_265.htm

²⁶ http://asenterprise.tradeindia.com/Exporters_Suppliers/Exporter12205.170698/Semi-Hermetic-Compressor.html

²⁷ http://www.hvacinfo.com/Compressors/cope_semi_asia.pdf

²⁸ <http://www.directindustry.com/prod/j-e-hall-international/open-refrigeration-compressors-39777-305282.html>

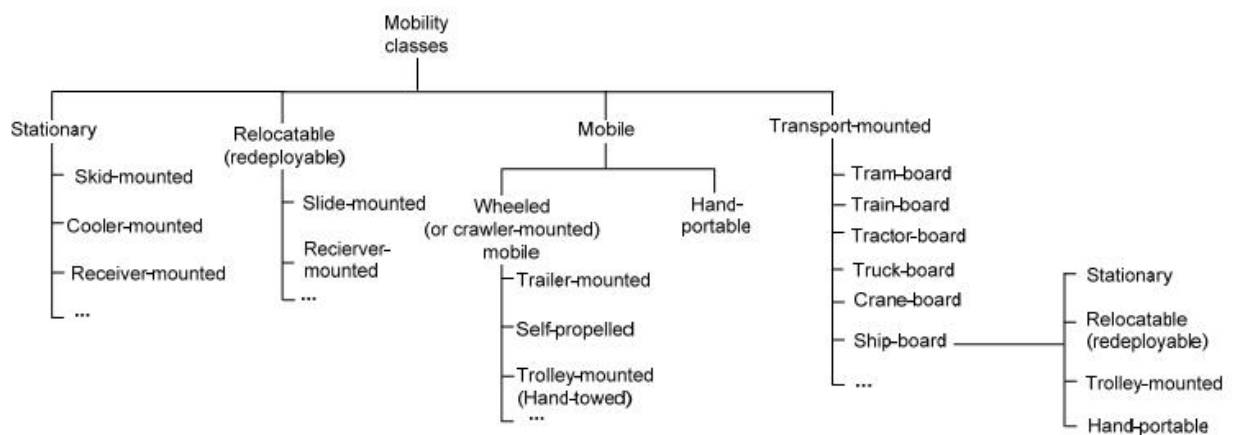


Hermetic and semi-hermetic compressors are most often applied in refrigeration applications, but not exclusively. (Semi-) hermetic sealed compressors may also be used for hazardous gas applications.

2.5.5 by mobility class

In the figure below an overview is given according to mobility classes as defined by ISO/TR 12942.

Figure 24: Mobility classes of compressors ISO/TR 12942



Compressors specifically designed for transport-related equipment ('transport-mounted') are considered to be out of the scope of this study, because the Ecodesign Directive (2009/125/EC, article 1) does not apply to products that are means of transport for good or persons.

This means that re-locatable and mobile compressors are considered to be inside the scope of the study, as far as these are driven by electric motors.

2.6 Categorisation by application

Compressors are used for a wealth of applications, too many to list them all. Just to give an idea of the range in applications the list below gives some examples. Note this list is not exhaustive, indicative only and based on a combination of sources²⁹:

The two main groups are **process gas** applications and **compressed air** applications.

1) Process gas applications / process enablers

²⁹ Such as the IPPC BREF documents on compressed air systems, manufacturers overview of application areas of their products, product brochures, etc.

- a) Refining
 - i) Hydrogen processes, hydrocracking, visbreaking, catalytic reforming, treating, other related processes;
 - b) Exploration and production
 - i) Gas lift, gas gathering, gas field depletion, gas transmission, gas storage, gas processing;
 - c) Chemical and petrochemical industries
 - i) Ethylene, propylene production and other related processes
 - d) Other industries
 - i) gas to liquids, coal to liquids, CNG, polysilicone, LDPE production
 - e) Medical applications
 - i) vaccines, medicines, drugs;
 - ii) breathing and Theatre air;
 - iii) oxygen concentration;
 - iv) driving dental machinery (see compressed air);
 - v) asthma medicine application (breathing apparatus);
 - f) Processed air systems
 - i) as integral component in industrial processes or "process enabler" (as in production of inert gas/ Nitrogen, oxidation processes (waste water treatment), clean room atmosphere, stirring in high temperature processes (glass, steel stirring), blowing processes (fibres, beverage glass containers), plastics moulding (PET!), pneumatic sorting (packaging), air separation;
- 2) Compressed gas/air as energy medium
- a) driving compressed air tools,
 - b) driving pneumatic actuators;

The latter group, compressed air applications, can be expanded by examples provided in the compressed air system sourcebook³⁰.

Table 4: Industrial sector uses of compressed air

Industry	Example compressed air uses
Apparel	Conveying, clamping, tool powering, controls and actuators, automated equipment
Automotive	Tool powering, stamping, control and actuators, forming, conveying
Chemicals	Conveying, controls and actuators
Food	Dehydration, bottling, controls and actuators, conveying, spraying coatings, cleaning, vacuum packing
Furniture	Air piston powering, tool powering, clamping, spraying, controls and actuators
General manufacturing	Clamping, stamping, tool powering and cleaning, controls and actuators
Lumber and wood	Sawing, hoisting, clamping, pressure treatment, controls and actuators
Metals fabrication	Assembly station powering, tool powering, controls and actuators, injection moulding, spraying
Petroleum	Process gas compressing, controls and actuators
Primary metals	Vacuum melting, controls and actuators, hoisting
Pulp and paper	Conveying, controls and actuators
Rubber and plastics	Tool powering, clamping, controls and actuators, forming, mould press powering, injection moulding
Stone, clay and glass	Conveying, blending, mixing, controls and actuators, glass blowing and moulding, cooling

³⁰ Improving compressed air system performance: a sourcebook for industry U.S. Department of Energy, Energy Efficiency and Renewable Energy

Textiles	Agitating liquids, clamping, conveying, automated equipment, controls and actuators, loom jet weaving, spinning, texturizing
----------	--

Table 5: Non-manufacturing sector use of compressed air Error! Bookmark not defined.

Sector	Example Compressed air uses
Agriculture	Farm equipment, materials handling, spraying of crops, dairy machines
Mining	Pneumatic tools, hoists, pumps, controls and actuators
Power generation	Starting gas turbines, automatic control, emissions control
Recreation	Amusement parks – air brakes Golf courses – seeding, fertilizing, sprinkler systems Hotels – elevators, sewage disposal Ski resorts – snow making Theaters – projector cleaning Underwater exploration – air tanks
Service industries	Pneumatic tools, hoists, air brake systems, garment pressing machines, hospital respiration systems, climate control
Transportation	Pneumatic tools, hoists, air brake systems
Wastewater treatment	Vacuum filters, conveying

Besides the application areas mentioned above, compressors are also widely in use in the following sectors:

- Electronics;
- Nuclear industry;
- Recycling;
- Pneumatic conveying.

Further categorisation and even attaching specific compressors designs to applications is difficult because even if an application appears similar (for instance: "clamping") there still may be huge differences in the pressures required, the capacity or size (what volume or mass-flow, or input power) and the final technology (including working principle) selected to deliver the required performance.

Still it is preferred to have at least some idea of compressor applications categories, as this may help to structure Task 3: Consumer/ user behaviour and local infrastructure.

The situation is similar to 'pumps' where several implementing measures are /will be created for different pump types used in different applications (see circulators, industrial pumps, waste water pumps, clean water pumps, etc.).

Categorisation via application is a suitable/helpful approach, as certain applications are quite often closely linked to:

- certain pressure range and/or;
- certain (or limited number of) compressor technologies and/or;
- certain compressor size (nominal power or volume flow rate).

Table 6: Typical application ranges

Typical application ranges	Typical function or application	Typical performance	Typical technologies
----------------------------	---------------------------------	---------------------	----------------------

(pressure increase)			
Standard air compressors	for very diverse applications	7-15 bar	Mainly (oil-injected) screw and piston
Low pressure air compressors	many are used in waste water treatment (oxygenation)	50 mbar – 3.5 bar	Various types
Oil free / non-lubricated air compressors	for applications requiring oil-free supply of air (food, medical, chemical sectors)	7-15 bar	Screw, turbo, incl. scroll and tooth)
Process gas compressors, air / inert gasses	for example in the air separation industry, regeneration or processes in the chemical, pharmaceutical, oil/gas industries	1 – 1 000 bar (depends on technology)	Mainly piston, turbo, screw, rotary lobe
Process gas compressors, other gasses	for example processes in the in chemical, pharmaceutical, oil/gas industries, includes handling of hazardous (toxic, flammable) gases	1 – 1 000 bar (depends on technology)	Mainly piston, turbo, screw, rotary lobe
Hobby air compressors	very diverse (tyre inflation, tools, spraying)	0 - 10 bar	Mainly piston

The non-process gas application ranges in the table have atmospheric inlet conditions and atmospheric air as medium to be compressed. The process gas compressors group many different and sometimes unique working principles with completely different inlet conditions and media.

The term “low pressure air compressors” in this study is used for compressors creating absolute pressure between 1.1 and 5 bar. One major application for these low pressure air compressors are water treatment plants.

The term “industrial air compressors” in this study is used for compressors creating absolute pressure between approximately 7-15 bar. These compressors are used as air compressors for example in the air separation industry, regeneration or processes in the chemical, pharmaceutical, oil/gas industries and they are used as process gas compressors for instance in processes in the in chemical, pharmaceutical, oil/gas industries, including handling of hazardous (toxic, flammable) gases. In the table above industrial compressors are represented by the group "standard air compressors" and "process gas compressors for air/inert gases".

Process gas compressors are used in e.g. in chemical or pharmaceutical processes or in the oil & gas industry handling all gases including predominantly hazardous (toxic, flammable etc.) gases.

Hazardous gas: Gas or vapour with chemical, radioactive or biological properties (such as flammable, explosive, unstable, pyrogenic, corrosive, caustic, toxic, carcinogenic), which generate hazards by reactions inside the compressor or through dispersal or through reactions with the environment. A hazardous gas may be a mixture of gases with these properties.

A very important aspect related to the application range is that compressors handling hazardous gases differ significantly from compressors handling inert gases (such as air or nitrogen). The safety requirements and process conditions place extra demands on the type and quality of sealing and gaskets in particular. These extra requirements have a direct effect on the energy efficiency of these compressors.

2.7 Product / system boundaries

In this study three compressor "product levels" are recognised:

1. the 'bare' compressor;
2. the compressor package (extended product) (also known as **compressor unit**);
3. the compressor system.

Bare compressor

The bare compressor is defined as the compression element without the motor (prime mover) or transmission. It is also known as the "air end".

Packaged compressor

The packaged compressor comprises the bare compressor, the prime mover and transmission (if applicable) and other components needed for safe operation and basic functionality.

Compressor system

The compressor system is understood as the product system from air intake to 'point-of-use', and thus includes distribution (piping) networks and end-use equipment (e.g. pneumatic tools).

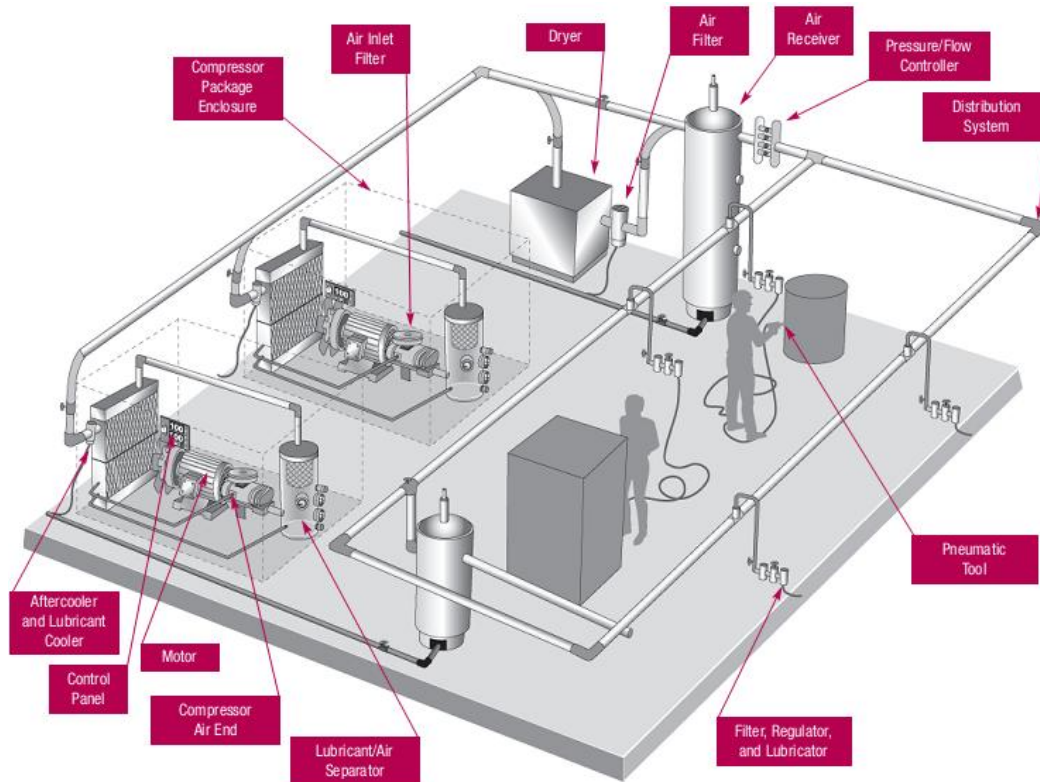
As an example, a compressed air system may consist the following major components besides the a compressor package itself,:

- Intake air filters to prevent dust from entering a compressor.
- Inter-stage coolers that reduce the temperature of the air before it enters the next stage to reduce the work of compression and increase efficiency.
- After-coolers with the objective to remove the moisture in the air by reducing the temperature in a water-cooled heat exchanger.
- Air-dryers that remove the remaining traces of moisture after after-cooler as equipment has to be relatively free of any moisture.
- Moisture drain traps that are used for removal of moisture in the compressed air. These traps resemble steam traps.
- Receivers that are provided as storage and smoothening pulsating air output - reducing pressure variations from the compressor.

The figure below presents a typical compressed air system.

Figure 25: Components of a typical industrial compressed air system ³¹

³¹ Source: Improving compressed air system performance: a sourcebook for industry U.S. Department of Energy, Energy Efficiency and Renewable Energy



This third level, e.g. a compressed air system (CAS), has the following drawbacks related to a possible use as product categorisation for legislative purposes:

- each CAS is a customer specific local installation;
- each CAS includes products of several manufacturers in most cases;
- a CAS can include several compressors, of different types, of different pressure levels, and several additional pieces of other CA equipment;
- the responsibility for design, planning, installation, maintenance of CAS is very diverse;

Concluding: There is no clear responsibility of a single manufacturer for a compressor system. The highest level for single manufacturer responsibility can be found at the compressor package.

3 Test standards

This section presents test standards relevant for the product group.

The two main technical standards are ISO 1217 for displacement compressors and ISO 5389 for turbocompressors. The test standard ISO 2151 is relevant for noise measurement. ISO/TR 12942 is not actually a standard, but provides valuable information relating to the classification and categorisation of compressors.

The chapter starts with an overview of harmonised standards.

3.1 Harmonised standards

3.1.1 Introduction

The free movement of goods lies at the heart of achieving an open market for business in Europe. In May 1985, European Community Ministers agreed on a “New Approach to Technical Harmonisation and Standards” to fulfil this objective.

“New Approach” Directives (that is Community Law) set out the essential requirements (on safety for example), written in general terms which must be met before products may be sold in the European Community. European harmonised standards provide the detailed technical information enabling manufacturers to meet the essential requirements. The directives also explain how manufacturers are able to demonstrate conformity with the essential requirements. Products which meet the essential requirements are to display the CE marking, as described in the particular directive, which means that the products can be sold anywhere in the Community/EEA.

A list of references to harmonised standards in the context of the “New Approach” Directives can be found on the European Commission website, and is included as Annex III. The standards developed apply to aspects of electric compressors such as electrical safety and electromagnetic compatibility, machinery and pressure equipment.

The two main standards used for assessment of compressor energy efficiency are ISO standards (ISO 1217 and ISO 5389 - see also next section), for which no EN equivalent is developed.

Currently the only harmonised standard applicable to electric motor driven compressors is EN 1012-1 on compressors safety (plus EN 1012-2³² on vacuum pump safety), EN ISO 2151:2008 on acoustic noise (publication OJ 08/09/2009) and EN 378-2 on Refrigerating systems and heat pumps - Safety and environmental requirements - Part 2: Design, construction, testing, marking and documentation.

These standards are harmonised for declaring conformity to the machinery Directive / Regulation (Directive 2006/42/EEC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast), later recast into Regulation (EC) N° 569/2009 - adaptation to the regulatory procedure with scrutiny [OJ L 188, 18 July 2009]).

Table 7 Overview EU Harmonised standards

Standard	Name/Title	Reference to EU legislation
EN 1012-1:2010	Compressors and vacuum pumps - Safety requirements - Part 1: Air compressors	98/37/EC (Expected) 2006/42/EC (C 110, 2011-04-08)
EN 1012-2:1996 + A1:2009	Compressors and vacuum pumps - Safety requirements - Part 2: Vacuum pumps	2006/42/EC (C 110, 2011-04-08) 98/37/EC (C 309, 2009-12-18)
EN 1012-3: 2008	Compressors and vacuum pumps - Safety requirements - Part 3: Process compressors	
ISO 2151:2004	Acoustics -- Noise test code for compressors and vacuum pumps -- Engineering method (Grade 2)	2006/42/EC (C 214, 2009-09-08) 98/37/EC (C 22, 2009-01-28)
EN 378-2:2008+A2:2012	Refrigerating systems and heat pumps - Safety and environmental requirements - Part 2: Design, construction, testing, marking and documentation	

³² EN 1012-2:1996+A1:2009, Compressors and vacuum pumps - Safety requirements - Part 2: Vacuum pumps (publication OJ: 08/09/2009)

3.1.2 EN 1012-1:2010

Title: Compressors and vacuum pumps, Safety requirements, Part 1. Compressors (publication OJ: 18/12/2009).

This standard comprises a definition of a 'compressor' but the actual meaning is that of a compressor unit or packaged compressor. To avoid confusion with the term 'compressors' that may also be used to describe that part which raises the pressure (also known as 'air end') the definition in EN 1012-2010 is amended as follows:

A compressor **unit** means: A machine which compresses air, gases or vapours to a pressure higher than the inlet pressure. A compressor **unit** comprises the bare compressor itself, the prime mover, and any component or device supplied which is necessary for safe operation of the compressor.

In doing so, the above definition therefore also covers packaged compressors (see ISO/TR 12942).

Compliance with clause 5 of this standard provides one means of conforming to the specific essential requirements of Directive 2006/42/EC regarding safety of machinery.

3.1.3 EN 1012-2:1996+A1:2009

Compressors and vacuum pumps - Safety requirements - Part 2: Vacuum pumps

As vacuum pumps do not increase above atmospheric pressure these products are placed outside the scope of the study.

3.1.4 EN 1012-3: 2008

Compressors and vacuum pumps. Safety requirements. Part 3. Process compressors

This part of EN 1012 is applicable to compressors having an operating pressure greater than 0,5 bar and designed to utilise all gases other than air, nitrogen or inert gases which are covered in part 1. This standard deals with all significant hazards, hazardous situations and events relevant to the design, installation, operation, maintenance, dismantling and disposal of compressors and compressor units, when they are used as intended and under conditions of misuse which are reasonably foreseeable by the manufacturer.

This part of EN 1012 includes under the general term compressors, those machines which comprise;

- the compressor itself;
- a prime mover;
- any component or device supplied which is necessary for safe operation of the compressor.

In addition it applies to partly completed compressors having a compressor in combination with some of these components as well as compressor assemblies operating in combination.

Excluded are refrigerant compressors used in refrigerating systems or heat pumps as defined in EN 378-1.

3.1.5 EN ISO 2151:2008

Acoustics - Noise test code for compressors and vacuum pumps - Engineering method (Grade 2) (ISO 2151:2004).

3.1.6 EN 378-2:2013

Refrigerating systems and heat pumps - Safety and environmental requirements - Part 2: Design, construction, testing, marking and documentation.

These applications are recommended to be placed outside the scope of the study

3.2 Other performance / categorisation standards

The two most important standards are the performance standards for displacement compressors (ISO 1217) and turbo compressors (ISO 5389).

3.2.1 ISO 1217: 2009

Title: Displacement compressors - Acceptance tests

The "Displacement compressor" covered by ISO 1217 (and listed under "Positive displacement (volumetric)" in Figure 2-3: Categorisation by working principle) is defined in this standard as:

- **Displacement compressor:** a machine that creates a static pressure rise by allowing successive volumes of gas to be aspirated into and exhausted out of a closed space by means of the displacement of a moving member

The standard also describes the following subtypes of compressors (a.o.):

- **Packaged compressor:** a compressor with prime mover, transmission, fully piped and wired internally, including ancillary and auxiliary items of equipment and being stationary or mobile (portable unit) where these are within the scope of supply;
- **Packaged compressor power input** (electrically driven machines) sum of the electrical power inputs to the prime mover and any ancillaries and auxiliaries driven from the compressor shaft or by a separate prime mover at rated supply conditions, including the effect of all equipment included in the package

NOTE 1 Auxiliaries include oil pump, cooling fan and integral compressed air dryer.

NOTE 2 Rated supply conditions refer to phase, voltage, frequency and ampere capability.

- **Shaft power:** power required at the compressor drive-shaft, equal to the sum of mechanical losses and the internal power, not including losses in external transmissions such as gear drives or belt drives unless part of the scope of supply

This International Standard specifies methods for acceptance tests regarding volume rate of flow and power requirements of displacement compressors. It also specifies methods for testing liquid-ring type compressors.

This International Standard specifies the operating and testing conditions which apply when a full performance test is specified.

Annex E, which is normative, applies to any electrically driven compressor manufactured in batches or in continuous production quantities and supplied against specified data having variable speed drive (e.g. variable frequency drive, direct current drive and switched reluctance), which incorporates a displacement compressor of any type driven by an electric motor.

Detailed instructions are given for a full performance test, including the measurement of volume flow rate and power requirement, the correction of measured values to specified conditions and means of comparing the corrected values with the guarantee conditions.

3.2.2 ISO 5389: 2006

Title: Turbocompressors - Performance test code

The "Turbo compressors" covered by ISO 5389 (and listed under "Dynamic" in Figure 2-3: Categorisation by working principle) are defined in the ISO 5389 standard as:

- **Turbocompressors** comprise machines in which inlet, compression and discharge are continuous flow processes. The gas is conveyed and compressed in impellers and decelerated with further increase in pressure in fixed vane or vane less stators.

Turbocompressors performance test code ISO 5389 excludes (high) vacuum pumps and jet-type compressors from its scope.

Presently standardisation work is done to create a simplified acceptance test code for turbo compressors intended to become an annex to ISO 5389 (reference CAGI/PNEUROP document):

- ASME PTC 10: Industry standard for performance measurement of turbo (similar to ISO 5389).

This International Standard applies to performance tests on turbocompressors of all types. It does not apply to fans and high-vacuum pump or to jet-type compressors with moving drive components.

Turbocompressors comprise machines in which inlet, compression and discharge are continuous flow processes. The gas is conveyed and compressed in impellers and decelerated with further increase in pressure in fixed vane or vane less stators.

This International Standard is intended to provide standard provisions for the preparation, procedure, evaluation and assessment of performance tests on compressors as specified above. The acceptance test of the performance is based on this performance test code. Acceptance tests are intended to demonstrate fulfilment of the order conditions and guarantees specified in the contract.

3.2.3 ISO/TR 12942 First edition 2012

Title: Compressors — Classification — Complementary information to ISO 5390

Technical report ISO/TR 12942 presents a classification of compressors based on working principle (main source for information of section 2.1), but also on design classes and functional classes.

According ISO/TR 12942 the generic term 'compressor' may refer to either a 'machine' or an 'apparatus'.

- **Compressor machine:** a compressor in which conversion of different types of energy into the potential energy of gas pressure is effected by mechanical motions of solid working members.

NOTE: In some design types of compressor machine, intermediate liquid service media can be used for driving-force transmitting from one solid member to the other one (e.g. in electrically/hydraulically driven piston and diaphragm compressor).

- **Compressor apparatus:** a compressor in which conversion of different types of energy into the potential energy of gas pressure is effected by stationary positions of working members effecting basic energy conversion functions, mechanical motions being used only for auxiliary functions, such as gas inlet and outlet, and energy-agent supply and withdrawal.

Given that the intended scope of the study comprises equipment driven by electric motors, it is evident that only compressor machines (that comprise mechanical motions of solid working members) can be part of the study scope.

Table 8: Overview of generic compressor standards

Standard	Name / title
EN ISO 1217:2009	Displacement compressors -- Acceptance tests
EN ISO 5389:2005	Turbo compressors -- Performance test code
ISO/TR 12942	Compressors — Classification — Complementary

information to ISO 5390

3.2.4 Other compressor related standards

Besides the standards presented above there are numerous other standards that may be used to define, describe and establish compressor aspects. These other standards are presented below, grouped into 'petrochemical standards' and 'standards for ancillary equipment'.

These standards are less relevant for ecodesign purposes as these mostly define compressor performance and characteristics to facilitate procurement and trade.

Table 9: Petrochemical standards

EN ISO 10439:2002	Petroleum, chemical and gas service industries -- Centrifugal compressors
ISO/DIS 10439-1	Petroleum, petrochemical and natural gas industries -- Axial and centrifugal compressors and expander-compressors -- Part 1: General requirements
ISO/DIS 10439-2	Petroleum, petrochemical and natural gas industries -- Axial and centrifugal compressors and expander-compressors -- Part 2: Non-integrally geared centrifugal and axial compressors
ISO/DIS 10439-3	Petroleum, petrochemical and natural gas industries -- Axial and centrifugal compressors and expander-compressors -- Part 3: Integrally geared centrifugal compressors
ISO/DIS 10439-4	Petroleum, petrochemical and natural gas industries -- Axial and centrifugal compressors and expander-compressors -- Part 4: Expander-compressors
ISO 10440-1:2007	Petroleum, petrochemical and natural gas industries -- Rotary-type positive-displacement compressors -- Part 1: Process compressors
EN ISO 10440-2:2001	Petroleum and natural gas industries - Rotary-type positive-displacement compressors - Part 2: Packaged air compressors (oil-free) (ISO 10440-2:2001)
EN ISO 10442:2002	Petroleum, chemical and gas service industries -- Packaged, integrally geared centrifugal air compressors
ISO 13631:2002	Petroleum and natural gas industries -- Packaged reciprocating gas compressors
ISO/NP 13707	Petroleum and natural gas industries -- Reciprocating compressors
ISO 13707:2000	Petroleum and natural gas industries -- Reciprocating compressors

Table 10: Compressors in heat pump / cooling applications

EN 810:1997	Dehumidifiers with electrically driven compressors - Rating tests, marking, operational requirements and technical data sheet
EN 12102:2008	Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling - Measurement of airborne noise - Determination of the sound power level 92/75/EEC (No)
EN 12693:2008	Refrigerating systems and heat pumps - Safety and environmental requirements - Positive displacement refrigerant compressors 2006/42/EC (C 214, 2009-09-08) 98/37/EC (C 22, 2009-01-28)
EN 13771-1:2003	Compressors and condensing units for refrigeration - Performance testing and test methods - Part 1: Refrigerant compressors
EN 13771-2:2007	Compressors and condensing units for refrigeration - Performance testing and test methods - Part 2: Condensing units
EN 12900:2005	Refrigerant compressors - Rating conditions, tolerances and presentation of manufacturer's performance data

EN 15218:2006	Air conditioners and liquid chilling packages with evaporative cooled condenser and with electrically driven compressors for space cooling - Terms, definitions, test conditions, test methods and requirements	2002/31/EC (No)
EN 16147:2011	Heat pumps with electrically driven compressors - Testing and requirements for marking of domestic hot water units	92/75/EEC (No)
EN 15879-1:2011	Testing and rating of direct exchange ground coupled heat pumps with electrically driven compressors for space heating and/or cooling - Part 1: Direct exchange-to-water heat pumps	
EN 14825:2012	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-Not yet available	
EN 14511-1:2011	Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling - Part 1: Terms and definitions	92/75/EEC (No)
EN 14511-2:2011	Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling - Part 2: Test conditions	92/75/EEC (No)
EN 14511-3:2011	Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling - Part 3: Test methods	92/75/EEC (No)
EN 14511-4:2011	Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling - Part 4: Requirements	92/75/EEC (No)
EN 16147:2011 / AC:2011	Heat pumps with electrically driven compressors - Testing and requirements for marking of domestic hot water units	92/75/EEC (No)

Table 11: Pneumatic tools

ISO 2787:1984	Rotary and percussive pneumatic tools -- Performance tests
ISO 3857-3:1989	Compressors, pneumatic tools and machines -- Vocabulary -- Part 3: Pneumatic tools and machines
ISO/DIS 3857-4	Compressors, pneumatic tools and machines -- Vocabulary -- Part 4: Air treatment
ISO 5391:2003	Pneumatic tools and machines -- Vocabulary
ISO 5393:1994	Rotary tools for threaded fasteners -- Performance test method

Table 12: Miscellaneous / ancillary equipment standards

ISO 3857-1:1977	Compressors, pneumatic tools and machines -- Vocabulary -- Part 1: General
ISO 3857-2:1977	Compressors, pneumatic tools and machines -- Vocabulary -- Part 2: Compressors
ISO 7183:2007	Compressed-air dryers -- Specifications and testing
ISO 8573-1:2010	Compressed air -- Part 1: Contaminants and purity classes
ISO 8573-2:2007	Compressed air -- Part 2: Test methods for oil aerosol content
ISO 8573-3:1999	Compressed air -- Part 3: Test methods for measurement of humidity
ISO 8573-4:2001 / Cor 1:2002	Compressed air -- Part 4: Test methods for solid particle content
ISO 8573-5:2001	Compressed air -- Part 5: Test methods for oil vapour and organic solvent content
ISO 8573-5:2001	Compressed air -- Part 5: Test methods for oil vapour and organic solvent content
ISO 8573-7:2003	Compressed air -- Part 7: Test method for viable microbiological contaminant content
ISO 8573-8:2004	Compressed air -- Part 8: Test methods for solid particle content by mass concentration

ISO 8573-9:2004	Compressed air -- Part 9: Test methods for liquid water content	
ISO 12500-1:2007	Filters for compressed air -- Test methods -- Part 1: Oil aerosols	
ISO 12500-2:2007	Filters for compressed air -- Test methods -- Part 2: Oil vapours	
ISO 12500-3:2009	Filters for compressed air -- Test methods -- Part 3: Particulates	
ISO 12500-4:2009	Filters for compressed air -- Methods of test -- Part 4: Water	
ISO 3857-1:1977	Compressors, pneumatic tools and machines -- Vocabulary -- Part 1: General	
ISO 3857-2:1977	Compressors, pneumatic tools and machines -- Vocabulary -- Part 2: Compressors	
ISO 5388:1981³³	Stationary air compressors -- Safety rules and code of practice	
ISO 5390:1977	Compressors -- Classification	
ISO 5941:1979	Compressors, pneumatic tools and machines -- Preferred pressures	
ISO/DIS 11011	Compressed air -- Energy efficiency -- Assessment	This standard applies to compressed air systems, not energy efficiency of the compressor package solely
EN 12583:2000	Gas supply systems - Compressor stations - Functional requirements	

3.2.5 EN 378-1:2013

Title: Refrigerating systems and heat pumps — Safety and environmental requirements

This standard includes a definition of compressors as it covers safety and environmental requirements of refrigerating systems and heat pumps; products that incorporate compressors.

The following definitions of components of refrigerating systems are established:

- 1) Refrigerating installation: Assembly of components of a refrigerating system and all the apparatus necessary for its operation.
- 2) Refrigerating equipment: Components forming a part of the refrigerating system, e.g. compressor, condenser, generator, absorber, liquid receiver, evaporator, surge drum.
- 3) Compressor: Device for mechanically increasing the pressure of a refrigerant vapour.
- 4) Motor compressor: Fixed combination of electrical motor and compressor in one unit.
 - a) Hermetic motor compressor: Combination consisting of a compressor and electrical motor, both of which are enclosed in the same housing, with no external shaft or shaft seals, the electrical motor operating in a mixture of oil and refrigerant vapour.
 - b) Semi hermetic (accessible hermetic) motor compressor: Combination consisting of a compressor and electrical motor, both of which are enclosed in the same housing, having removable covers for access, but having no external shaft or shaft seals, the electrical motor operating in a mixture of oil and refrigerant vapour.
 - c) Canned rotor motor compressor: Motor compressor within a sealed housing not enclosing the motor windings and having no external shaft.
- 5) Open compressor: Compressor having a drive shaft penetrating the refrigerant-tight housing.
- 6) Positive displacement compressor: Compressor in which compression is obtained by changing the internal volume of the compression chamber.

³³ At this moment there is the committee ballot NWIP working on ISO 5388. Time schedule is at this moment: annual meeting of TC118/SC06 in San Diego on 03/11/2012 and will probably take 36 months. After approval a number will be allocated by ISO.

- 7) Non-positive displacement compressor: Compressor in which compression is obtained without changing the internal volume of the compression chamber.

As this standard only applies to compressors handling refrigerants, the definition of a refrigerant is also provided below:

Refrigerant: Fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure and rejects heat at a higher temperature and a higher pressure usually involving changes of the state of the fluid.

Fluids mentioned in standards include all liquids, vapours, gasses and their mixtures.

3.2.6 Test codes

Furthermore following test codes are used for certain vacuum pumps:

- ISO/FDIS 21360-1: Vacuum technology -- Standard methods for measuring vacuum-pump performance -- Part 1: General description
- ISO/FDIS 21360-2: Vacuum technology -- Standard methods for measuring vacuum-pump performance -- Part 2: Positive displacement vacuum pumps
- ISO 5302:2003 Vacuum technology -- Turbo molecular pumps -- Measurement of performance characteristics

3.3 Product performance parameters

This section presents an overview of the physical units and thermodynamics that are relevant for evaluating compressor (energetic) performance. The sections 3.3.1 and 3.3.2 are taken from the workbook **Atlas Copco Compressed Air Manual (7th ed.)**³⁴, which provides a useful overview of compressor basics.

3.3.1 Physical Units

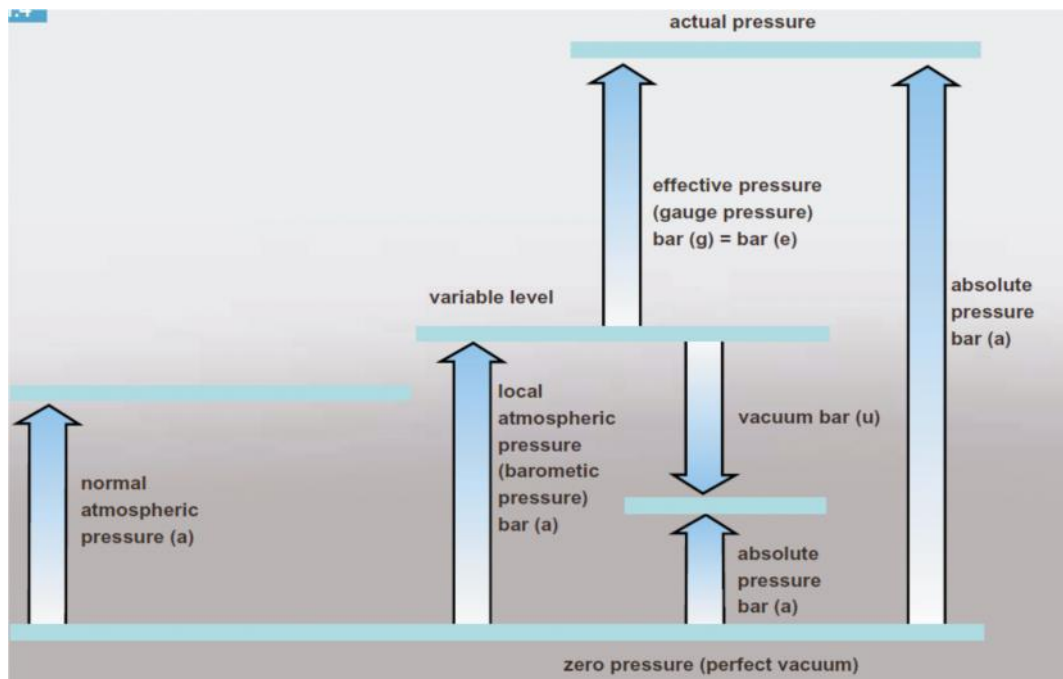
3.3.1.1 Pressure

The force on a square centimetre area of an air column, which runs from sea level to the edge of the atmosphere, is about 10.13 N. Therefore, the absolute atmospheric pressure at sea level is approximately $10.13 \cdot 10^4$ N per square meter, which is equal to $10.13 \cdot 10^4$ Pa (Pascal, the SI unit for pressure). Expressed in another frequently used unit:

1 bar = $1 \cdot 10^5$ Pa. The higher you are above (or below) sea level, the lower (or higher) the atmospheric pressure.

³⁴ Atlas Copco Compressor Air Manual - 7th edition. Published by Atlas Copco Air power NV, Belgium.

Figure 26: Absolute pressure, barometric pressure and effective or gauge pressure explained



3.3.1.2 Temperature

The temperature of a gas is more difficult to define clearly. Temperature is a measure of the kinetic energy in molecules. Molecules move more rapidly the higher the temperature, and movement completely ceases at a temperature of absolute zero. The Kelvin (K) scale is based on this phenomenon, but otherwise is graduated in the same manner as the centigrade or Celsius (C) scale:

$$T = t + 273.2$$

T = absolute temperature (K)

t = centigrade temperature (°C)

3.3.1.3 Thermal capacity

Heat is a form of energy, represented by the kinetic energy of the disordered molecules of a substance. The thermal capacity (also called heat capacity) of an object refers to the quantity of heat required to produce a unit change of temperature (1K), and is expressed in J/K. The specific heat of a substance is more commonly used, and refers to the quantity of heat required to produce a unit change of temperature (1K) in a unit mass of substance (1 kg).

Specific heat is expressed in J/ (kg * K). Similarly, the molar heat capacity is dimensioned J/ (mol * K).

The specific heat at constant pressure (c_p) is always greater than the specific c heat at constant volume (c_v). The specific heat for a substance is not a constant, but rises, in general, as the temperature rises. For practical purposes, a mean value may be used. For liquids and solid substances $c_p \approx c_v \approx c$. To heat a mass flow (m) from temperature t_1 to t_2 will then require:

$$P = \dot{m} * c * (T_2 - T_1)$$

P = heat power (W)

\dot{m} = mass flow (kg/s)

c = specific c heat (J/(kg * K))

T = temperature (K)

The explanation as to why c_p is greater than c_v is the expansion work that the gas at a constant pressure must perform. The ratio between c_p and c_v is called the isentropic exponent or adiabatic exponent, K , and is a function of the number of atoms in the molecules of the substance.

$$K = c_p / c_v$$

3.3.1.4 Work

Mechanical work may be defined as the product of a force and the distance over which the force operates on a body. Exactly as for heat, work is energy that is transferred from one body to another. The difference is that it is now a matter of force instead of temperature. An illustration of this is gas in a cylinder being compressed by a moving piston. Compression takes place as a result of a force moving the piston. Energy is thereby transferred from the piston to the enclosed gas. This energy transfer is work in the thermodynamic sense of the word. The result of work can have many forms, such as changes in the potential energy, the kinetic energy or the thermal energy.

The mechanical work associated with changes in the volume of a gas mixture is one of the most important processes in engineering thermodynamics. The SI unit for work is the Joule: $1 \text{ J} = 1 \text{ Nm} = 1 \text{ Ws}$.

3.3.1.5 Power

Power is work performed per unit of time. It is a measure of how quickly work can be done. The SI unit for power is the Watt: $1 \text{ W} = 1 \text{ J/s}$. For example, the power or energy flow to a drive shaft on a compressor is numerically similar to the heat emitted from the thermodynamic system plus the heat applied to the compressed gas.

3.3.1.6 Volume rate of flow

The volumetric flow rate of a system is a measure of the volume of fluid flowing per unit of time. It may be calculated as the product of the cross-sectional area of the flow and the average flow velocity. The SI unit for volume rate of flow is m^3/s . However, the unit litre/second (l/s) is also frequently used when referring to the volume rate of flow (also called the capacity) of a compressor. It is either stated as Normal litre/second (NI/s) or as free air delivery (l/s). With NI/s the air flow rate is recalculated to "the normal state", i.e. conventionally chosen as 1.01325 bar as defined in DIN 1343 (abs.) and 0°C . The Normal unit NI/s is primarily used when specifying a mass flow. For free air delivery (FAD) the compressor's output flow rate is recalculated to a free air volume rate at standard³⁵ inlet condition (e.g. inlet pressure 1 bar (a) and inlet temperature 20°C). The relation between the two volume rates of flow is (note that the simplified formula below does not account for humidity):

$$\begin{aligned} q_{\text{FAD}} &= q_{\text{N}} * (T_{\text{FAD}}/T_{\text{N}}) * (P_{\text{N}}/P_{\text{FAD}}) \\ q_{\text{FAD}} &= q_{\text{N}} * (273 + 20)/273 * (1.01325/1.00) \\ q_{\text{FAD}} &= q_{\text{N}} * 1.0872 \\ q_{\text{FAD}} &= \text{Free Air Delivery (l/s)} \\ q_{\text{N}} &= \text{Normal volume rate of flow (NI/s)} \\ T_{\text{FAD}} &= \text{standard inlet temperature (} 20^\circ\text{C)} \\ T_{\text{N}} &= \text{Normal reference temperature (} 0^\circ\text{C)} \\ p_{\text{FAD}} &= \text{standard inlet pressure (1.00 bar (abs.))} \\ p_{\text{N}} &= \text{Normal reference pressure (1.01325 bar(abs.))} \end{aligned}$$

³⁵ There are many "standard" conditions in use., depending on the test standard used and also depending on preferences of manufacturers.

3.3.2 Thermodynamics

3.3.2.1 Main principles

Energy exists in various forms, such as thermal, physical, chemical, radiant (light etc.) and electrical energy. Thermodynamics is the study of thermal energy, i.e. of the ability to bring about change in a system or to do work. The first law of thermodynamics expresses the principle of conservation of energy. It says that energy can be neither created nor destroyed, and from this, it follows that the total energy in a closed system is always conserved, thereby remaining constant and merely changing from one form into another. Thus, heat is a form of energy that can be generated from or converted into work. The second law of Thermodynamics states that there is a tendency in nature to proceed toward a state of greater molecular disorder. Entropy is a measure of disorder: Solid crystals, the most regularly structured form of matter, have very low entropy values. Gases, which are more highly disorganized, have high entropy values. The potential energy of isolated energy systems that is available to perform work decreases with increasing entropy. The Second Law of Thermodynamics states that heat can never of “its own effort” transfer from a lower-temperature region to a higher temperature region.

3.3.2.2 Gas laws³⁶

Boyle’s law states that if the temperature is constant (isotherm), then the product of the pressure and volume are constant. The relation reads:

$$p_1 * V_1 = p_2 * V_2$$

Where:

p = absolute pressure (Pa)

V = volume (m³)

This means that if the volume is halved during compression, then the pressure is doubled, provided that the temperature remains constant.

Charles’s law says that at constant pressure (isobar), the volume of a gas changes in direct proportion to the change in temperature. The relation reads:

$$V_1 / T_1 = V_2 / T_2$$

Where:

V = volume (m³)

T = absolute temperature (K)

The universal law of state for gases is a combination of Boyle’s and Charles’s laws. This states how pressure, volume and temperature will affect each other. When one of these variables is changed, this affects at least one of the other two variables. This can be written:

$$p * v = R' * T$$

Where:

p = absolute pressure (Pa)

v = specific volume (m³/kg)

T = absolute temperature (K)

R' = R / M = individual gas constant (J/kg K)

³⁶ Atlas Copco Compressed Air Manual 2010

R = universal gas constant = 8314.4621 (J/[kmol K])

M = Molecular weight of a gas type (kg/mol)

The individual gas constant R' only depends on the properties of the gas.

Changes in state for a gas can be followed from one point to another in a p/V diagram. For real-life cases, three axes for the variables p , V and T are required. With a change in state, we are moved along a 3-dimensional curve on the surface in the p , V and T space.

However, to simplify, we usually consider the projection of the curve in one of the three planes. This is usually the p/V plane. Five different descriptions of changes in state can be considered:

- 1) Isochoric change of state (constant volume),
- 2) Isobaric change of state (constant pressure),
- 3) Isothermal change of state (constant temperature),
- 4) Isentropic change of state is adiabatic (without heat exchange with surroundings) and reversible (without change in entropy),
- 5) Polytropic change of state is a replacement model that describes the change of a gas between states 1 and 2 that is unknown in detail. P , V and T can all change. Isochoric, isobaric, isothermal and isentropic are special polytropic changes of state.

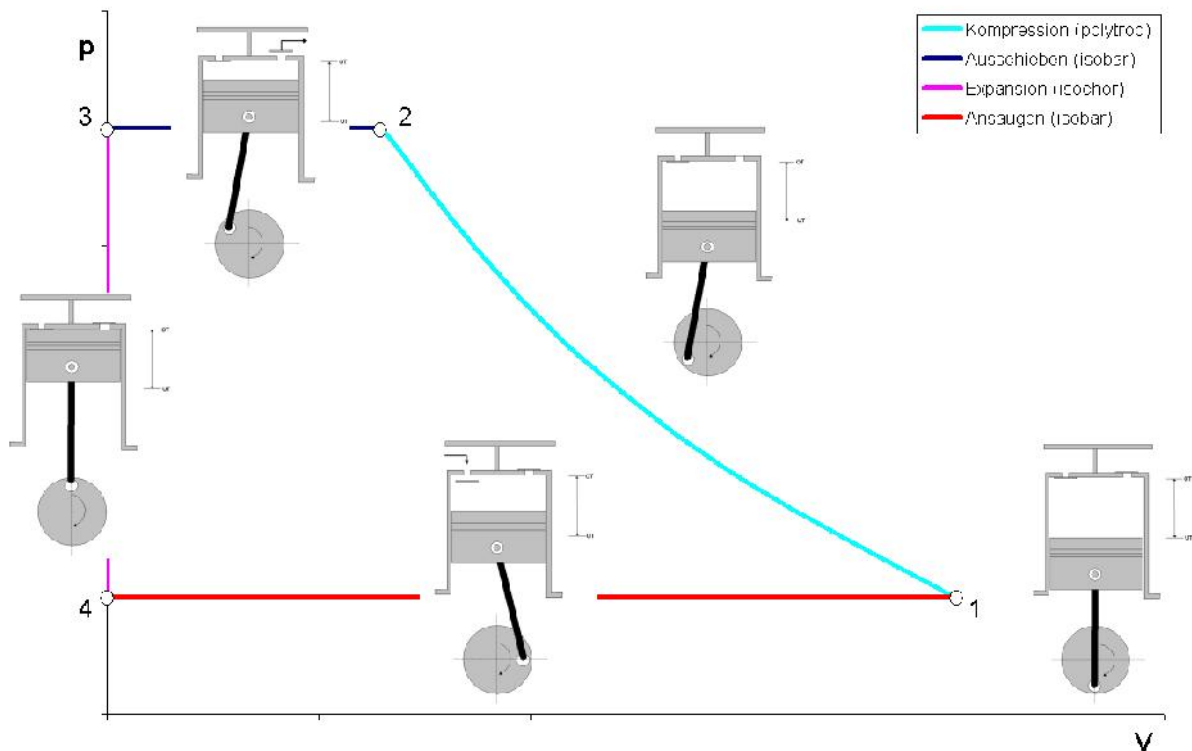
Each change of state is associated with an amount of work (input or output). The equations to calculate the amount of work involved in the change of state are explained in Annex I. These equations show that e.g. more work is required for isentropic compression than for isothermal compression.

The compression procedure involves several changes of state and follows, **for displacement compressors**, always the subsequent principle:

- 1) Drawing in of the gas at p_1 (basically isobaric)
- 2) Closure of inlet valves (e.g. reciprocating or membrane compressors) or passing of control edges in the housing by rotors or slides (e.g. screw or vane compressors). The working chamber is now completely separated from the suction- and the pressure side.
- 3) Compression (or conveying in the special case of isochoric compressors) from p_1 to p_2 .
- 4) Opening of outlet valves or passing of outlet control edges in the housing.
- 5) Discharge of the compressed gas at p_2 (basically isobaric) into the system on the pressure side.

One procedure (cycle) comprises all five changes of state and can be seen in the figure below.

Figure 27: Pressure-volume-diagram of a simplified (idealised) reciprocating compressor with no clearance volume



It can be shown that in a pressure-volume diagram, that the work required by the compression procedure equals the area inside the lines that connect the states 1-2-3-4

$$(W = \oint V dp).$$

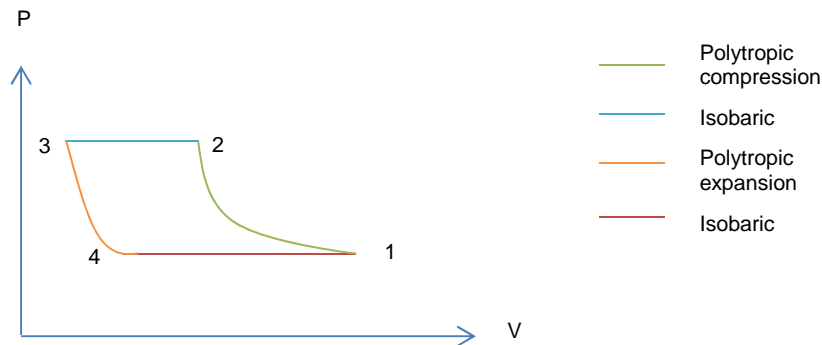
A real or more realistic reciprocating compressor experiences aerodynamic pressure losses at the inlet and outlet valves and re-expansion before the actual intake of new gas. Figure 28 shows the pressure-volume diagram of such a compressor, still without internal or external leakages. Again, the area inside the lines that connect the states 1-2-3-4 represents the work of the compression procedure. Mechanical losses e.g. caused by friction in bearings and seals are not included.

It is important to note that obviously even an ideal compressor without any leakage, friction, aerodynamic pressure losses etc. requires an amount of energy to compress gas from state 1 to state 2 and that this theoretical minimum energy requirement is depending on the compression task.

This is a major difference to e.g. electric motors that without friction and electromagnetic losses could transform electrical energy (pure exergy) into mechanical energy (pure exergy) without extra energy requirements.

The compression process of a piston compressor with re-expansion of the clearance volume can be seen in the figure below.

Figure 28: Pressure-Volume-diagram with clearance volume, but no intake/outlet pressure losses



Annex I explains in more detail the changes of state described above.

3.3.3 Efficiency of compressors

After having defined the units/metrics used for evaluating compressor performance, the current approaches for expressing energy efficiency of compressors can be explained.

In compressors, the useful output cannot be clearly defined. Therefore it is common practice to compare the energy needed for a real compressor with that needed by an ideal compressor for the same task. Preferably both are expressed in the same unit (for example power in W or energy in J or kWh).

The efficiency of compressors can be measured by comparing typically with e.g.:

- isentropic (adiabatic and reversible) compression process;
- isothermal compression process.

Then there are also other forms of expressing the energy "efficiency" or energetic performance of compressors, such as the **specific energy requirement**. Also the volumetric efficiency will be discussed.

3.3.3.1 Isentropic efficiency

The compressor efficiency can be expressed as **isentropic efficiency**, the ratio of the required isentropic power to shaft power.

ISO 1217 and ISO 5389 both describe the formula for the isentropic efficiency:

$$\eta_{isen} = \frac{P_{isen}}{P}$$

where:

$$P_{isen} = \dot{V}_1 \cdot p_1 \frac{1}{(\gamma - 1)} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$$

P = input power (W or kW), where P depends on the chosen system boundaries

And:

p_1 = Absolute intake pressure (Pa)

\dot{V}_1 = Intake volume flow rate (m³/s)

$\kappa = c_p / c_v$ = isentropic exponent

The isentropic efficiency is therefore the amount of work needed by the ideal isentropic compression divided by the power input of the real compressor for the same compression task (p_1, p_2, \dot{V}_1)

The isentropic efficiency assumes that no heat exchange to the surroundings takes place, but in reality the gas is often cooled down to certain operating temperatures. This heat can be recovered, but this aspect is not considered in the isentropic efficiency. Cooling after compression does not affect the efficiency of the compression process itself. Oil-injection and multiple stage compression with intercooling do affect the energy efficiency of the compression process.

Adiabatic efficiency is quite often used instead of the more precise name "isentropic efficiency" (isentropic is adiabatic and reversible). The isentropic efficiency is the thermodynamically correct way to evaluate compressor performance.

Note: In thermodynamics, an isentropic change of state or isentropic change of state is one in which for purposes of engineering analysis and calculation, one may assume that the process takes place from initiation to completion without an increase or decrease in the entropy of the system, i.e., the entropy of the system remains constant. Entropy is a measure of how evenly energy is distributed in a system. In a physical system, entropy provides a measure of the amount of energy that cannot be used to do work. It can be proven that any reversible adiabatic change of state is an isentropic change of state.

Depending on the type, the application range, the compressor size and compression task the isentropic efficiency is in the range of 55-85% for most compressor designs.

3.3.3.2 Isothermal efficiency

The **isothermal efficiency**, being the ratio of the required isothermal power to shaft power, can also be used as basis for expressing compressor energy efficiency.

Isothermal efficiency = P_{isoth}/P

$$P_{\text{isoth}} = \dot{V}_1 * p_1 * \ln(p_2/p_1)$$

where:

P = input power (W or kW), where P depends on the chosen system boundaries

\dot{V}_1 = Intake volume flow rate (m³/s)

p_1 = Absolute intake pressure (Pa)

p_2/p_1 = Pressure ratio

However, usage of **isentropic efficiency** is considered more suitable for the following reasons:

- Simplified comparison between different operating pressures / pressure ratios;
- Isentropic efficiency is widely accepted in other (i.e. non-industrial air) technical fields like energy technology;
- Isentropic efficiency is less sensitive regarding deviation of measurement conditions (operating point) and gas properties when comparing to specific power requirement;
- Compressors without internal or interstage cooling are physically not able to compress isothermally;
- Due to additional losses, even no compressor with internal cooling is able to reach even isentropic compression.

3.3.3.3 Other energetic performance parameters

Specific power requirement

The **specific power requirement** or $\text{kW}/(\text{m}^3/\text{min})$) is commonly used in the field of industrial compressed air packages (see e.g. ISO 1217). Variations of this specific power requirement exist and may be referred to as specific energy requirement or consumption (expressed as e.g. J/l , J/m^3 (SI units), kWh/m^3) or deviations thereof.

The specific power requirement and isentropic efficiency can both be calculated based on ISO 1217 or ISO 5389 measurement data (no other or additional measurement required), conversion by calculation is possible.

Volumetric efficiency

Then there is also a volumetric efficiency which describes how good the geometric volume of the displacement compressor is used. This efficiency has no direct influence on the energetic efficiency, and therefore not used in further analysis as parameter.

3.3.4 Primary performance parameters

From the explanation on isentropic efficiency above it can be seen that the volume flow rate \dot{V}_1 is characterizing the capacity of the compressor, the isentropic exponent κ is characterizing the type of gas and the inlet pressure p_1 together with the outlet pressure p_2 are characterizing the compression task.

Therefore these are the primary product performance parameters:

- Inlet pressure plus pressure ratio;
- Volume- or (mass-) flow-rate;
- Type of gas (represented by κ);

To complete the possible calculation of the isentropic efficiency the electric power input of the compressor also needs to be known.

Table 13 Primary performance parameters

Parameter	Unit or metric (SI units)
Inlet pressure, delivery pressure / pressure ratio	bar, (Pa)
Displaced volume of gas	m^3/hour , l/min , l/s
Displaced mass of gas	ton/hour
Type of gas	represented by κ
(electric) power input at specific operating points	(W), kW

In order to allow comparative assertions these values need to be established for specific operating conditions. Therefore operating conditions become a primary performance parameter as well.

ISO 1217 and ISO 5389 are both suitable to measure performance data (energy consumption, volume flow, etc.) in arbitrary operating points (full load, part load), whereby ISO 1217 also specifies information on idle power consumption and ISO 1217 annex E provides information regarding performance data of variable speed compressors for five operating points in the control range.

Part load in the compressor context can mean:

- volume flow lower than maximum;

- operating pressure lower than maximum;

However, considering the vast variety in applications of compressors, the above primary performance parameters have to be seen in the context of their application. This context can be expressed by secondary performance parameters.

3.3.5 Secondary performance parameters

The secondary performance parameters describe aspects that indirectly influence the primary performance parameters and may relate to gas quality, control capabilities, cooling/ heat rejection strategies and - very important - type of gas processed, a.o.

- 1) Gas quality
 - a) compressed gas and air quality as required by the application, is affected / determined by:
 - i) suction gas quality
 - ii) compressor technology
 - iii) gas treatment integrated in the compressor package (product level)
 - iv) gas treatment downstream the compressor package (system level)
 - b) for compressed air: ISO 8573 categories
 - i) to be detailed later on...
 - c) discharge temperature at compressor package outlet (isentropic or isothermal)
- 2) Control capabilities
 - a) regarding volume flow
 - i) constant flow:
 - (1) on/off - more typical for reciprocating equipment
 - (2) load/idle/stop - more typical for rotary equipment
 - ii) variable flow
 - (1) variable speed
 - (2) inlet throttling
 - (3) variable displacement
 - b) Regarding operating pressure
 - i) changes suction and discharge pressure (consequently varying pressure ratio)
 - c) others?
- 3) Type of heat rejection / cooling (air, water)
- 4) Capability of handling certain gases (including gas contaminations)
 - a) air
 - b) inert gases (see definition in EN 1012-1)
 - c) process gases (also hazardous media)
 - d) explosive media -> ATEX
- 5) Heat recovery
 - a) using hot compressor cooling air for room heating
 - b) using compressor heat rejection for
 - i) process heating
 - ii) water heating
- 6) Sound emission
 - a) for mobile compressors covered by 2000/14/EC (OND)

Especially the type of gas handled has an influence on compressor efficiency as the requirements that handling of certain gases impose upon sealing (that create the barrier between the compression chamber and the rest of the equipment) may introduce significant losses: Processing of hazardous gases requires considerable efforts regarding the performance (gas tightness) of the sealing (in particular seals combined with bearings, to isolate the compression chamber through a rotating shaft from its surroundings).

Table 14 Secondary performance parameters

Parameter	Aspect (unit or metric, if applicable)
Inlet/outlet gas quality	temperature (K or °C), moisture, removal of contaminants (oil, dust, other...), corrosion resistance, ...
Part load capabilities	can the output be adjusted according actual load?
Sound power	(dB)
Waste heat	--

The primary and secondary performance parameters are expected to be the main drivers in the selection of compressors for a certain job. Other selection parameters (price, installation issues, maintenance issues, etc.) shall be discussed later on.

Categorisation by air quality delivered

Compressors can also be categorised by the quality of air (or gas) they supply. The quality of air delivered depends on the type of compressor and/or associated equipment (oil separators etc.). The industry has set up a categorisation. The first three air quality levels are commonly used in industrial applications.

Table 15: Air quality differentiation Error! Bookmark not defined.

Quality	Applications
Plant air	Air tools, general plant air
Instrument air	Laboratories, paint spraying, powder coating, climate control
Process air	Food and pharmaceutical process air, electronics
Breathing air	Hospital air systems, diving tank refill stations, respirators for cleaning and/or grit blasting

4 Existing legislation and measures

This section presents an initial assessment of existing legislation inside and outside the EU.

At the moment there is no specific legislation applicable to (electric driven) compressors in the EU, apart from a requirement for outdoor noise of compressors. Other pieces of EU legislation may be indirectly relevant to compressors.

4.1 Legislation and agreements at EU level

Compressors may be addressed, directly or indirectly, by the following EU legislation (non-exhaustive list):

- Ecodesign Directive 2009/125/EC;
- Electric Motors Regulation 640/2009;
- Fan Regulation 327/2011;
- Energy Labelling Directive 2010/30/EC
- LVD - Low Voltage Directive 2006/95/EC;
- MD - Machinery Safety Directive No 2006/42/EC;
- Noise by outdoor equipment - Directive 2000/14/EC;
- PED - Pressure Equipment Directive 97/23/EC ;
- Simple Pressure Vessels Directive (87/404/EEC);
- *GAD 2009/142/EC*
- *ATEX directive 94/9/EC*
- *EMC directive 2004/108*
- *WEEE 2012/19/EU*
- *RoHS 2002/95/EC*
- *Packaging 94/62/EC* (amended by 2004/12/EC, 2005/20/EC and Regulation No 219/2009)
- *EPBD 2010/31/EU*
- *(IED - Industrial Emissions Directive 2010/75/EC) includes former Large Combustion Plant Directive and Integrated Pollution Prevention and Control (IPPC) Directive;*

The latter is more applicable to compressors using combustion engines or compressors handling hazardous substances only.

For the Machinery Regulation harmonised standards specifically applying to compressors (EN 1012 and EN 2151) have been identified. For the other Regulations/Directives/measures requirements may affect compressors, but no direct link in the form of standards could be identified.

4.1.1 Ecodesign Directive 2009/125/EC

The Ecodesign Directive is relevant for electrically driven compressors as its implementing measures may address compressors directly or indirectly.

Almost all Ecodesign preparatory studies that have dealt with / are dealing with compressors relate to cooling and heating applications of compressors.

Table 16: Overview of compressors in equipment covered by ecodesign/energy labelling

EUP study	Scope	Products using compressors in scope of lot 31	Compressor type (indicative only / examples only)
LOT 1	Central Heating Boilers (max. 400 kW power input)	Heat pumps	Many are scroll, fully hermetic
LOT 2	Water heaters (gas/oil/electric)	Heat pumps	
LOT 10	Air-conditioners < 12kW	Air to air-conditioners (split package / single package)	Reciprocating hermetic, scroll and rotary (fix-vane) compressors
LOT 11	Electric motor systems	Electric motors, pumps, circulators and fans	Compressors may incorporate products covered by these lots
LOT 12	Commercial refrigerators and freezers	Display cabinets, vending machines	Hermetic piston, rotary and reciprocating compressors
LOT 13	Domestic refrigerators and freezers		Hermetic piston, rotary and reciprocating compressors
LOT 16	Laundry dryers	Heat pump dryers	Hermetic piston, rotary and reciprocating compressors
LOT 21	Central air heating products	Heat pumps > 12kW	Reciprocating hermetic, scroll compressors
ENTR LOT 1	Refrigeration application	Chillers, condensing units	Hermetic reciprocating, Hermetic scroll, Semi-hermetic reciprocating, Open reciprocating, Open screw, Semi-hermetic screw
ENTR LOT 6	Air-conditioning and ventilation	water/air to air-conditioners > 12kW Air to water chillers Condensing units	rotary, scroll, reciprocating, screw, centrifugal

Up to now (July 2012) the preparatory studies for Lot 10 - room air conditioners, Lot 13 - domestic refrigerating equipment, Lot 16 - domestic tumble dryers, have resulted in ecodesign and energy labelling requirements for products that may contain refrigerating (and heating) compressors.

The Lot 11 preparatory studies on **electric motor systems** have resulted in measures that are (indirectly) relevant for compressor definitions or performances: the **Electric Motor Regulation**, and the **Fan Regulation**, as fans are also equipment handling gaseous media and a definitions is needed to discern the one from the other. These two measures are described in more detail below.

As regards the other Lots implementing measures are being developed / have been proposed, but have not yet been finalised.

4.1.2 Electric motors Regulation 640/2009

The Electric motor Regulation is relevant for electrically driven compressors as the motor may be included in the definition of what comprises a 'compressor' (just the bare compressor or the compressor package).

In Regulation 640/2009 the definition of the electric motor is:

‘Motor’ means an electric single speed, three-phase 50 Hz or 50/60 Hz, squirrel cage induction motor that:

- has 2 to 6 poles,
- has a rated voltage of U_N up to 1 000 V,
- has a rated output P_N between 0.75 kW and 375 kW,

- is rated on the basis of continuous duty operation.

Excluded are motors that:

- motors designed to operate wholly immersed in a liquid;
- motors completely integrated into a product (for example gear, pump, fan or compressor) of which the energy performance cannot be tested independently from the product;
- motors specifically designed to operate in non-standard ambient conditions (see Regulation for more specific descriptions of these conditions);
- brake motors.

The ecodesign requirements address the energy efficiency of the motor, expressed in IE levels of efficiency. The ecodesign requirements apply in accordance with the following timetable:

- 1) from 16 June 2011, all motors placed on the market shall not be less efficient than the IE2 efficiency level (IE levels defined in Annex I, point 1);
- 2) from 1 January 2015: motors with a rated output of 7,5-375 kW shall not be less efficient than the IE3 efficiency level or meet the IE2 efficiency level and be equipped with a variable speed drive.
- 3) from 1 January 2017: all motors with a rated output of 0,75-375 kW shall not be less efficient than the IE3 efficiency level, or meet the IE2 efficiency level and be equipped with a variable speed drive.

4.1.3 Fan Regulation 327/2011

In Regulation 327/2011 'Fan' means a rotary bladed machine that is used to maintain a continuous flow of gas, typically air, passing through it and whose work per unit mass does not exceed 25 kJ/kg, and which:

- is designed for use with or equipped with an electrical motor with an electric input power
- between 125 W and 500 kW (≥ 125 W and ≤ 500 kW) to drive the impeller at its optimum energy efficiency point,
- is an axial fan, centrifugal fan, cross flow fan or mixed flow fan,
- may or may not be equipped with a motor when placed on the market or put into service;

Excluded are fans that:

- products with a sole electric motor of 3 kW or less where the fan is fixed on the same shaft used for driving the main functionality;
- laundry and washer dryers ≤ 3 kW maximum electrical input power;
- kitchen hoods < 280 W total maximum electrical input power attributable to the fan(s).

The ecodesign requirements address the energy efficiency of the driven fan. The ecodesign requirements apply in accordance with the following timetable:

1. first tier: from 1 January 2013, ventilation fans shall not have a lower target energy efficiency than as defined in Annex I, Section 2, Table 1 (the target values differ per fan type);
2. second tier: from 1 January 2015, all fans shall not have a lower target energy efficiency than as defined in Annex I, Section 2, Table 2.

4.1.4 Energy Labelling Directive 2010/30/EU (recast)

The recast Energy Labelling Directive 2010/30/EU was adopted by the European Parliament and Council the 19th May 2010. The directive introduces the possibility for new efficiency classes A+, A++ and A+++ on top of the existing A grade for the most energy-efficient household products.

The new directive extends the energy label to energy-related products in the commercial and industrial sectors, e.g. cold storage rooms and vending machines. A Commission working group will determine the energy classes and the specific products that will be labelled.

The extension of the scope from energy-using to energy-related products (including construction products) implies that the Directive covers any good having an impact on energy consumption during use. These products could not only consume energy but could also "have a significant direct or indirect impact" on energy savings. Examples are window glazing and outer doors.

Energy labelling requirements are already in force for a number of products and the Commission will adopt delegated regulations for energy labelling in parallel with the adoption of the Ecodesign regulations. The new labels will be mandatory for products placed on the market a defined time after the regulation has been published in the OJ.

According to the new Energy Labelling Directive, the layout of the energy efficiency label gives room to up to three new energy classes to reflect technological progress. However, the total number of classes will still be limited to seven. The labelling colour scheme will be adjusted accordingly, so that the highest energy efficiency class will remain dark green and the lowest energy efficient class will be red.

4.1.5 LVD - Low Voltage Directive 2006/95/EC

The Low Voltage Directive (LVD) 2006/95/EC is one of the oldest Single Market Directives adopted before the "New" or "Global" Approach. However, it does characterise both with a conformity assessment procedure applied to equipment before placing on the Market and with Essential Health and Safety Requirements (EHSRs) which such equipment must meet either directly or by means of harmonised standards. The LVD ensures that electrical equipment within certain voltage limits both provides a high level of protection for European citizens and enjoys a Single Market in the European Union.

The Directive covers electrical equipment with a voltage between 50 and 1 000 V for alternating current and between 75 and 1 500 V for direct current. It should be noted that these voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment. For most electrical equipment, the health aspects of emissions of Electromagnetic Fields are also under the domain of the Low Voltage Directive.

For electrical equipment within its scope, the Directive covers all health and safety risks, thus ensuring that electrical equipment is safe in its intended use. Guidelines on application and Recommendations are available - including LVD Administrative Co-operation Working Group (LVD ADCO) documents and recommendations - as well as European Commission opinions within framework of the Directive.

In respect of conformity assessment, there is no third party intervention, as the manufacturer undertakes the conformity assessment. There are "Notified Bodies" which may be used to provide reports in response to a challenge by a national authority as to the conformity of the equipment. Note that this Directive is a codified version of the original Directive (73/23/EEC) which was published for the purpose of clarity following numerous amendments.

4.1.6 MD - Machinery Safety Directive No 2006/42/EC

The Machinery Directive 2006/42/EC provides the regulatory basis for the harmonisation of the essential health and safety requirements for machinery at European Union level. Machinery can be described as "an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application".

The essential requirements related to environmental aspects may address noise, vibrations, radiation, emissions of hazardous materials and substances (Annex 1, item 1.5).

Essentially performing a dual function, the Directive not only promotes the free movement of machinery within the Single Market, but also guarantees a high level of protection to EU workers and citizens. Being a "New Legal Framework" Directive, it promotes harmonisation through a combination of mandatory health and safety requirements and voluntary harmonised standards.

Such directives apply only to products which are intended to be placed (or put into service) on the EU market for the first time.

The Machinery Safety Directive 2006/42/EC was published on 9th June 2006 and it is applicable from 29th December 2009, replacing the Machinery Directive 98/37/EC.

4.1.7 Noise by outdoor equipment - Directive 2000/14/EC

As amended by 2005/88/EC, on the noise emission in the environment by equipment for use outdoors defines compressors as follows:

Any machine for use with interchangeable equipment which compresses air, gases or vapours to a pressure higher than the inlet pressure. A compressor comprises the bare compressor itself, the prime mover and any component or device supplied, which is necessary for safe operation of the compressor.

Excluded are the following categories of device:

1. fans, i.e. devices producing air circulation at a positive pressure of not more than 110 000 Pascal's
2. vacuum pumps, i.e. devices or appliances for extracting air from an enclosed space at a pressure not exceeding atmospheric pressure
3. gas turbine engines.

The administrative and legal position is given in the Directive 2000/14/EC of the European Parliament and of the Council of 8 May 2000, on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors. Noise emissions of outdoor machinery are regulated by European directive 2000/14/EC. This directive lays down minimal requirements (such as noise marking, noise emission limits) for outdoor machinery that must be respected before equipment can be placed on the European market. It represents a conventional ("command-and-control") regulatory approach. The directive has been amended by the Directive 2005/88/EC of the European Parliament and of the Council of 14 December 2005 and by the Regulation (EC) 219/2009.

Figure 29: Noise requirements per product group (type of equipment)

Type of equipment	Net installed power P (in kW) Electric power P_d (1) in kW Mass of appliance m in kg Cutting width L in cm	Permissible sound power level in dB/1 pW	
		Stage I as from 3 January 2002	Stage II as from 3 January 2006
Compaction machines (vibrating rollers, vibratory plates, vibratory rammers)	$P \leq 8$	108	105
	$8 < P \leq 70$	109	106
	$P > 70$	$89 + 11 \lg P$	$86 + 11 \lg P$
Tracked dozers, tracked loaders tracked excavator-loaders	$P \leq 55$	106	103
	$P > 55$	$87 + 11 \lg P$	$84 + 11 \lg P$
Wheeled dozers, wheeled loaders, wheeled excavator-loaders, dumpers, graders, loader-type landfill compactors, combustion-engine driven counterbalanced lift trucks, mobile cranes, compaction machines (non-vibrating rollers), paver-finishers, hydraulic power packs	$P \leq 55$	104	101
	$P > 55$	$85 + 11 \lg P$	$82 + 11 \lg P$

Type of equipment	Net installed power P (in kW) Electric power P_d (1) in kW Mass of appliance m in kg Cutting width L in cm	Permissible sound power level in dB/1 pW	
		Stage I as from 3 January 2002	Stage II as from 3 January 2006
Excavators, builders' hoists for the transport of goods, construction winches, motor hoes	$P \leq 15$	96	93
	$P > 15$	$83 + 11 \lg P$	$80 + 11 \lg P$
Hand-held concrete-breakers and picks	$m \leq 15$	107	105
	$15 < m < 30$	$94 + 11 \lg m$	$92 + 11 \lg m$
	$m \geq 30$	$96 + 11 \lg m$	$94 + 11 \lg m$
Tower cranes		$98 + \lg P$	$96 + \lg P$
Welding and power generators	$P_{ei} \leq 2$	$97 + \lg P_{ei}$	$95 + \lg P_{ei}$
	$2 < P_{ei} \leq 10$	$98 + \lg P_{ei}$	$96 + \lg P_{ei}$
	$P_{ei} > 10$	$97 + \lg P_{ei}$	$95 + \lg P_{ei}$
Compressors	$P \leq 15$	99	97
	$P > 15$	$97 + 2 \lg P$	$95 + 2 \lg P$
Lawnmowers, lawn trimmers/lawn edge trimmers	$L \leq 50$	96	94 (2)
	$50 < L \leq 70$	100	98
	$70 < L \leq 120$	100	98 (2)
	$L > 120$	105	103 (2)

(1) P_{ei} for welding generators: conventional welding current multiplied by the conventional load voltage for the lowest value of the duty factor given by the manufacturer.

P_{ei} for power generators: prime power according to ISO 8528-1:1993, point 1.3.3.2.

(2) Indicative figures only. Definitive figures will depend on amendment of the Directive following the report required in Article 20(3). In the absence of any such amendment, the figures for stage I will continue to apply for stage II.

The permissible sound power level shall be rounded to the nearest whole number (less than 0,5 use lower number; greater than or equal to 0,5 use higher number).

4.1.8 PED - Pressure Equipment Directive 97/23/EC

The Pressure Equipment Directive (PED) became obligatory throughout the EU from 29 May 2002 and provides the legislative framework for equipment subject to a pressure hazard. The main aims

are to harmonise standards regarding the design, manufacture, testing and conformity assessment of pressure equipment and assemblies of pressure equipment.

4.1.9 Simple Pressure Vessels Directive (87/404/EEC)

The Directive applies to series produced, unfired pressure vessels of welded construction which are intended to contain air or nitrogen at an internal gauge pressure greater than 0.5 bar. There are also limits to the maximum working pressure and the minimum working temperature, and it has specific requirements covering the geometry of the design and the materials that can be used.

The main application of vessels covered by the Directive is to provide a pressurised reservoir to smooth the air supply from a compressor and minimise the change in pressure with variations in the load or flow rate. The compressed air from the vessel could be used as part of a paint spraying system, or to drive various pneumatic tools, fluid logic systems and actuators in a factory.

4.1.10 GAD - Appliances burning gaseous fuels (non-electric compressors)

The European Parliament and the Council Directive 2009/142/EC (codified version) on Appliances burning gaseous fuels (GAD) is based on the New Approach. The scope of the GAD is restricted to appliances burning gaseous fuels used for cooking, heating, hot water production, refrigeration, lighting and washing, i.e. the GAD covers mainly common consumer and commercial products.³⁷ So-called fittings are also covered.

Appliances specifically designed for use in industrial processes carried out on industrial premises are excluded.

4.1.11 ATEX regulation 94/9/EC

Directive 94/9/EC of the European Parliament and the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres (OJ L 100, 19.4.1994)

This directive applies to equipment used in hazardous areas (potential for an explosion) including equipment designed to prevent explosions³⁸. The safety of workers is covered by a separate directive. The directive only applies to equipment that introduces energy, electrically or mechanically, into a potentially explosive atmosphere.

4.1.12 EMC – Electromagnetic Compatibility Directive 2004/108/EC

The Electromagnetic Compatibility Directive was adopted on 15th December 2004 and repealed Directive 89/336/EEC. The EMC³⁹ is in place to ensure that electrical equipment is designed such that it doesn't interfere with or get disturbed by other electrical equipment and thus functions properly.

The main objective of the Directive 2004/108/EC of the European Parliament and of the Council, of 15 December 2004, on the approximation of the Laws of Member States relating to electromagnetic compatibility (EMC) is thus to regulate the compatibility of equipment regarding EMC:

- equipment (apparatus and fixed installations) needs to comply with EMC requirements when it is placed on the market and/or taken into service;

³⁷ Article 1 of this directive states the scope as: Appliances specifically designed for use in industrial processes carried out on industrial premises shall be excluded from its scope.

³⁸ <http://www.conformance.co.uk/adirectives/doku.php?id=atex>

³⁹ OJ L 390, 31.12.2004, p. 24–37, <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:390:0024:0037:EN:PDF>

- the application of good engineering practice is required for fixed installations, with the possibility for the competent authorities of Member States to impose measures if non-compliance is established.

The EMC Directive first limits electromagnetic emissions of equipment in order to ensure that, when used as intended, such equipment does not disturb radio and telecommunication as well as other equipment. The Directive also governs the immunity of such equipment to interference and seeks to ensure that this equipment is not disturbed by radio emissions when used as intended.

Before equipment is placed on the market (including both apparatus and fixed installations) they must be shown to meet the requirements set out in the EMC Directive.

4.1.13 Waste Electrical and Electronic Equipment Directive

The European Parliament and the Council Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) apply to compressors⁴⁰ under category 6 and 9 of “Annex I and II”.⁴¹

The requirements of the Directive are transposed into national law by individual Member States and it is important to be aware of national take back and recycling schemes and arrangements in specific Member States. The Directive requires electrical and electronic equipment to be taken to a suitable authorised treatment facility at the end of its life so that it can be treated/ dismantled and materials recovered for recycling where possible. The Directive outlines minimum requirements for the treatment and recovery of WEEE.

The WEEE Directive also requires products to be labelled, in order to identify them as EEE, with the aim of minimising the wrong disposal of WEEE. Where it is not feasible to put the label on the actual product it should be included in the documentation accompanying the product.

This Directive therefore deals with many of the end-of-life environmental impacts of electrical and electronic equipment.

For this category Member states shall ensure to reach the following targets:

- the rate of recovery shall be increased to a minimum of 80 % by an average weight per appliance, and component, material and substance reuse and recycling shall be increased to a minimum of 75 % by an average weight per appliance.

4.1.14 RoHS - Restriction of the Use of Certain Hazardous Substances

Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment OJ L 174 of 1 July 2011

Recast of RoHS - Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment 2002/95/EC.

The RoHS Directive, in tandem with the WEEE Directive prevents the use of certain hazardous materials in new electrical and electronic equipment (EEE) placed on the market. This limits the impact of the EEE at the end of its life and it also ensures harmonisation of legislation on the use of hazardous materials in EEE across all Member States.

⁴⁰ It is not clear whether the complete compressor or only its electric/electronic parts are subject to the WEEE Directive.

⁴¹ Category 6: electrical and electronic tools (with the exception of large-scale stationary industrial tools) and category 9: monitoring and control instruments. Subcategory of “Annex IB”, for category 6 is: Equipment for spraying, spreading, dispersing or other treatment of liquid or gaseous substances by other means and for category 9: other monitoring and control instruments used in industrial installations (e.g. in control panels).

In Annex II of the RoHS directive a list of restricted substances for Electrical and Electronic Equipment is given⁴². These substances are:

- Lead
- Mercury
- Cadmium
- Hexavalent chromium
- Polybrominated biphenyls (PBB)
- Polybrominated diphenyl ethers (PBDE)

There are exemptions and limit values listed in the Annex to the Directive for some equipment where it is understood that one or more these substances is required for their functioning and no economically viable alternatives exist in sufficient quantity at present. Therefore, some of these substances may still be found in some electrical and electronic equipment.

The Annex has been revised on a number of occasions, altering the list of exclusions and limit values.

In this assessment it is assumed that that some 'knock-on' effects⁴³ occur from the RoHS Directive to products outside its original scope.

Other hazardous substances, as indicated by environmental organisations

According a coalition of environmental and health NGO's the following other substances are to be regulated under this Directive.⁴⁴

PVC and other chlorinated polymers

Chlorinated polymers such as PVC are commonly present in conjunction with brominated materials, primarily brominated flame retardants. The combination of these two groups of materials can result in emissions of mixed chlorinated-brominated dioxins/furans when combusting, possibly during end of life processing. These chemicals could constitute a significant fraction of the total halogenated dioxin/furan burden from use of such materials, and the mixed chlorinated-brominated dioxins/furans may be as toxic, than the more well-known chlorinated dioxins/furans.⁴⁴

Areas of use of PVC⁴⁵:

- External cabling and wire
- Internal cabling and wires (including ribbon cables)
- Housing
- Packaging
- Plastic coated/encased electrical connectors
- Home cinema sets, DVD players/ recorders, lighting equipment, PC's.

Brominated flame retardants (BFRs)

The RoHS directive currently allows an exemption for one chemical of the PBDE group, namely deca-BDE. Studies have demonstrated the potential for environmental contamination with persistent, bio accumulative and toxic chemicals that can be produced during the processing of materials containing organic-bound bromine (which include all BFRs), as well as organic-bound chlorine (which includes the plastic PVC)⁴⁴. The data from these studies relating to halogenated dioxins/furans

(polychlorinated dibenzo-dioxins and –furans), include;

- chlorinated dioxins/furans arising from chlorinated materials (e.g. PVC)
- brominated dioxins/furans from brominated materials (e.g. all BFRs)

⁴² DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment

⁴⁴ <http://www.greenpeace.org/raw/content/international/assets/binaries/ngo-rohs-submission.pdf>

⁴⁵ <http://www.greenpeace.org/international/Global/international/planet-2/report/2009/1/green-electronics-survey-2.pdf>

- mixed chlorinated-brominated dioxins/furans arising from mixtures of chlorinated and brominated materials (e.g. PVC and BFRs in the same source)⁴⁴.

Areas of use of BFRs⁴⁵:

- Laminates of printed wiring boards, including flexible circuit boards.
- Battery, including casing and components
- Housing (including for periphery equipment, e.g. transformer)
- Fan and fan housing
- Ribbon cables
- Electrical insulation sheet
- Plastic coated/encased electrical connectors

Phthalate esters (phthalates)

Subsequent to this submission, studies have been released that demonstrate the widespread use of phthalates in some classes of EEE; laptop computers and mobile phones. These studies demonstrate the use of numerous phthalates, primarily as plasticisers (softeners) in materials manufactured from PVC and other polymers.

Due to concerns over human exposure to toxic and potentially toxic chemicals, the use of certain phthalates is banned in toys and childcare articles.⁴⁶

Areas of use of phthalates:

- Polyvinylchloride (PVC)⁴⁷

Beryllium

Beryllium is primarily used as a hardening agent in alloys, notably beryllium copper. Beryllium, beryllium alloys and beryllium compounds are used in for instance connectors or as a component in heat sink⁴⁷. Beryllium has been used in the past in the form of beryllium copper in connectors of various kinds. Certain manufacturers have phased out the use of Beryllium voluntarily and their products are now beryllium-free.

Antimony

Antimony is mainly used in combination with BFRs to increase fire protective properties. Certain manufacturers have already phased out antimony voluntarily and antimony trioxide is no longer used in any major part. There are also other applications for antimony such as moisture protection and in varistors. For moisture protection, alternatives have been developed and replacement is well on the way, but for varistors no alternatives have been identified and this use is exempted from the phase-out plan until replacement materials have been identified.

Also Nickel-compounds and Bismuth are considered hazardous by these organisations.

4.1.15 Packaging - Directive on Packaging and Packaging Waste

The Directive 94/62/EC (amended by 2004/12/EC, 2005/20/EC and Regulation No 219/2009) covers all packaging placed on the market in the Community and all packaging waste, whether it is used or released at industrial, commercial, office, shop, service, household or any other level, regardless of the material used.

The EC Packaging Directive seeks to reduce the impact of packaging and packaging waste on the environment by introducing recovery and recycling targets for packaging waste, and by encouraging minimisation and reuse of packaging⁴⁸. A scheme of symbols, currently voluntary, has been prepared

⁴⁶ <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/99/829&format=HTML&aged=1&language=EN&guiLanguage=en>

⁴⁷ http://www.sonyericsson.com/cws/download/1/308/336/1193062465/SE_Environmental_Policy_local.pdf

⁴⁸ OJ L 365 , 31.12.1994 P. 10-23, <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31994L0062:EN:HTML>

through Commission Decision 97/129/EC⁴⁹. These can be used by manufacturers on their packaging so that different materials can be identified to assist end-of-life recycling.

The Commission updates the list of examples given in Annex I to illustrate the definition of the term “packaging”. According Article 1 packaging is either the 'primary packaging' (sales packaging), the 'secondary packaging' (grouped packaging) or the 'tertiary (transport) packaging'.

Member States should take measures to prevent the formation of packaging waste, and to develop packaging reuse systems reducing their impact on the environment. The Member States must introduce systems for the return and/or collection of used packaging to attain the following targets:

- a) by no later than 30 June 2001, between 50 and 65% by weight of packaging waste to be recovered or incinerated at waste incineration plants with energy recovery;
- b) by no later than 31 December 2008, at least 60% by weight of packaging waste to be recovered or incinerated at waste incineration plants with energy recovery;
- c) by no later than 30 June 2001, between 25 and 45% by weight of the totality of packaging materials contained in packaging waste to be recycled (with a minimum of 15% by weight for each packaging material);
- d) by no later than 31 December 2008, between 55 and 80% by weight of packaging waste to be recycled;
- e) no later than 31 December 2008 the following targets for materials contained in packaging waste must be attained:
 - 60% for glass, paper and board;
 - 50% for metals;
 - 22.5% for plastics and;
 - 15% for wood.

The 2006 Report on the implementation of Directive 94/62/EC on packaging and packaging waste concluded that almost half of the Member States held derogations applying until 2015. Nevertheless, the objectives set for 2008 in Directive 2004/12/EC were to remain valid, even after 2008.

The incineration of waste at plants with energy recovery is regarded as contributing to the realisation of these objectives.

Directive 94/62/EC lays down essential requirements with which these countries should comply regarding the composition and the reusable and recoverable nature of packaging and packaging waste. The Commission is to promote the development of European standards relating to these essential requirements.

Member States must ensure that packaging placed on the market complies with the essential requirements of Annex II:

- to limit the weight and volume of packaging to a minimum in order meet the required level of safety, hygiene and acceptability for consumers;
- to reduce the content of hazardous substances and materials in the packaging material and its components;
- to design reusable or recoverable packaging.

Member States should develop information systems (databases) on packaging and packaging waste so that realisation of the targets of this Directive can be monitored. The data they hold must be sent to the Commission in the formats laid down in Annex III.

⁴⁹ OJ L 050, 20.02.1997 P. 28 – 31, <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31997D0129:EN:HTML>

4.1.16 Energy Performance of Buildings Directive 2010/31/EU (recast)

On 19 May 2010, a recast of the Energy Performance of Buildings Directive was adopted by the European Parliament and the Council of the European Union in order to strengthen the energy performance requirements and to clarify and streamline some of the provisions from the 2002 Directive (2002/91/EC) it replaces. In November 2008, the Commission adopted the proposal for a recast of the Energy Performance of Buildings Directive. Throughout 2009, the proposal went through the approval process of the European Parliament and Council and a political agreement was achieved 17 November 2009. The recast proposal confirms the importance of effective implementation at the Member State level, the importance of Community-wide co-operation and the strong long-term commitment and role of the Commission itself to support such effective implementation. As the November 2008 Commission Communication for the original proposal states, buildings have significant untapped potential for cost effective energy savings “which, if realised, would mean that in 2020 the EU will consume 11 % less final energy.” The magnitude of the potential savings is such that every effort must be made to achieve it.

4.1.17 European Union Ecolabel Regulation 66/2010

The EU Ecolabel may be awarded to products and services which have a lower environmental impact than other products in the same group. The label criteria were devised using scientific data on the whole of a product’s life cycle, from product development to disposal.

The label may be awarded to all goods or services distributed, consumed or used on the Community market whether in return for payment or free of charge. It does not apply to medicinal products for human or veterinary use, or to medical devices.

The system was introduced by Regulation (EEC) No 880/92 and amended by Regulation (EC) No 1980/2000. This Regulation (EEC) No 66/2010 aims to improve the rules on the award, use and operation of the label.

Award criteria

The label shall be awarded in consideration of European environmental and ethical objectives. In particular:

- the impact of goods and services on climate change, nature and biodiversity, energy and resource consumption, generation of waste, pollution, emissions and the release of hazardous substances into the environment;
- the substitution of hazardous substances by safer substances;
- durability and reusability of products;
- ultimate impact on the environment, including on consumer health and safety;
- compliance with social and ethical standards, such as international labour standards;
- taking into account criteria established by other labels at national and regional levels;
- reducing animal testing.

The label cannot be awarded to products containing substances classified by Regulation (EC) No 1272/2008 as toxic, hazardous to the environment, carcinogenic or mutagenic, or substances subject to the regulatory framework for the management of chemicals.

Competent bodies

Member States shall designate one or more bodies responsible for the labelling process at national level. Their operations shall be transparent and their activities shall be open to the involvement of all interested parties.

They are specifically responsible for regularly checking that products comply with the label criteria. Their remit also includes receiving complaints, informing the public, monitoring false advertising and prohibiting products.

The procedure for award and use of the label

In order to be awarded the label, economic operators shall submit an application to:

- one or more Member State(s), which will send it to the competent national body;
- a third State, which will send it to the Member State where the product is marketed.

If the product complies with the label criteria, the competent body shall conclude a contract with the operator, establishing the terms of use and withdrawal of the label. The operator may then place the label on the product. The use of the label is subject to payment of a fee when the application is made, and an annual fee.

The European Union Ecolabelling Board (EUEB)

The Commission shall establish a committee representing the national competent bodies. The Commission shall consult the EUEB when developing or revising the award criteria and requirements of the label.

Context

Regulation (EC) No 1980/2000 is repealed. However, it shall continue to apply to contracts concluded before the current Regulation entered into force, until the date of expiry specified in the contracts.

4.1.18 IED - Industrial Emissions Directive 2010/75/EC

Industrial production processes account for a considerable share of the overall pollution in Europe (for emissions of greenhouse gases and acidifying substances, wastewater emissions and waste). In order to take further steps to reduce emissions from such installations, the Commission adopted its proposal for a Directive on industrial emissions on 21 December 2007. The Industrial Emissions

Directive 2010/75/EC (IED) entered into force on 6 January 2011 and has to be transposed into national legislation by Member States by 7 January 2013.

The Directive on industrial emissions recasts seven existing Directives related to industrial emissions into a single clear and coherent legislative instrument. The recast includes:

- The **IPPC Directive** (Directive 96/61/EC, replaced by Directive 2008/1/EC concerning integrated pollution prevention and control - the IPPC Directive)
- the **Large Combustion Plants Directive** (Directive 2001/80/EC on pollutants emitted by large combustion plants);
- the **Waste Incineration Directive** (Directive 2000/76/EC on the incineration of waste);
- the **Solvents Emissions Directive** (Directive 1999/13/EC on volatile organic compounds) and;
- three Directives on **Titanium Dioxide** (Directives 78/176/EEC, 82/883/EEC and 92/112/EEC on waste and discards from the titanium dioxide industry).

This integrated approach to issuing permits to industrial installations should allow major progress to be made in the field of atmospheric pollution. The central element of this approach is the implementation of Best Available Techniques (BAT).

The IED is the successor of the IPPC Directive and in essence, it is about minimising pollution from various industrial sources throughout the European Union. Operators of industrial installations operating activities covered by Annex I of the IED are required to obtain an integrated permit from the authorities in the EU countries. About 50 000 installations were covered by the IPPC Directive

and the IED will cover some new activities which could mean the number of installations rising slightly.

The IED is based on several principles, namely (1) an integrated approach, (2) best available techniques, (3) flexibility, (4) inspections and (5) public participation.

1. The integrated approach means that the permits must take into account the whole environmental performance of the plant, covering e.g. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, and restoration of the site upon closure. The purpose of the Directive is to ensure a high level of protection of the environment taken as a whole. Should the activity involve the use, production or release of relevant hazardous substances, the IED requires operators to prepare a baseline report before starting an operation of an installation or before a permit is updated having regard to the possibility of soil and groundwater contamination, ensuring the integrated approach.
2. The permit conditions including emission limit values (ELVs) must be based on the Best Available Techniques (BAT), as defined in the IPPC Directive⁵⁰. BAT conclusions (documents containing information on the emission levels associated with the best available techniques) shall be the reference for setting permit conditions. To assist the licensing authorities and companies to determine BAT, the Commission organises an exchange of information between experts from the EU Member States, industry and environmental organisations. This work is co-ordinated by the European IPPC Bureau of the Institute for Prospective Technology Studies at the EU Joint Research Centre in Seville (Spain). This results in the adoption and publication by the Commission of the BAT conclusions and BAT Reference Documents (the so-called BREFs).
3. The IED contains certain elements of flexibility by allowing the licensing authorities to set less strict emission limit values in specific cases. Such measures are only applicable where an assessment shows that the achievement of emission levels associated with BAT as described in the BAT conclusions would lead to disproportionately higher costs compared to the environmental benefits due to:
 - a. geographical location or the local environmental conditions or
 - b. the technical characteristics of the installation.The competent authority shall always document the reasons for the application of the flexibility measures in the permit including the result of the cost-benefit assessment. Moreover, Chapter III on large combustion plants includes certain flexibility instruments (Transitional National Plan, limited lifetime derogation, etc.)
4. The IED contains mandatory requirements on environmental inspections. Member States shall set up a system of environmental inspections and draw up inspection plans accordingly. The IED requires a site visit shall take place at least every 1 to 3 years, using risk-based criteria.
5. The Directive ensures that the public has a right to participate in the decision-making process, and to be informed of its consequences, by having access to:
 - a. permit applications in order to give opinions,
 - b. permits,
 - c. results of the monitoring of releases and
 - d. the European Pollutant Release and Transfer Register (E-PRTR). In E-PRTR, emission data reported by Member States are made accessible in a public register, which is intended to provide environmental information on major industrial activities. E-PRTR has replaced the

⁵⁰ Note that the IPPC definition of BAT may be different to that used in Ecodesign studies, following the MEEuP, MEErP.

previous EU-wide pollutant inventory, the so-called European Pollutant Emission Register (EPER).

The Commission also formulated an action plan for 2008-2010 to improve the implementation of existing legislation. Under this plan, the Commission will ensure that the legislation on industrial emissions is fully transposed and will assist Member States in cutting unnecessary administrative burdens and in implementing legislation. It will also improve the monitoring of the enforcement of legislation and compliance checking, as well as improving the collection of data on best available techniques, and will create stronger links with the Research Framework Programme.

Also discussed is extending the scope of the IPPC Directive to cover certain activities (e.g. combustion plants between 20 and 50 MW) and clarifying the scope for certain sectors (e.g. waste treatment) to increase consistency and coherence of current permitting practices.

Finally, the Commission discusses the possibility of using flexible instruments such as an emission trading scheme for NO_x and SO₂.

4.2 Legislation and agreements at MS level

An analysis of the Clasp online database on measures shows that within the EU only the Nordic Swann label (mainly active in Scandinavia, but criteria also available in English) has introduced a voluntary label for compressors.

Table 17 Clasp standards overview intra EU

Economy	Product Type	Scope	Policy Name	Policy Type	Mandatory / Voluntary	Most Recent Effective Date	Test Procedures
"Scandinavia"	Air Compressor	Compressors that can be Nordic Eco labelled in accordance with these criteria are stationary electricity powered air compressors designed to produce compressed air.	Nordic Ecolabel	Label Endorsement	Voluntary	1-1-2009 0:00	Pneurop PN8NTC2.2

The criteria are for stationary, electric air compressors only and relate to energy (type of speed control, possibility for water-cooling and/or air-cooling), oil-free operation, information on noise (acoustic pressure at 1 m) and information relating to installation.

The test method PN8NTC2.2 was a noise test code, and has been withdrawn and replaced by ISO 2151.

4.3 Legislation and agreements at third country level

An analysis of the Clasp online database⁵¹ on measures shows that China has introduced mandatory and voluntary measures for refrigerant compressors and air compressors.

Mandatory measures

The requirements for air compressors relate to minimum efficiency and labelling requirements for reciprocating, screw and sliding vane compressors intended for various applications.

Voluntary initiatives

In Mexico a voluntary endorsement label scheme exists for air compressors.

⁵¹ http://www.clasponline.org/ResourcesTools/Tools/SL_Search/SL_SearchResults?p=compressors

Table 18 Clasp standards overview extra EU

Economy	Product Type	Scope	Policy Name	Policy Type	Mandatory / Voluntary	Most Recent Effective Date	Test Procedures
China (PRC)	Refrigerant Compressor	Applies to wholly-closed electric motor-compressor, wholly-closed turbine type cooling compressor, piston type single stage cooling compressor and screw type cooling compressor.	CQC Mark Certification - Refrigerant compressors used in air-conditioning applications	Label Endorsement	Voluntary	1-1-2009 0:00	CQC 2209-2009
China (PRC)	Air Compressor	The following types of air compressors are covered: Direct drive portable reciprocating piston air compressors, Reciprocating piston micro air compressors, Oil-free reciprocating piston air compressors, Stationary reciprocating piston air compressors for general use, Oil injected screw air compressors for general use, Oil injected single screw air compressors for general use, and Oil flooded sliding vane air compressor for general use.	GB 19153-2009 Minimum allowable values of energy efficiency and energy efficiency grades for displacement air compressors	Minimum Efficiency Performance Standard	Mandatory	1-1-2009 0:00	GB/T 3853-1998
China (PRC)	Air Compressor	The following types of air compressors are covered: Direct drive portable reciprocating piston air compressors, Reciprocating piston micro air compressors, Oil-free reciprocating piston air compressors, Stationary reciprocating piston air compressors for general use, Oil injected screw air compressors for general use, Oil injected single screw air compressors for general use, and Oil flooded sliding vane air compressor for general use.	China Energy Label - Air Compressor (Displacement Air Compressor)	Label Comparative	Mandatory	1-1-2010 0:00	GB/T 3853-1998
Mexico	Air Compressor	This endorsement label establishes specifications for screw type air compressors with or without integrated dryer, using AC electric motors from 2.24kW (3HP) to 447.60kW (600HP), with a supply rated voltage of 208-230/460V and a frequency of 60Hz.	Sello FIDE No. 4142	Label Endorsement	Voluntary	2-1-2012 0:00	CAGI/PNEUROP PN2CPTC2

Note: PN2CPTC2 has been withdrawn and been completely replaced by ISO 1217.

The Chinese mandatory measures are described in more detail below:

China

As indicated above China has introduced both minimum energy efficiency requirements as well as mandatory efficiency labelling for air compressors.

The energy efficiency regulation adopted in China is referred to as:

GB19153 -2009: Limited Values of Energy Efficiency and Evaluating Values of Energy Conservation for Displacement Air Compressors.

The measure refers to following Chinese (and international) standards⁵²:

- GB/T 3853 "Displacement Compressor - Acceptance Tests" (GB/T 3853-1998, eqv. ISO 1217: 1996)
- GB/T 4975 "Displacement compressors Vocabulary-General" (GB/T 4975-1995, eqv. ISO 3857: 1977)
- GB/T 13279 "Stationary Reciprocating Piston Air Compressor for General Use"
- GB/T 13928 "Reciprocating Piston Minitype Air Compressors"
- JB/T 4253 "Oil Flooded Sliding Vane Air Compressor for General Use"
- JB/T 6430 "Oil Injected Screw Air Compressor for General Use"
- JB/T 7662 "Displacement Compressor Vocabulary-Rotating Compressor"
- JB/T 8933 "Oil-free Reciprocating Piston Air Compressors"
- JB/T 8934 "Direct Drive Portable Reciprocating Piston Air Compressors"
- JB/T 9107 "Reciprocating Compressors-Vocabulary"
- JB/T 10525 "Oil Injected Single Screw Air Compressor for General Use"

Scope

The standard specifies the energy efficiency grades, minimum allowable values of energy efficiency, target minimum allowable values of energy efficiency, evaluating values of energy conservation, test methods, and inspection standards for displacement air compressors (hereinafter referred to as "air compressors").

It applies to direct drive portable reciprocating piston air compressors, reciprocating piston miniature air compressors, oil-free reciprocating piston air compressors, stationary reciprocating piston air compressors for general use, oil injected screw air compressors for general use, oil injected single screw air compressors for general use, and oil flooded sliding vane air compressors for general use.

The rating in this standard is set according to three energy efficiency grades and a target value:

1. Compressor energy efficiency rating:

There are three energy efficiency grades for air compressors. Grade 1 is the highest energy efficiency. Energy efficiency grades of different air compressors should conform to provision of Table 1-7 (Annex I).

2. Energy evaluation of the value of air compressor:

Evaluating values of energy conservation for air compressor should not be bigger than values in Grade 2 of Table 1-7 (Annex I).

3. Limited value of energy efficiency compressor:

⁵² http://www.energyrating.gov.au/wp-content/uploads/Energy_Rating_Documents/Library/Standards/Standards/2009-motors-session7-xin.pdf

Minimum allowable values of energy efficiency for air compressor should not be bigger than values in Grade 3 of Table 1-7 (Annex I).

4. Target Minimum Allowable Values of Energy Efficiency for Air Compressor

Target minimum allowable values of energy efficiency for air compressor should not be bigger than specified values in Column T of Table 1-7. The values will substitute for minimum allowable values of energy efficiency for air compressor in Item 2 after the standard is implemented for 4 years.

The requirements are expressed as *specific energy requirements*, with units " $\text{kW}/(\text{m}^3/\text{min})$ ".

According stakeholders the requirements are relatively easily understood, but do not provide in a clear-cut definition of the compressor (the product borders are not clear). The requirement also shows lack of clarity and deficiencies regarding consistency and the operating conditions are not clear as well.

4.4 Industry initiatives

CAGI - Compressed air challenge

The Compressed Air Challenge is a voluntary collaboration of industrial users; manufacturers, distributors and their associations; consultants; state research and development agencies; energy efficiency organizations; and utilities. This group has the purpose to help users and others involved to enjoy the benefits of improved performance of compressed air systems.⁵³

The CAGI performance verification program is based on ISO 1217, Annex C.

⁵³ www.compressedairchallenge.org

5 Discussion of proposed scope of study

This section presents a discussion on the conclusion of the preceding analysis as regards the scope of the study, including the definition of 'compressors'.

5.1 Scope of the study

The scope of the study is guided by both the definition of the product group and the exclusions that apply (thereby limiting the scope of the study). The definition describes the product (and relevant features or parameters) so that the products can be discerned from other products. The exclusions make clear which products that meet the definitions are included and excluded from the study. If possible, the definition of the product group may already contain descriptions that include or exclude specific products.

5.1.1 Compressor definition

The following definition of a compressor machine is proposed. The definition below is similar in structure to that of Regulation 327/2011.

Compressor machine means: a machine which compresses a gas or vapour media *to a pressure higher than atmospheric* at the inlet with pressure ratios exceeding 1.1, is effected by mechanical motions of solid working members, and which:

- is designed for use or equipped with an electrical motor with an electric input power [to decide] to drive the compressor at its optimum energy efficiency point,
- is a positive displacement compressor or dynamic compressor (or combination thereof),
- may or may not be equipped with a motor when placed on the market or put into service.

The sentence part "is effected by mechanical motions of solid working members" can eventually be left out, as the reference to positive displacement and turbocompressors effectively reduces the definition of compressors to compressor machines only.

Positive-displacement compressor means a compressor machine in which the admission and compression of successive volumes of the gaseous medium are performed periodically by forced expansion and diminution of a closed space(s) in a working chambers(s) by means of displacement of a moving member(s) or by displacement and forced discharge of the gaseous medium into the high-pressure area.

NOTE The closed spaces with variable or displaceable volumes represent compression chambers. In one working chamber, there can be one or several variable-volume compression chambers.

Dynamic compressor (or 'turbocompressor') means a compressor machine in which inlet, compression and discharge are continuous flow processes. The gas is conveyed and compressed in impellers and decelerated with further increase in pressure in fixed vane or vaneless stators (based on ISO 5389)

5.1.2 Bare and packaged compressors

Compressors can be placed on the market as 'bare compressors' (without driver, or gear that connects the driver to the bare compressor) or as 'packaged compressors' which may include gear, driver and also ancillary equipment like apparatuses, vessels, pipes and fittings for performing following gas-processing operations: filtration, water and condensate separation, gas transportation, pre-compressor and interstage cooling, oil separation, attenuation of gas pulsations, etc.

In Task 8, the section on recommendations for possible measures, the possible difference in treatment of bare and packaged compressors shall be made explicit, and corresponding definitions shall be provided. Helpful in this respect may be the definition of a 'packaged compressor' as defined in ISO 1217:

Compressor with prime mover, transmission, fully piped and wired internally, including ancillary and auxiliary items of equipment and being stationary or mobile (portable unit) where these are within the scope of supply.

The compressor package includes the compressor, motor, gear (if necessary) and ancillary equipment for gas processing, piping, safety equipment and controls. The packaged compressor can therefore be considered a manifestation of the 'extended product'.

The 'package' is the largest 'product' to be placed on the market under the responsibility of one single manufacturer (or importer). In case the product consists of multiple compressors and multiple drivers (motors) the total package power input may exceed that of 375 kW, whereas that of the single (component) motor remains below that threshold. The legal status of such products need to be discussed when finalising the recommendations or even at a later stage, beyond the scope of this study.

The definition is not limited to stationary compressors. As long as the compressor is designed to be driven by an electric motor, also towable and mobile compressors (skid mounted) are considered to be within scope.

5.1.3 Proposed subject matter and scope of the study

The scope of the study is limited according the parameters discussed below:

5.1.3.1 Performance

The generic definition of a compressor already contains reference to a minimum pressure increase ratio exceeding 1.1 (dimensionless), which could be substituted by a minimum work per unit mass exceeding that of 25 kJ/kg (threshold value taken from Fan Regulation 327/2011).

A minimum or maximum mass or volume flow rate (kg or m^3/min) can be specified, but given the wide variety in application ranges, such thresholds may not be suitable for limiting the scope.

5.1.3.2 Electric motor: phase, voltage, current

The electric power input can be defined by a bottom or lower limit and an upper limit:

Lower limit

Proposed is to focus the study to compressors that operate on three phase alternating current only. This limitation of scope will exclude mainly single (and two-phase, if applicable) 'hobby compressors' which have insignificant relevance for the overall energy consumption of compressors (see DRAFT Report Task 2 and Task 3). Most industrial equipment, responsible for > 99% of estimated compressor energy consumption, uses three-phase power.

Upper limit

The scope is limited to compressors that run on a supply voltage of 50 to 1 000 V AC or 75 to 1 500 V DC. This limitation allows exact alignment with equipment covered by the Low Voltage Directive and the Electric Motor Regulation 640/2009 and improves internal consistency of legislation.

The possibility to set the upper limit at 6.6 kV (Medium Voltage), coinciding with a maximum motor power of some 1 000 kW, shall be discussed with stakeholders, also involving the experts associated with the related ecodesign preparatory studies (e.g. ENER Lot 30).

Initial analysis has shown that these larger compressors are mainly process gas turbocompressors and take up one quarter of the overall energy consumption of three phase compressors. The possible savings of this segment for future years are determined to a large degree by the remaining saving potential (estimated to be limited) and the product life (generally very long, between 20-30 years).

5.1.3.3 Gas characteristics and operating conditions

Operating conditions and the type of gases handled by compressors have an impact on the efficiency of the compressor, in particular when compressors operate under non-standard operating conditions, such as ATEX conditions, certain temperature ranges (for ambient and media), beyond certain altitudes, ambient humidity, and or dust loading, etc. For the moment, this equipment will still be part of the analysis, if only to show that indeed the improvement potential is limited and the missed energy savings (when placed out of scope) are limited.

When the preparatory study has reached the stage that recommendations are given for possible measures, the scope may be limited by excluding compressors that:

- operate under ATEX conditions (potentially explosive gas conditions, as defined in Directive 94/9/EC) as safety requirements are considered of higher importance than efficiency;
- are designed to handle hazardous gases, whereby hazardous refers to "gas or vapour with chemical, radioactive or biological properties (such as flammable, explosive, unstable, pyrogenic, corrosive, caustic, toxic, carcinogenic), which generate hazards by reactions inside the compressor or through dispersal or through reactions with the environment. A hazardous gas may be a mixture of gases with these properties" (text taken from EN 1012-1);
- are designed to function in ambient temperatures exceeding .. °C and/or designed to handle gases in below .. °C or beyond .. °C (exact values to determine later on).

Together with stakeholders the operating range in gas conditions shall be defined: This comprises the minimum/maximum temperatures of the gases being moved by the compressor, whether these gases may be abrasive, toxic, highly corrosive or flammable, etc.

Together with stakeholders the range in ambient applications shall be defined: This comprises whether the compressor is designed for operation in explosive, toxic, highly corrosive or flammable environments, the minimum/maximum ambient temperatures in the room or area where the compressor is intended to be operating, etc.

Compressors designed for emergency use only

In the Fan and Motor Regulation products that are designed for emergency use only, at short-time duty, with regard to fire safety requirements set out in Council Directive 89/106/EC (2) have been excluded from the scope.

The study team envisages that a similar exclusion may apply to compressors if proven relevant.

5.1.3.4 Application exclusions from the study

Compressors in heating / cooling applications

As regards applications it is suggested to **exclude** from the scope of the study compressor (packages) that are designed or intended for use in vapour compression cycles used for generation of heat or cold. The reason being that these compressors are indirectly covered by implementing measures as (being) developed under:

1. Lot 1: heat pumps for hydronic central heating;
2. Lot 2: heat pumps for sanitary hot water;
3. Lot 10: room air conditioners (< 12 kW);
4. Lot 12: commercial refrigeration - display cabinets etc.;
5. Lot 13: domestic refrigeration (household refrigerators and freezers);

6. Lot 21: Central heating (products other than CHP);
7. ENTR Lot 1: commercial refrigeration systems (chillers, etc.);
8. ENTR Lot 6: commercial (large) air conditioning systems.

The savings identified for these product groups include improvements in the efficiency of the compressor part. Therefore it is expected that any remaining saving potential to be identified in the Lot 31 study for these products is greatly reduced.

The difficulty for the legislator is to identify unambiguous parameters that allow identification of such refrigerating compressors.

One way is through a declared 'intended use', to be specified by manufacturers in technical documentation.

Other, objective technical parameters can be:

- the presence of a blow-off valve to the atmosphere indicates the compressor is not a refrigerating compressor - this mainly applies to air compressors. Process gas compressors may be excluded on this basis as well;
- the presence of atmospheric intake indicates the compressor is not a refrigerating compressor - this mainly applies to air compressors. Process gas compressors may be excluded on this basis as well.

Vacuum pumps

The study team concludes that although some types of vacuum pumps apply technologies that are similar to those applied by compressors, the inclusion of the vacuum pump within the study scope would introduce complications for the study which cannot easily be resolved. These complications are:

- The vacuum pump does not comply with the generic definition of compressors, which refers to a pressure increase above atmospheric pressure. The vacuum pump function is different to that of other compressors and a definition containing reference to pressures above atmospheric and below atmospheric must be provided;
- Inclusion of the vacuum pump would introduce technologies (entrapment pumps) that are not shared or comparable to technologies applied by compressors;
- The inclusion of the vacuum pump would extend the application range of products covered by the study from 10^{-12} mbar to over 1 000 bar - thus covering several orders of magnitude in primary product performance. Even the most complex products groups up to date (e.g. fans or central heating boilers) cover only a magnitude range of 10^2 or 10^3 (e.g. 4 to 400 kW or 0.1-500 kW). Covering such a wide range in product performance in a single study means that fewer resources can be devoted to individual application ranges, since the study budget and time remains the same. In the light of the above argumentation this is expected to result in suboptimal spending of resources (as these should be focused on the most significant application range).
- The indicative assessment of the energy consumption of vacuum pumps shows that the energy consumption of the installed base is less than $1/10^{\text{th}}$ of that of the total overall energy consumption of above atmospheric compressors - the significance of vacuum pumps appears to be limited;

Therefore the study team excluded vacuum pumps from the remainder of the study.

5.2 Summary

The study will initially focus on the following product scope: Compressors driven by three phase electric motors.

Excluded from the study scope will be compressors designed specifically or exclusively for use in heating or cooling applications, and compressors that are vacuum pumps (do not establish a discharge pressure above atmospheric pressure).

Annex I - Changes in state for a gas

Changes in state for a gas can be followed from one point to another in a p/V diagram. For real-life cases, three axes for the variables p, V and T are required. With a change in state, we are moved along a 3-dimensional curve on the surface in the p, V and T space. However, to simplify, we usually consider the projection of the curve in one of the three planes. This is usually the p/V plane.

Five distinct changes of states that will be discussed in more detail below, are:

1. Isochoric change of state - Heating a gas in an enclosed container is an example of the isochoric change of state at constant volume.
2. Isobaric change of state - Heating a gas in a cylinder with a constant load on the piston is an example of the isobaric change of state at constant pressure.
3. Isothermal change of state - If a gas in a cylinder is compressed isothermally, a quantity of heat equal to the applied work must be gradually removed. This is impractical, as such a slow change of state cannot occur.
4. Isentropic change of state - An isentropic change of state exists if a gas is compressed in a fully-insulated cylinder without any heat exchange with the surroundings. It may also exist if a gas is expanded through a nozzle so quickly that no heat exchange with the surroundings has time to occur.
5. Polytropic change of state - The polytropic change of state is a replacement model that describes the change of a gas between states 1 and 2 that is unknown in detail. P, V and T can all change. Isochoric, isobaric, isothermal and isentropic are special polytropic changes of state.

Isochoric change of state

In an isochoric change of state the pressure is increased while the volume is kept constant. This thermodynamic change of state adds or removes heat to the contents of the container (the closed system). The inability of the container to deform imposes the constant-volume condition. An typical example is a pressure cooker.

The relation for applied energy of heat is according the equation below:

$$q = m \cdot c_v \cdot (T_2 - T_1)$$

q = quantity of heat (J)

m = mass (kg)

c_v = the heat capacity at constant volume (J/kg*K)

T = absolute temperature (K)

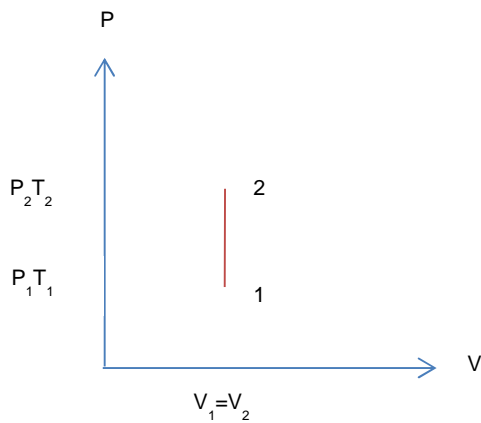


Figure 30: Isochoric change of state⁵⁴

The isochoric efficiency (expressed as 'q' divided by the electric energy input) is not an adequate performance indicator for compressors as volume will not be constant.

Isobaric change of state

In an isobaric change of state the volume changes while the pressure is constant. This change of state is usually obtained by allowing the volume to expand or contract in such a way that any pressure changes that would be caused by heat transfer is neutralized. Heating a gas in a cylinder with a constant load on the piston is an example of the isobaric change of state at constant pressure.

The relation for the applied quantity of heat is:

$$q = m \cdot c_p \cdot (T_2 - T_1)$$

where:

q = quantity of heat (J)

m = mass (kg)

c_p = the heat capacity at constant pressure (J/[kg*K])

T = absolute temperature (K)

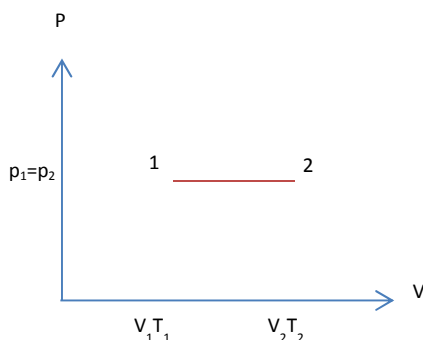


Figure 31: Isobaric change of state⁵⁵

The isobaric change of state is however not an adequate description for most compressor changes of states.

⁵⁴ <http://www.markcompressors.co.uk/learning-space/theory/thermodynamics/isochoric-process>

⁵⁵ <http://www.markcompressors.co.uk/learning-space/theory/thermodynamics/isobaric-process>

Isothermal change of state

The temperature of a gas mixture is constant in an isothermal change of state, when the pressure and volume are changed. The relation for the quantity of heat led off is:

$$q = m * R * T * \ln \frac{P_2}{P_1}$$

or

$$(p_1 * V_1) / T_1 = (p_2 * V_2) / T_2 \quad \text{with } T_1 = T_2 = \text{constant} \rightarrow p_2 / p_1 = V_1 / V_2$$

q = quantity of heat (J)

m = mass (kg)

R = individual gas constant (J/[kg*K])

T = absolute temperature (K)

V = volume (m³)

p = absolute pressure (Pa)

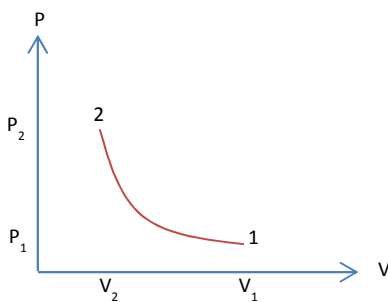


Figure 32: Isothermal change of state⁵⁶

$$\text{Isothermal_efficiency} = \frac{\text{Isothermal_power}}{\text{Actual_power}} = \frac{\dot{V}_1 * p_1 * \ln(p_2/p_1)}{\text{Actual_power}}$$

where:

\dot{V}_1 = inlet volume flow rate (m³/s)

p₁ = absolute intake pressure (Pa)

p₂/p₁ = pressure ratio

Isentropic change of state

In an isentropic change of state the entropy of the compressed or expanded gas is constant and no heat exchange to the environment takes place.

⁵⁶ <http://www.markcompressors.co.uk/learning-space/theory/thermodynamics/isothermic-process>

Note: In thermodynamics, an isentropic change of state is one in which for purposes of engineering analysis and calculation, one may assume that the change of state takes place from initiation to completion without an increase or decrease in the entropy of the system, i.e., the entropy of the system remains constant. Entropy is a measure of how evenly energy is distributed in a system. In a physical system, entropy provides a measure of the amount of energy that cannot be used to do work. It can be proven that any reversible adiabatic change of state is an isentropic change of state.

ISO 1217 does only mention the definitions of isentropic power and isentropic efficiency, while ISO 5389 describes the formula for the isentropic efficiency. According to equation E 1.01 the isentropic efficiency is:

$$\eta_{isen} = \frac{P_{isen}}{P}$$

According to equation E.68 of ISO 5389 the isentropic efficiency is calculated as follows

$$P_{isen} = \dot{V}_1 \cdot p_1^{\frac{1}{\gamma}} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

with

P_{isen} = isentropic compression power.

γ = isentropic exponent

p_1 = inlet pressure

p_2 = outlet pressure

\dot{V}_1 = inlet volume flow rate (m³/s)

The isentropic reference change of state in the h, s diagram below.

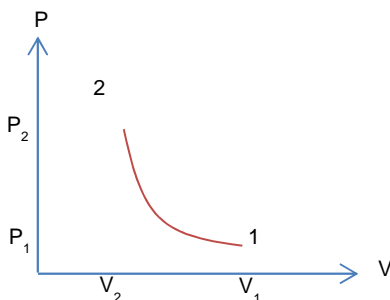


Figure 33: Isentropic change of state⁵⁷

From this it can be seen that the volume flow rate \dot{V}_1 is characterizing the amount or size, the isentropic exponent γ is characterizing the type of gas and the inlet pressure p_1 together with the outlet pressure p_2 are characterizing the compression task.

⁵⁷ <http://www.markcompressors.co.uk/learning-space/theory/thermodynamics/isothermal-process>

Therefore these are the primary product performance parameters:

- Inlet pressure plus pressure ratio
- Volume- or (mass-) flow-rate (characterizing the size)
- Type of gas (represented by γ)

Polytropic change of state

In real-life compression processes P , V and T will all change. The polytropic change of state is a replacement change of state that describes the change of a gas between states 1-2 that is unknown in detail.

During a real change of state the polytropic exponent n will probably not stay constant but its mean value will be the one that describes the change of state between 1-2. All changes of state (processes) described in this chapter are a special polytropic change of state.

The isothermal change of state involves full heat exchange with the environment and the isotropic change of state involves no heat exchange at all. The relationship for such a change of state is:

$$p \cdot v^n = \text{constant}$$

p = absolute pressure (Pa)

v = specific volume (m^3/kg)

$n = 0$ means isobaric change of state

$n = 1$ means isothermal change of state

$n = \gamma$ means isentropic change of state

$n = \infty$ means isochoric change of state

Volumetric Efficiency (displacement compressors)

This parameter is not an efficiency as in 'energy efficiency' but merely describes the performance of the compression stage as a result of the geometrical characteristics of the product.

In a theoretical cycle the piston expels all the air and there is no restriction at the valves. The pressure/volume cycle is as follows:

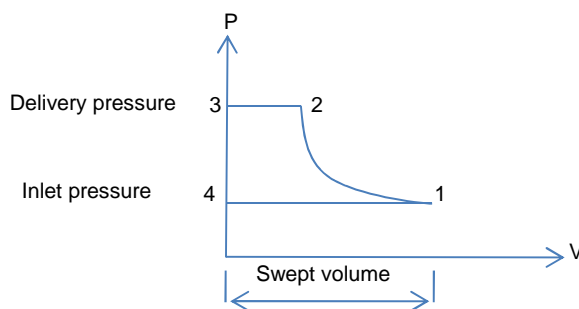


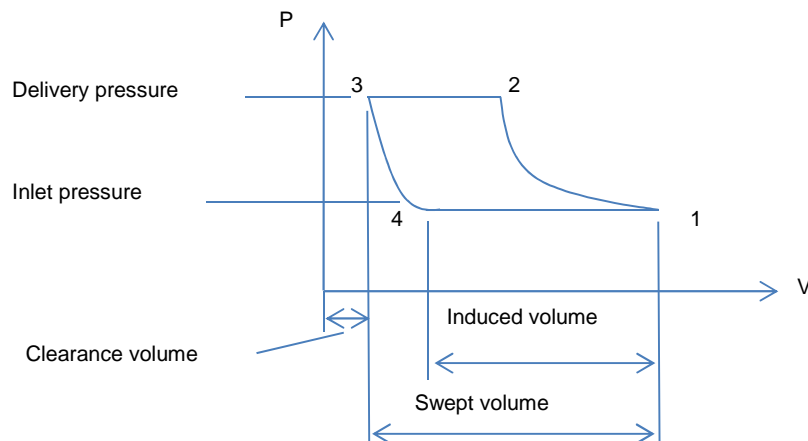
Figure 34: Pressure/ volume cycle (reciprocating piston compressor)⁵⁸

⁵⁸ <http://www.freestudy.co.uk/thermodynamics/t2201.pdf>

Gas is drawn into the cylinder on the suction stroke (4 to 1). In point 1 the suction valve is closed and the gas is compressed according the law $p \cdot V^n = c$ (1 to 2). In point 2 the discharge valve is opened when the pressure reaches the same level as the delivery pressure and the gas is delivered under pressure (2 to 3). The last stage (3 to 4) the discharge valve is closed and the suction valve opens again and the cycle starts all over again. The area 1234 is representative for the power requirement of the compression process.

In reality the piston cannot expel all the gas and clearance volume is needed between the piston and the cylinder head. This gives a different pressure/volume diagram. The trapped gas in point 3 expands according to the law $p \cdot V^n = c$ until it reaches the inlet pressure, at which the suction valve opens and gas is drawn in. Due to the expansion of the gas the induced volume is not equal to the swept volume like it is with an ideal cycle discussed above. The area 1234 is representative for the power requirement of the compression process.

Figure 35: Real pressure volume cycle



The volumetric efficiency is defined as: $\frac{\text{Induced volume}}{\text{Swept volume}} = \text{Actual intake volume / Theoretical (geographical) volume}$.

$$\text{Volumetric efficiency} = 1 - \left[\left(\frac{P_2}{P_1} \right)^{\frac{1}{n}} - 1 \right] \frac{V_c}{V_s}$$

$$V_i = V_1 - V_4$$

$$V_c = \text{Clearance volume}^{59} \text{ (in practise 3-5\% of the stroke)}^{60}$$

Ideally the change of state 2 to 3 and 4 to 1 is isobaric (no temperature change during change of state).

Another way to calculate the volumetric efficiency is:

$$\text{Volumetric efficiency} = \frac{\text{Free air delivered m}^3/\text{min}}{\text{Compressor displacement}}$$

$$\text{Compressor displacement} = \frac{\pi}{4} * D^2 * L * S * \chi * n$$

D = Cylinder bore (m)

⁵⁹ In ISO 1217:2009 clearance volume is mentioned as E

⁶⁰ http://www.roytech.co.uk/Related/Thermos/Thermos_Air_com_mot.html

L = Cylinder stroke (m)

S = Compressor speed (rpm)

$\chi = 1$ for single acting and 2 for double acting cylinders

n = No. of cylinders

Annex II - Vacuum Pump technology Overview

This overview has been compiled by ISVT, and has been supplied by PN5, the Pneurop Working Group for vacuum pumps. The report form for vacuum pumps covers all relevant industry machines. The region "Europe" is defined as "Data for Europe shall include sales to the United Kingdom, Ireland, and continental Europe including the following countries bordering Europe to the east – Russia, Ukraine, Romania, and Bulgaria, and the following countries bordering Europe to the southeast – Turkey, Cyprus, and Israel".

Figure 36: Technology overview vacuum pumps

Pos	Class	Vacuum pump
1	A	Liquid ring pumps (including packages)
2	A	Side channel pumps (including packages)
3.1	B	Multi-stage oil-sealed rotary vane/piston pumps < 1 mbar (ultimate pressure) includes: Oil-sealed stage oil-sealed rotary vane pumps (typically double stage) Oil-sealed sliding vane and multi-vane pumps Oil-sealed rotary piston pumps Oil-sealed rotary plunger pumps
3.2	A	Single stage oil-sealed rotary vane/piston pumps > 1 mbar (ultimate pressure) includes: Oil-sealed stage oil-sealed rotary vane pumps (typically single stage) Oil-sealed sliding vane and multi-vane pumps Oil-sealed rotary piston pumps Oil-sealed rotary plunger pumps
4.1	B	Single stage roots pumps (separately sold) includes: All lobe-type vacuum booster pumps sold separately 2-lobe and 3-lobe mechanical booster pumps. Do not include: Vacuum booster pumps sold as pumping packages. These should be included in the relevant primary pump category.
4.2	B	Roots pumping packages, backed by oil sealed pumps
5	A	Radial blowers (including packages)
6	A	Ejector pumps - water, steam & compressed air (including packages) includes: Steam ejector pumps Liquid jet pumps Gas jet pumps Vapour jet pumps Nitrogen aspirators Water aspirators
7.1	B	Dry pumps (including packages) < 1 mbar (ultimate pressure) includes: Vacuum pumps of all types which are free of sealing fluid or oil in the pumping mechanism and which are capable of producing ultimate pressures below 1mbar. Screw pumps Orbital scroll pumps Multi-stage roots pumps Multi-stage 2- and 3- lobe pumps Claw pumps Piston pumps Diaphragm pumps Kinetic primary pumps Regenerative pumps Multi stage pumps Combined stage pumps Pumping packages, pumping stations, pumpsets, pumping outfits based on drypumps <1mar and including vacuum boosters, hardware and instrumentation. Do not include: High vacuum pumping packages with Turbomolecular, diffusion or other high vacuum pumps. These should be included in the relevant high vacuum pump cat.

7.2	A	<p>Rough dry pumps (including packages) > 1 mbar (ultimate pressure)</p> <p>includes: Vacuum pumps of all types which are free of sealing fluid or oil in the pumping mechanism and which typically produce ultimate pressures above 1mbar.</p> <p>Screw pumps Orbital scroll pumps Multi-stage roots pumps Multi-stage 2- and 3-lobe pumps Claw pumps Piston pumps Diaphragm pumps Kinetic primary pumps Regenerative pumps Multi stage pumps Combined stage pumps</p> <p>Pumping packages, pumping stations, pumpsets, pumping outfits based on Rough drypumps and including vacuum boosters, hardware and instrumentation.</p> <p>Do not include: High vacuum pumping packages with Turbomolecular, diffusion or other high vacuum pumps. These should be included in the relevant high vacuum pump category.</p>
8.1	C	<p>Turbomolecular pumps (incl. compound and drag pumps)</p> <p>includes: Molecular drag secondary pumps Hybrid turbo and drag pumps Compound turbo and drag pumps</p>
8.2	C	<p>Turbomolecular pumping packages (incl. compound and drag pumps)</p> <p>includes: Pumping packages, pumping stations, pumping stacks, pumping carts, pumping outfits based on Turbomolecular pumps including the primary and booster pumps, hardware and instrumentation.</p>
9	C	Diffusion pumps (including packages)
10	C	<p>Ion getter pumps (including packages)</p> <p>includes: Ion pump and their power supplies and controllers Penning pumps Sputter ion pumps Diode and triode ion pumps Noble Diode Pumps</p>
11	C	<p>Sublimation/sorption/getter pumps (including packages)</p> <p>includes: Titanium sublimation pums, controllers and cooled shrouds Evaporable getter pumps</p>
12	C	Cryopumps (<-160°C) (excl. water pumps)
13	C	Cryo water pumps (>-160°C)

Key:

A = Rough vacuum pumps (10^3 - 10^0 mbar)
B = Medium vacuum pumps (10^0 - 10^{-5} mbar)
C = High vacuum pumps (10^{-5} - 10^{-12} mbar)

Figure 37: Vacuum pump market segmentation

Rough Vacuum	Process Vacuum	Industrial Vacuum	Semiconductor Process Vacuum	Thin Film Deposition (non-Semiconductor)	Solar	Instrumentation Manufacturers	R&D
<u>Markets</u> <ul style="list-style-type: none"> - Packaging (except food) - Central Vacuum - Printing and Paper Handling - Pick and Place - Conveying - Moulding - Air sampling - Medical 	<u>Markets</u> <ul style="list-style-type: none"> - Chemical (Bulk, Fine,...) - Petrochemical - Pharmaceutical - Plastics (Extrusion,...) - Food - Beverage - Textile - Paper - Ceramics - Freeze drying - Energy (Wind, Nuclear, Steam Turbines,...) - Central Vacuum (Batteries,...) 	<u>Markets</u> <ul style="list-style-type: none"> - Vacuum Metallurgy (Metal Degassing, Melting, Re-melting, E-beam welding, Casting,...) - Vacuum Heat Treatment (Brazing, Carburising, Nitriding, Quenching,...) - Laser Technology - Electron Tubes - TV Tubes - Lamps and Bulbs - Industrial leak detection - Refrigeration and Air Conditioning - Automotive (Dehydration, Charging and Test) - Electrical (Encapsulation,...) - Medical sterilisation 	<u>Markets</u> <ul style="list-style-type: none"> - Silicon Semiconductor (Memory, Logic, MEMS,...) - Compound Semiconductor (LEDs,...) - TFT-LCD Displays - Semicon Crystal Pulling <p><i>Please note: Above includes both Process Equipment Manufacturers and End Users for PVD, CVD, Etching, Ion Implantation, MBE</i></p>	<u>Markets</u> <ul style="list-style-type: none"> - Glass/Web/Optical Coating - Optical Data Storage (CD, DVD, Hi Def Disk,...) - Magnetic Data Storage (HDD) - Thin Film Heads - Surface Coating (wear protection, decorative, ...) - Display Coatings (OLED, FED, PDP, SED,...) - Thin Film batteries 	<u>Markets</u> <ul style="list-style-type: none"> - Photovoltaic Solar (c-Si & Thin-Film Deposition, Laminating,...) - Thermal Solar (Water Heaters,...) - Solar Crystal Growth (Pulling, Re-melt, ...) 	<u>Markets</u> <ul style="list-style-type: none"> - Mass Spectrometers - Electron Microscopes - Metrology/ Inspection/ Defect Review systems for Semiconductor including Focused Ion Beam systems and Electron Beam systems - Surface Analysis - Gas Analysis - X-Ray Analysis - MRI and NMR - Sample preparation (Driers, Centrifuges, Concentrators,...) - Leak Detectors - Medical accelerators (Linac, Synchrotron, Cyclotron...) 	<u>Markets</u> <ul style="list-style-type: none"> - Universities - Government Labs - Scientific Research Laboratories - Space Simulation
Typical operating pressure (mbar)							
> 1	> 10 ⁻²	10 ⁻³ - 10 ⁻⁴	1 - 10 ⁻⁸	10 ⁻³ - 10 ⁻⁴		10 ⁻⁴ - 10 ⁻¹⁰	10 ⁻² - 10 ⁻¹¹
PVD: CVD: MBE: MEMS: TFT-LCD: SED: HDD:	Physical Vapour Deposition Chemical Vapour Deposition Molecular Beam Epitaxy Micro Electro Mechanical Systems Thin-Film Transistor Liquid Crystal Display Surface Emission Display Hard Disk Drive			CD: DVD: OLED: FED: PDP: MRI: NMR:	Compact Disk Digital Video Disk Organic Light Emitting Diode (or OLED: Organic Electro Luminescent Display) Field Emission Display Plasma Display Panel Magnetic Resonance Imaging Nuclear Magnetic Resonance		

This Vacuum Market Segmentation Chart was developed by the Working Group of the International Statistics on Vacuum Technology Program (ISVT), and is published with their permission. Organisations that participate in the program are the Association of Vacuum Equipment Manufacturers International (AVEM), the Japan Vacuum Industry Association (JVIA), the European Vacuum Technology Association (EVTA), and the Semiconductor Equipment and Materials International (SEMI).

Version 2011.0, Frankfurt, Germany, October 28th 2010

Figure 38: Vacuum pump energy consumption

(based on ISVT results of year 2011, made available by PN5 Pneurop)

Pos	Class	Vacuum Pump	Technology	pieces (2011)	average power installed (KW)	average load factor	average power consumption (KW)	average runtime per year (hours)	power consumption per year (KW)	average lifecycle (years)	average power consumption over life cycle (KW) on the Basis of 2011
1	A	Liquid ring pumps (including packages)	PD rotary	30.000	3	0,7	2,1	5.000	315.000.000	8	2.520.000.000
2	A	Side channel pumps (including packages)	PD rotary	40.000	2	0,7	1,4	4.000	224.000.000	8	1.792.000.000
3.1	B	Multi-stage oil-sealed rotary vane/piston pumps < 1 mbar (ultimate pressure)	PD rotary / reciprocating	15.000	2	0,2	0,4	6.000	36.000.000	10	360.000.000
3.2	A	Single stage oil-sealed rotary vane/piston pumps > 1 mbar (ultimate pressure)	PD rotary / reciprocating	35.000	2,2	0,7	1,54	4.000	215.600.000	10	2.156.000.000
4.1	B	Single stage roots pumps (separately sold)	PD rotary	5.000	10	0,5	5	6.000	150.000.000	10	1.500.000.000
4.2	B	Roots pumping packages, backed by oil sealed pumps	PD rotary	7.000	15	0,5	7,5	6.000	315.000.000	10	3.150.000.000
5	A	Radial blowers (including packages)	PD rotary	not relevant for vacuum applications							0
6	A	Ejector pumps - water, steam & compressed air (including packages)	K jet	no drive by mechanical work							0
7.1	B	Dry pumps (including packages) < 1 mbar (ultimate pressure)	PD rotary / reciprocating	10.000	5	0,5	2,5	5.000	125.000.000	10	1.250.000.000
7.2	A	Rough dry pumps (including packages) > 1 mbar (ultimate pressure)	PD rotary / reciprocating	20.000	1,6	0,7	1,12	4.000	89.600.000	8	716.800.000
8.1	C	Turbomolecular pumps (incl. compound and drag pumps)	K turbo	15.000	0,25	0,2	0,05	8.000	6.000.000	8	48.000.000
8.2	C	Turbomolecular pumping packages (incl. compound and drag pumps)	K turbo	4.000	2	0,4	0,8	6.000	19.200.000	8	153.600.000
9	C	Diffusion pumps (including packages)	K diffusion	no drive by mechanical work							0
10	C	Ion getter pumps (including packages)	E getter	no drive by mechanical work							0
11	C	Sublimation/sorption/getter pumps (including packages)	E getter	no drive by mechanical work							0
12	C	Cryopumps (<-160°C) (excl. water pumps)	E cryo	no drive by mechanical work							0
13	C	Cryo water pumps (>-160°C)	E cryo	no drive by mechanical work							0
		Sum		181.000					1.495.400.000		13.646.400.000

Ecodesign Preparatory Study on

Electric motor systems / Compressors

ENER Lot 31

FINAL Report Task 2

Economic and market analysis



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Prepared *for the European Commission*

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1 Introduction to Task 2

1.1 Scope

This is the final Task 2 report of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **‘ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives’**.

The aim of Task 2 is to place the product group within the total of EU industry and trade policy (subtask 2.1). To provide market and cost inputs for the EU-wide environmental impact of the product group (subtask 2.2). To provide insight in the latest market trends so as to indicate the place of possible Eco-design measures in the context of the market-structures and on-going trends in product design (subtask 2.3, also relevant for the impact analyses in Task 3). And finally, to provide a practical data set of prices and rates to be used in a Life Cycle Cost (LCC) calculation (Subtask 2.4).

1.2 Subtasks

The technical tender specifications for the Task 2 subtasks are:

Subtask 2.1 Generic economic data

Identify, retrieve data and report on

- EU Production;
- Extra-EU Trade;
- Intra-EU Trade;
- Apparent EU-consumption.⁶¹

Data should relate to the latest full year for which at least half of the Member States have reported. Preferably data should be in physical volume and in money units and split up per Member State.

Information for this subtask should be derived from official EU statistics so as to be coherent with official data used in EU industry and trade policy.

Subtask 2.2 Market and stock data

In physical units, for EU-27, for each of the categories as defined in 1.1 and for reference years

- 1990 or 1995 (Kyoto ref.);
- 2003-2005 (most recent real data);
- 2010-2012 (forecast, end of Kyoto phase 1, relevant also for Stockholm, etc.);
- 2020-2025 (forecast, year in which all new eco-designs of today will be absorbed by the market).

The following parameters are to be identified:

- Installed base (“stock”)⁶² and penetration rate;
- Annual sales growth rate (% or physical units);
- Average Product Life (in years), differentiated in overall life time and time in service, and a rough indication of the spread (e.g. standard deviation);

⁶¹ Calculated from production, imports and exports. If available, changes in product stock should be taken into account, but usually this will not be the case.

⁶² Forecasts are to take into account population growth rates and/or building growth rates

- Total sales/ real EU-consumption⁶³, (also in €, when available);
- Replacement sales (derived);
- New sales (derived).

Subtask 2.3 Market trends

This entails

- Latest consumer tests (anecdotal, not necessarily valid for the whole of the EU);
- Description of the market and production structure and identification of the major players;
- General trends in product-design and product-features.⁶⁴

Subtask 2.4 Consumer expenditure base data

For each of the categories defined in Task 1 determine:

- Average consumer prices, incl. VAT, in Euro. [Note: most compressors are sold in a "B2B" context and the applicability of VAT shall be reviewed]

Determination of applicable rates for running costs and disposal, per EU Member State, specifically⁶⁵:

- Electricity rates (€/ kWh);
- if applicable: fossil fuel rates (€/ GJ);
- Water (and sewage) rates (€/m³);
- Consumer prices of other consumables (air filters, oil, etc.) (€/unit, etc.);
- Repair and Maintenance costs (€/product life);
- Installation costs (for installed appliances only);
- Disposal tariffs/ taxes (€/product);
- Interest and inflation rates (%).

⁶³ The objective is to define the actual consumption as reliably as possible for the categories defined in task 1.1, for the latest full year for which consistent data could be retrieved. Significant differences between the actual consumption and the apparent consumption in subtask 2.2 may occur.

⁶⁴ From the marketing point of view, not from the perspective of a detailed technical analysis

⁶⁵ Note that a part of these data could be harmonized for all product groups.

2 Generic economic data

2.1 Introduction

Sales data from Prodcom and other sources are presented in this task. Prodcom sales data relates where possible to 'apparent consumption' (EU production, plus intra EU trade, minus extra EU trade). Sales data from other sources are presented as industry numbers. The relevance of sales data lies in that, combined with the estimated product life, the sales can be used as indicator for the stock.

2.2 Prodcom generic data

2.2.1 Apparent consumption

Eurostat provides data regarding European business statistics of manufactured goods generally referred to as 'Prodcom'. International trade statistics are structured using the Combined Nomenclature (CN). Prodcom and CN categories are to a large extent similar, but completely.

Prodcom provides information on EU production, extra EU trade, intra EU trade and thus allows calculation of apparent consumption (based on production, import, export).

The table below shows the categories that list "compressors" according Prodcom nomenclature year 2010 and the corresponding international Combined Nomenclature (CN).

Table 19 Prodcom production/import/export plus apparent consumption UNITS for year 2010

Group	Prodcom year 2010	Production	Import to EU	Export from EU	Apparent consumption (* 1 000)
Refrigeration	28132300 Compressors for refrigeration equipment	41.407.837	14.237.788	18.759.588	36.886
Mobile	28132400 Air compressors mounted on a wheeled chassis for towing	187.700	767.908	172.264	783
Centrifugal	28132530 Turbo-compressors, single stage	7.503.267	2.273.348	1.716.884	8.060
	28132550 Turbo-compressors, multistage	1.113	1.104.975	508.995	597
Reciprocating	28132630 Reciprocating displacement compressors having a gauge pressure capacity <= 15 bar, giving a flow <= 60 m ³ /hour	1.000.000	5.553.749	853.656	5.700
	28132650 Reciprocating displacement compressors having a gauge pressure capacity <= 15 bar, giving a flow per hour > 60 m ³	11.321	121.553	28.274	105
	28132670 Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour <= 120 m ³	40.000	260.900	207.082	94
	28132690 Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m ³	4.170	77.136	31.366	50
Rotary	28132730 Rotary displacement compressors, single-shaft	80.000	601.827	86.980	595
Multi-shaft	28132753 Multi-shaft screw compressors	210.000	23.291	113.483	120
	28132755 Multi-shaft compressors (excluding screw compressors)	20.000	16.129	28.029	8
Air/gas	28132800 Air/gas compressors excluding air/vacuum pumps used in refrigeration, air compressors mounted on wheeled chassis, turbo compressors, reciprocating and rotary displacement compressors	2.100.000	7.586.858	2.250.502	7.436
TOTAL					2410.082

The Prodcum data suggest a total apparent consumption (production + imports - exports) of over 60 million compressor units. Of these 60 million some 61% are compressors for refrigeration (and possibly heat pump) applications.

Of the remaining 23.5 million units a significant share is turbocompressors/single- stage (34% of 23.5), miscellaneous air/gas compressors (31%) and reciprocating compressors (25%).

As indicated in Task 1 report many of the Prodcum/CN8 categories do not match the intended scope of products. In most categories compressor types are included that are either transport-related, or non-electric or not industrial compressors as intended in the scope. The below table is a copy of table 1 in the Task 1 report which explains the possible 'mismatches':

Table 20: Prodcum 2010 categories that list compressors

PRODCOM	Combined Nomenclature	Description	Remarks
28 13 23 00		Compressors for refrigeration equipment	Refrigeration (cooling and freezing)
28 13 24 00	84144010 84144090	Air compressors mounted on a wheeled chassis for towing	These are often reciprocating compressors, but screw and vane compressors can also be applied. This category is very diverse as it ranges from small electrically driven piston compressors with two wheels, up to diesel engine driven compressors, to be towed behind vehicles. This means that part of this category is within scope (electric motor driven) and part will be outside scope (diesel engine driven).
28 13 25 30	84148011	Turbo-compressors, single stage	These are centrifugal compressors as axial compressors are always multi stage. This group may also include "turbochargers" included in "Trade statistics No. 84148011, PRODCOM No. 28132530 - Turbo-compressors, single stage" according to EU Commission EXPLANATORY NOTES TO THE COMBINED NOMENCLATURE OF THE EUROPEAN COMMUNITIES (2008/C 133/01) ⁶⁶ . A typical application for compressors for transport is the production of compressed air for braking systems (transport equipment). This means that part of this category is outside scope if designed for use in 'means of transport'.
28 13 25 50	84148019	Turbo-compressors, multistage	This group can be both centrifugal and axial compressors. As above, part of this category is outside scope if designed for use in 'means of transport'
28 13 26 30	84148022	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow ≤ 60 m ³ /hour	These groups may include mini- compressors used as tyre-repair-kit, a household application inflating toys, balls, air mattresses or other inflatable objects (reciprocating compressors (excluding reciprocating compressor pumps), giving a flow not exceeding 2 cubic metres per minute); according COUNCIL IMPLEMENTING REGULATION (EU) No 1306/2011 of 12 December 2011. (concerning CN codes ex 8414 40 10, ex 8414 80 22, ex 8414 80 28 and ex 8414 80 51)
28 13 26 50	8414 80 28	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow per hour > 60 m ³	
28 13 26 70	8414 80 51	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour ≤ 120	

⁶⁶ see also <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2008:133:0001:0402:EN:PDF>

		m ³	
28 13 26 90	84148059	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m ³	
28 13 27 30	84148073	Rotary displacement compressors, single-shaft	Typical rotary compressors with a single shaft are vane, scroll and liquid ring type compressors.
28 13 27 53	84148075	Multi-shaft screw compressors	
28 13 27 55	84148078	Multi-shaft compressors (excluding screw compressors)	These are e.g. lobe type compressors and single screw compressors (with two additional gate rotors).
28 13 28 00	84148080	Air/gas compressors excluding air/vacuum pumps used in refrigeration, air compressors mounted on wheeled chassis, turbo compressors, reciprocating and rotary displacement compressors	According Nomenclature of Trade statistics HS 84148080 this category includes air pumps and ventilating or recycling hoods incorporating a fan, whether or not fitted with filters, with a maximum horizontal side > 120 cm (excl. vacuum pumps, hand- or foot-operated air pumps and compressors). This means that part of this category is outside the scope if they are considered to be 'fans' or other non-compressor equipment ⁶⁷ .

Therefore, although the Prodcum data on turbocompressors - single stage shows apparent consumption of over 8 million units in 2010, many of these compressors are assumed to be applied in engine turbocharger systems and braking systems in means of transport. Note that also pistons, screws, scrolls type compressors may be used in braking systems in transport like trains, trucks . Being driven by (exhaust air) of internal combustion engines, a significant share of these turbocompressors should be outside the scope of this study.

Also for the product group air/gas compressors 28 13 28 00 many of these may be equipment that do not fit the definition of compressors as intended (these could be fans and blowers - see Task 1 report).

As regards the mobile compressors (towable) a significant share will be powered by an internal combustion engine and not an electrical motor and are thus outside the intended scope.

There is also an unknown share of non-electrical motor driven compressors present in the other/remaining product categories.

Therefore the total market of non-refrigeration compressors as calculated on the basis of Prodcum (roughly 23.5 million annually) is assumed to be a severe overestimation of the sales of products actually within the broadly defined scope of compressors driven by electric motors and the product definition of compressors.

Multi-annual analysis

Prodcum does allow multi-annual analysis, but given the above comments its usefulness is considered very limited and no conclusions will be drawn on this basis for future projections. The data is provided below.

Table 21: Prodcum production/import/export plus apparent consumption UNITS for year 2005-2011

Quantity	Production	Import	Export	Apparent consumption
28132300 Compressors for refrigeration equipment				
2005	38.893.022	14.854.540	11.699.128	42.048.434

⁶⁷ see also http://www.zolltarifnummern.de/2012_en/84148080.html

Quantity	Production	Import	Export	Apparent consumption
2006	42.350.736	14.995.666	13.838.445	43.507.957
2007	43.609.701	31.492.468	14.992.103	60.110.066
2008	37.911.308	15.992.812	15.513.875	38.390.245
2009	33.089.420	11.576.395	11.761.126	32.904.689
2010	41.407.837	14.237.792	18.759.588	36.886.041
2011	33.793.341	17.023.783	14.705.174	36.111.950
28132400 Air compressors mounted on a wheeled chassis for towing				
2005	461.803	406.913	293.148	575.568
2006	155.834	729.385	227.301	657.918
2007	257.168	751.958	223.852	785.274
2008	181.676	554.133	199.960	535.849
2009	123.705	670.694	200.095	594.304
2010	187.793	767.908	172.264	783.437
2011	135.897	540.882	166.409	510.370
28132530 Turbo-compressors, single stage				
2005	7.181.710	840.485	1.443.886	6.578.309
2006	7.763.613	637.104	1.735.435	6.665.282
2007	8.338.671	813.302	2.027.031	7.124.942
2008	6.987.883	1.217.477	2.446.321	5.759.039
2009	5.859.952	849.560	1.357.377	5.352.135
2010	7.503.267	2.273.348	1.716.884	8.059.731
2011	9.322.118	2.620.124	1.882.814	10.059.428
28132550 Turbo-compressors, multistage				
2005	884	29.112	12.735	17.261
2006	2.531	122.882	20.626	104.787
2007	1.400	251.199	40.309	212.290
2008	1.200	416.899	53.960	364.139
2009	1.134	456.179	50.496	406.817
2010	1.113	1.104.975	508.995	597.093
2011	1.367	1.211.579	659.755	553.191
28132630 Reciprocating displacement compressors having a gauge pressure capacity <= 15 bar, giving a flow <= 60 m³/hour				
2005	1.500.000	2.022.476	505.819	3.016.657
2006	1.000.000	1.720.611	584.422	2.136.189
2007	1.500.000	2.379.460	634.077	3.245.383

Quantity	Production	Import	Export	Apparent consumption
2008	1.500.000	2.499.140	723.562	3.275.578
2009	1.500.000	2.805.804	706.474	3.599.330
2010	1.000.000	5.553.749	853.656	5.700.093
2011	2.000.000	7.202.399	954.219	8.248.180
28132650 Reciprocating displacement compressors having a gauge pressure capacity <= 15 bar, giving a flow per hour > 60 m ³				
2005	22.940	23.375	4.311	42.004
2006	27.700	192.358	162.308	57.750
2007	33.617	118.076	49.686	102.007
2008	19.089	35.573	19.236	35.426
2009	13.310	84.096	26.044	71.362
2010	11.321	121.553	28.274	104.600
2011	11.578	95.253	40.285	66.546
28132670 Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour <= 120 m ³				
2005	30.000	349.615	144.001	235.614
2006	230.245	170.979	234.554	166.670
2007	720.000	134.519	206.722	647.797
2008	48.955	89.430	423.548	-285.163
2009	35.000	139.375	125.949	48.426
2010	40.000	260.900	207.082	93.818
2011	46.956	389.356	186.484	249.828
28132690 Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m ³				
2005	3.106	6.246	4.726	4.626
2006	3.949	48.883	18.124	34.708
2007	4.558	65.962	9.984	60.536
2008	4.313	49.480	18.497	35.296
2009	4.227	37.141	16.154	25.214
2010	4.170	77.136	31.366	49.940
2011	4.938	65.265	16.292	53.911
28132730 Rotary displacement compressors, single-shaft				
2005	108.873	661.128	74.629	695.372
2006	100.000	513.340	92.344	520.996
2007	150.000	593.733	61.964	681.769

Quantity	Production	Import	Export	Apparent consumption
2008	160.000	459.341	56.786	562.555
2009	76.305	402.880	35.336	443.849
2010	80.000	601.827	86.980	594.847
2011	120.000	1.289.083	281.741	1.127.342
28132753 Multi-shaft screw compressors				
2005	180.000	5.687	118.810	66.877
2006	180.000	9.363	224.023	-34.660
2007	250.000	11.476	154.595	106.881
2008	218.578	5.831	106.005	118.404
2009	200.000	22.651	72.118	150.533
2010	210.000	23.291	113.483	119.808
2011	280.000	14.605	165.862	128.743
28132755 Multi-shaft compressors (excluding screw compressors)				
2005	20.825	403.094	11.768	412.151
2006	22.134	314.081	278.032	58.183
2007	25.060	458.658	450.178	33.540
2008	25.077	522.625	42.516	505.186
2009	19.232	127.701	31.820	115.113
2010	20.000	16.129	28.029	8.100
2011	27.000	25.759	25.993	26.766
28132800 Air/gas compressors excluding air/vacuum pumps used in refrigeration, air compressors mounted on wheeled chassis, turbo compressors, reciprocating and rotary displacement compressors				
2005	2.014.536	5.926.738	1.313.769	6.627.505
2006	2.000.000	7.595.468	1.337.718	8.257.750
2007	2.200.000	9.651.753	1.532.389	10.319.364
2008	2.400.000	8.824.558	1.347.044	9.877.514
2009	1.616.658	7.301.088	1.149.598	7.768.148
2010	2.100.000	7.586.961	2.250.502	7.436.459
2011	2.800.000	7.354.964	2.217.953	7.937.011

2.2.2 Economic significance

The apparent EU-2010 market, derived from PRODCOM and Eurostat external trade data, constitutes a value (in msp⁶⁸) of € 6,4 billion, of which € 2,3 billion for refrigeration compressors and € 4,1 billion for other types.

⁶⁸ Manufacturer selling prices

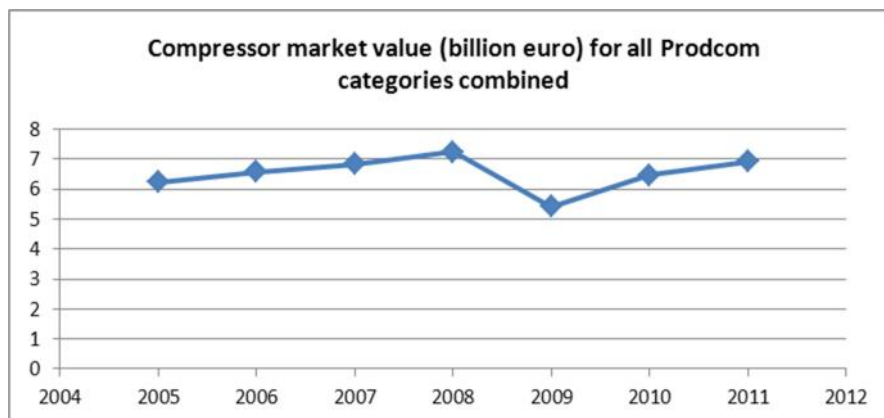
Table 22: Prodcom production/import/export plus apparent consumption VALUE for year 2005-2011 (billion)

Value (billion euro)	Production	Import	Export	Apparent consumption
28132300 Compressors for refrigeration equipment				
2005	2,42	0,89	0,74	2,57
2006	2,64	0,97	0,87	2,74
2007	2,79	1,06	1,02	2,83
2008	2,47	0,97	0,99	2,46
2009	2,09	0,71	0,78	2,01
2010	2,64	0,81	1,08	2,37
2011	2,52	0,98	1,13	2,36
28132400 Air compressors mounted on a wheeled chassis for towing				
2005	0,30	0,02	0,17	0,15
2006	0,31	0,04	0,17	0,17
2007	0,38	0,04	0,18	0,24
2008	0,33	0,03	0,17	0,19
2009	0,19	0,02	0,19	0,02
2010	0,22	0,03	0,20	0,05
2011	0,25	0,03	0,25	0,03
28132530 Turbo-compressors, single stage				
2005	1,23	0,18	0,35	1,07
2006	1,44	0,18	0,38	1,24
2007	1,54	0,20	0,48	1,26
2008	1,60	0,27	0,57	1,30
2009	1,32	0,25	0,39	1,17
2010	1,58	0,34	0,53	1,40
2011	2,05	0,33	0,60	1,78
28132550 Turbo-compressors, multistage				
2005	0,86	0,03	0,44	0,45
2006	0,59	0,04	0,39	0,23
2007	0,56	0,06	0,59	0,04
2008	0,92	0,08	0,57	0,43
2009	1,41	0,08	0,75	0,74
2010	1,40	0,11	0,85	0,66
2011	1,41	0,13	0,76	0,79
28132630 Reciprocating displacement compressors having a gauge pressure capacity <= 15 bar, giving a flow <= 60 m³/hour				
2005	0,24	0,10	0,09	0,25
2006	0,15	0,08	0,10	0,13
2007	0,24	0,09	0,11	0,22

2008	0,23	0,11	0,14	0,20
2009	0,20	0,08	0,11	0,17
2010	0,23	0,14	0,13	0,23
2011	0,26	0,16	0,14	0,27
28132650 Reciprocating displacement compressors having a gauge pressure capacity <= 15 bar, giving a flow per hour > 60 m ³				
2005	0,05	0,00	0,02	0,04
2006	0,06	0,01	0,05	0,02
2007	0,07	0,01	0,02	0,06
2008	0,07	0,01	0,05	0,03
2009	0,05	0,02	0,08	-0,01
2010	0,04	0,00	0,08	-0,04
2011	0,04	0,00	0,04	0,00
28132670 Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour <= 120 m ³				
2005	0,13	0,01	0,06	0,08
2006	0,16	0,01	0,08	0,10
2007	0,24	0,01	0,09	0,15
2008	0,21	0,01	0,09	0,12
2009	0,14	0,00	0,07	0,07
2010	0,18	0,00	0,10	0,08
2011	0,22	0,00	0,10	0,13
28132690 Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m ³				
2005	0,24	0,01	0,07	0,18
2006	0,28	0,01	0,09	0,20
2007	0,36	0,01	0,14	0,23
2008	0,39	0,04	0,14	0,29
2009	0,43	0,02	0,21	0,24
2010	0,42	0,07	0,18	0,31
2011	0,37	0,02	0,17	0,22
28132730 Rotary displacement compressors, single-shaft				
2005	0,16	0,05	0,06	0,15
2006	0,18	0,06	0,09	0,15
2007	0,21	0,04	0,11	0,15
2008	0,14	0,03	0,12	0,06
2009	0,08	0,03	0,13	-0,01
2010	0,09	0,05	0,12	0,02
2011	0,12	0,04	0,14	0,01

28132753 Multi-shaft screw compressors				
2005	1,00	0,01	0,37	0,65
2006	1,50	0,02	0,29	1,23
2007	1,40	0,01	0,35	1,06
2008	1,80	0,02	0,37	1,45
2009	0,90	0,01	0,34	0,58
2010	1,50	0,02	0,63	0,89
2011	1,60	0,01	0,78	0,83
28132755 Multi-shaft compressors (excluding screw compressors)				
2005	0,15	0,04	0,05	0,15
2006	0,13	0,03	0,07	0,09
2007	0,16	0,04	0,07	0,12
2008	0,16	0,05	0,07	0,13
2009	0,15	0,02	0,08	0,09
2010	0,18	0,00	0,11	0,07
2011	0,20	0,00	0,11	0,10
28132800 Air/gas compressors excluding air/vacuum pumps used in refrigeration, air compressors mounted on wheeled chassis, turbo compressors, reciprocating and rotary displacement compressors				
2005	0,62	0,28	0,40	0,50
2006	0,66	0,28	0,66	0,28
2007	0,77	0,29	0,58	0,48
2008	0,91	0,24	0,58	0,57
2009	0,80	0,23	0,69	0,34
2010	0,75	0,23	0,56	0,42
2011	0,81	0,19	0,61	0,39

Figure 39: Compressor market value for all Prodcom categories combined (2005-2011)



However, in the light of the aforementioned comments regarding the mismatch in Prodcom categories and the intended scope of the study, it is proposed to base the economic value on data to be provided by the industry itself.

2.2.3 Parts

Other relevant Eurostat statistics relate to Prodcom category 28133200 - Parts of air and vacuum pumps, of air and gas compressors, of fans, and of hoods and that are traded as CN8 category: 84149000 - Parts of : air or vacuum pumps, air or other gas compressors, fans and ventilating or recycling hoods incorporating a fan, n.e.s.

Table 23: Parts production/import/export VALUE in billion euros in the EU-27

28133200 - Parts of air and vacuum pumps, of air and gas compressors, of fans, and of hoods etc.									
Value (billion euro)	2003	2004	2005	2006	2007	2008	2009	2010	2011
Production	1,76	2,04	1,92	2,13	2,50	2,07	1,83	2,00	2,29
Import	0,76	0,92	0,95	1,12	1,33	1,47	1,15	1,61	1,92
Export	1,38	1,60	1,62	1,61	2,17	2,08	2,30	2,52	2,49
Apparent consumption	1,14	1,37	1,25	1,65	1,66	1,47	0,69	1,10	1,72

2.2.4 Installation, repair and maintenance

Eurostat also gives production statistics on repair and maintenance of pumps and compressors but the relevance of the values remains limited as it comprises compressors and pumps of un-identified types and applications .

Table 24 Repair and maintenance of pumps and compressors VALUE for year 2006-2011

33121210 Repair and maintenance of pumps and compressors in million Euro																				
Year	Value EU27	BE	BU	CZ	DE	IR	GR	ES	FR	IT	HU	NL	AT	PL	PT	RO	SK	FI	SE	UK
2011	2358	56	5	48	472		3	130	309	345	15	263	19	53	15	10	23	8	49	515
2010	2296	59	5	42	463		3	121	305	335	4	284	17	49	15	8	31	11	49	472
2009	2231	60	3	39	445	1	4	111	333	427	10	232	15	41	9	20	24	12	44	400
2008	2288	58	6	42	460	7	5	103	403	378	15	238	17	109	7	17	31	15	46	329
2007	1821		8	31	432	1	4	97	187		10	201	16	57	9	11	20	14	68	257
2006	1464		7	24	372	1	4	95	139	209	11	180	16	33	10	11		11	54	217
Not shown:																				
Cells market as confidential (:C)																				
Countries with no data: Denmark, Cyprus, Luxembourg, Malta																				
Countries > 1.0 million LV, LT, SL, EE																				

3 Market and stock data

3.1 Introduction

As concluded in the previous chapter the information by official trade statistics (Prodcom) is not suitable for identification of sales and installed base (stock). Instead this chapter presents industry data provided by other market actors, most notably Pneurop, which shall be used as reference data for the remainder of the study.

The data provided by Pneurop is compared to that from other public sources, more specifically the 1999 study on industrial air compressors by Fraunhofer.

The description of sales and stock should include projections for future years, up to 2030, to include the absorption of 'improved products' (with a long product life) by the market. In case no sources for future projections were available these were estimated on the basis of stable market conditions (trend line extrapolations).

3.2 Sales

Earlier estimates

Based on the installed base (stock) of '**compressed air systems**' identified in the study by Fraunhofer in 1999 the sales of ("standard air") compressors (assuming a typical lifetime of 13 years for compressors between 10-110 kW and 16 years for systems between 110-300 kW and assuming no market change/only replacement sales) are 18 000 units for systems between 10-110 kW and 5 600 units for systems between 110-300 kW. This gives a total some **23.6 thousand** units per year of compressors for 'compressed air systems' (assumed indicative for year 1999 or 2000).

Pneurop 2012 estimates

The main stakeholder Pneurop conducted in 2012 and 2013 two surveys under its members to provide more information on the sales of compressors in the EU27: The first survey of 2012 covered all application ranges, the second (performed in the summer of 2013) focused on the standard air application range only.

1st survey 2012

The sales have been assessed on the basis of indicative values from three main members in Pneurop: VDMA for Germany, BCAS for United Kingdom and Profluid for France. The indicative sales have been extrapolated to the EU27 on the assumption that these three countries make up for 50% of the EU27 market.

The sales were structured according the "application ranges" identified in task 1, which are a very coarse description (extreme generalisation) of typical compressor applications. These application ranges are:

Table 25: Description of application ranges

Application ranges	Typical function or application	Typical performance (pressure increase)	Typical technologies
Standard air compressors	for very diverse applications	7-15 bar	Oil-injected / -lubricated screw, vane and piston
Low pressure air compressors	many are used in waste water treatment (oxygenation)	50 mbar – 3.5 bar	Various types (lobe, screw and turbocompressors)
Oil free / non-lubricated air compressors	for applications requiring oil-free supply of air	7-15 bar	Various types such as screw, turbo, incl. scroll and tooth

Hobby air compressors	very diverse (tyre inflation, tools, spraying)	0 - 10 bar	Mainly piston
Process gas compressors, air / inert gasses	for example in the air separation industry, regeneration or processes in the chemical, pharmaceutical, oil/gas industries	1 – 1 000 bar (depends on technology)	Mainly piston, but also turbo, screw, rotary lobe
Process gas compressors, other gasses	for example processes in the in chemical, pharmaceutical, oil/gas industries, includes handling of hazardous (toxic, flammable) gases	1 – 1 000 bar (depends on technology)	Mainly piston, but also turbo, screw, rotary lobe

Table 26: Sales by application range 1st survey (indicative year 2010)

Application range	Sales (units)	Remarks
Standard air compressor	123 362	typical power 9.7 kW (average over whole range of sales)
- piston	76 654	typical power 4 kW
- oil-injected screw	46 708	typical power 37 kW
- vane	sales volume is incorporated in above volume	typical power not provided
Low pressure air compressor	12 800	typical power 46 kW
Oil free / non-lubricated air compressors	2 000	typical power 189 kW
Process compressors inert gasses		
- turbo	14	typical power 8 MW
- rotary lobe	13	typical power 203 kW
Process compressors other gasses		
- piston	150	typical power 314 kW
- turbo	12	typical power 10 MW
- screw oil-free	7	typical power 1 MW
- screw oil-injected	13	typical power 893 kW
- Rotary lobe	14	typical power 112 kW
Hobby air compressors	500 000	between 1-3 kW
TOTAL EU27	638 384	

“Hobby compressors” apply single phase motors from 0 to maximum 3 kW that can be connected to domestic low voltage electric plug and have loads (maximum currents) not exceeding 16 A. The pressure range is between 0-10 gauge pressure.

2nd survey

In the summer of 2013 an extensive data collection exercise (survey) was performed between members of the Pneurop Ecodesign JWG. This data collection addressed number of sales, the efficiencies of sold products and average power of compressors in the standard air application range.

This data collection was performed specifically to generate inputs for Task 6, 7 and 8, but in order to maintain overall consistency of the Lot 31 reports, the results are repeated here under Task 2 and are considered an update (improvement) of the sales presented under the 1st survey.

The results of this second survey are shown below together with the first survey results.

Table 27 Sales 2nd survey (compared to 1st survey)

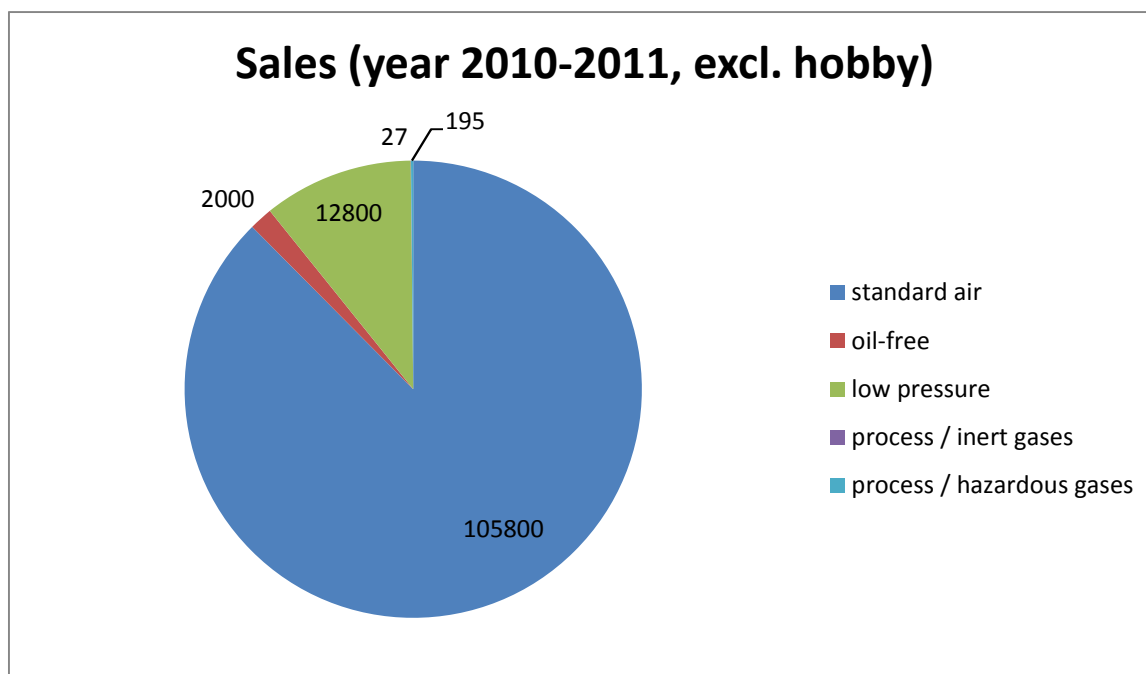
1 st survey			2 nd survey		
	Volume 2010	Avg power (kW)		Volume 2011	Avg power (kW)
Screw and vane	46 708	37	fixed speed OIS+OIV	45 200	24,7
		unknown	variable speed OIS+OIV	8 600	35,4
pistons	76 654	4	pistons	52 000	4,3
Totals	123 362		Totals	105 800	

The more thorough second survey identified less overall sales (86% of first estimate), but larger sales for screw and vane type compressors within the standard air application range (115% of first estimate) and lesser sales of piston compressors in this application range.

The change in sales volume is not because of the mere shift of one year in sales period considered (from 2010 to 2011).

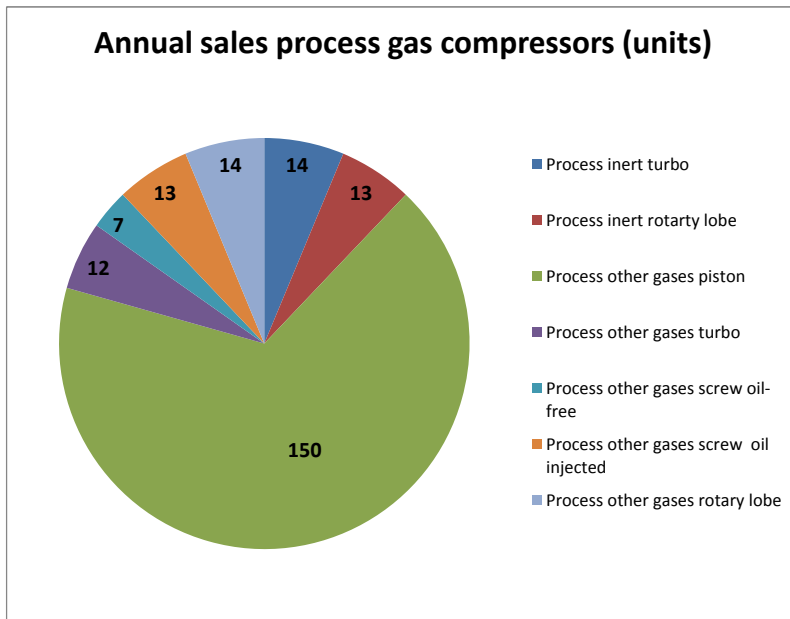
The total sales (combining the Pneurop 2012 estimate with the 2013 assessment for standard air application range) are presented in the figure below.

Figure 40: Sales of compressors by application range in the EU27 (units/year)



Annual sales for process gas compressors can be subdivided in inert gases and other gases as shown in the figure below (basis: 1st survey).

Figure 41: Details of sales process gas compressors for 'air/..' and 'other' gases (units/year)

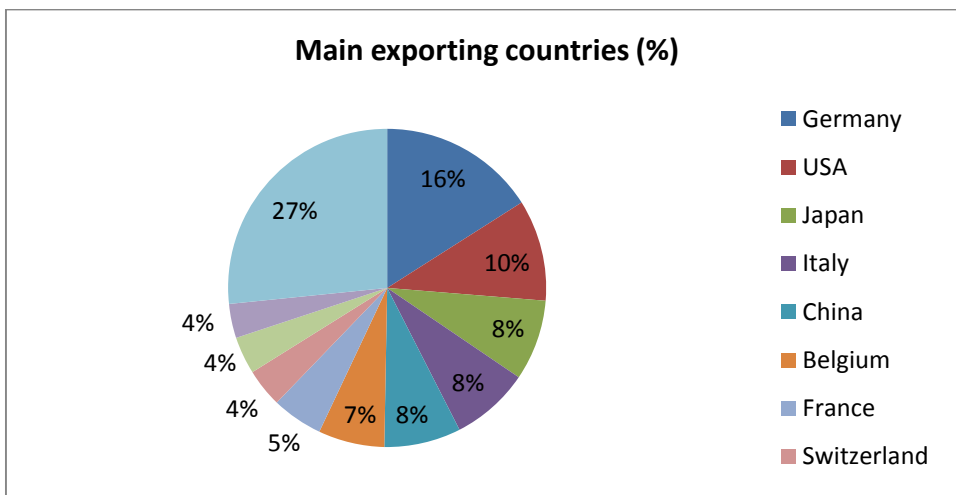


3.3 Import / export

The data presented below is extracted from an analysis by VDMA (2013) ⁶⁹. According to this source Germany is the world's biggest exporter of compressor products, as it accounts for 16% of the global market for compressors, compressed Air and Vacuum Technology. If we add known export shares of other EU countries a total share of at minimum 43% of the global export market results (combined values for Germany, Italy, Belgium, France, Great Britain and Netherlands).

The total global trade value was estimated to be some 31 billion euro in 2011.

Figure 42 Main exporting countries (global)

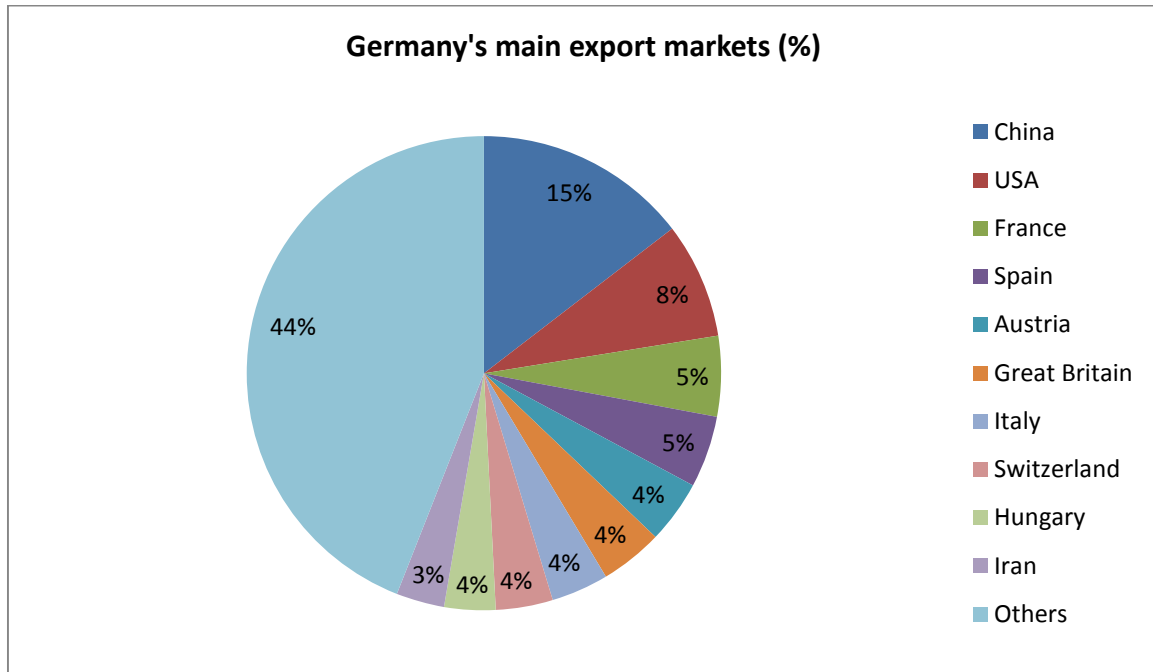


Germany itself is mainly exporting to outside the EU, mainly China and USA. The figure below shows Germany's main export markets.

⁶⁹ Pumps and Compressors for the World market 2013, with compressed Air and vacuum technology, by VDMA, Dipl.-Wirt.-Ing. Christoph Singrun and Dipl.-Volksw. Ulrike Matje. The analysis appears to be based on Eurostat statistical data and is limited to value (euro) only.

The main partner companies for German compressor, compressed air and vacuum technology exporters are still in the EU. However, the share fell from around 46% in 2008 to just 40% in 2009 before increasing again in 2010 to 43% and 42% in 2011. After the EU, East and South East Asia is the second key customer market for German manufacturers.

Figure 43 Germany's main export markets (%)



The German production has a total value of 4.9 billion in 2011, of which some 40% is allocated to turbocompressors, 18% is rotary displacement compressors, 15% are vacuum pumps and 125 are parts for compressors and vacuum pumps.

The German export value is estimated to be close to 4.8 billion in 2011. It can therefore be assumed that a large part of the production is exported (not possible to quantify on the basis of these values is the value of imported goods that are exported again).

Industry stakeholders have been asked to provide inputs or a response to above presented data, but as sales data is treated with extreme confidentiality no correction or supplementary data has been received so far.

3.4 Product life

Earlier estimates

The study by Fraunhofer in 1999 presented an estimate of air compressors sales and stock, being based on the following assumptions regarding product life: compressors below 90 kW have an average product life of 13 years and compressors above 90kW have a product life of around 16 years. Replacement of existing stock is around 6.7% per year⁷⁰.

Pneuop 1st survey estimates

The assessment by Pneuop indicates a product life ranging from approximately 7 years for a standard air compressor, to max. 35 years for a piston process gas compressor.

⁷⁰ Based on average lifetime of 15 year

Figure 44: Product life of compressors in application range (Source: Pneurop)

Application range	Product life
standard air compressor	7 - 14 yrs, see detailed table below
low pressure air compressor	15 yrs
oil free/non-lubricated air compressors	20 yrs
hobby air compressors	5 yrs (est.), motor usually lasts 250 hrs full load
process gases: air/nitrogen/noble	
- process - piston	35 yrs
- process - turbo	30 yrs
- process - screw/rotary lobe	20 yrs
- process - rotary lobe w/o inner compressors	20 yrs

For the standard air application range compressors the product life varies according the size of the equipment, whereby larger equipment has a longer product life.

Table 28 Product life of compressors (source: Task 8)

Volume flow	Product life (yrs)		Volume flow	Product life (yrs)
l/s	fixed speed OIS+OIV	variable speed OIS+OIV	l/s	Pistons
7.5	10	10	3	7
15	11	11	6	10
30	11,5	11,5	12	10
60	12	12	24	10
120	12,5	12,5		
240	13	13		
480	14	14		
960	14,5	14,5		
Average	12	12.5		7

3.5 Stock

Earlier estimates

As a first indication of the stock of compressors, this Fraunhofer study estimated the installed base of air compressors in the industrial and service sector in 1999 at over 321 thousand units. The split up into small and large system is about 70/30 (see Table 3-5: Installed air compressors in industrial and service sectors in 1999).

Table 29: Installed air compressors in industrial and service sectors in 1999⁷¹

Country	Total	10-110 kW	110-300 kW
---------	-------	-----------	------------

⁷¹ Compressed air systems in the European Union

France	43.765	28.885	14.880
Germany	62.000	43.400	18.600
Greece + Spain + Portugal	35.660	25.685	9.976
Italy	43.800	30.660	13.140
United Kingdom	55.000	46.750	8.250
Rest of the EU	81.040	56.015	25.024
Total	321.265	231.395	89.870

The study did not describe the installed base of turbocompressors.

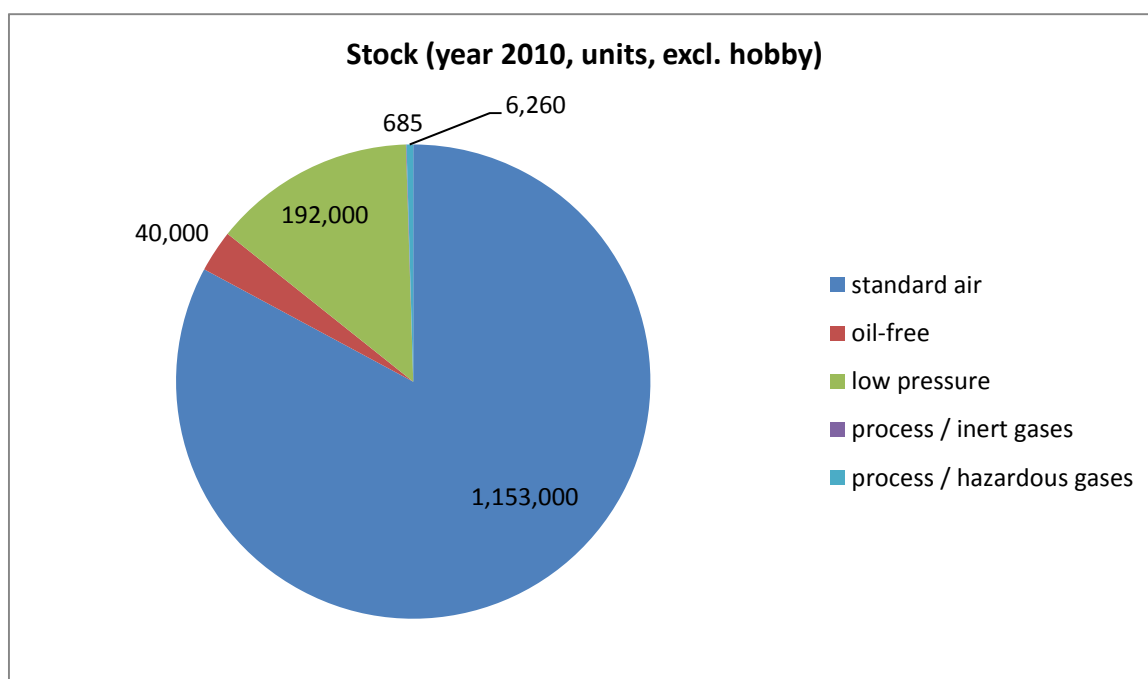
Pneurop 2012 estimates

The 1st assessment by Pneurop indicated an installed base (based on constant sales multiplied by product life presented in the previous section) of some 2 million units in the EU27. This figure excludes hobby compressors which comprise some 2-2,5 million installed products (estimate based on sales of 0,5 million and average 5 year product life).

However, the detailed survey performed for Task 8 shows that the actual sales, combined with a more modest assumption for product life, results in a smaller stock than previously presented under the Final report for Task 2.

The most recent estimates of the stock (installed base) of compressors for the standard air application range is some 1,1 million units in 2010, increasing to 1,2 million units in 2030. The slow down of sales between say 2008 and 2013 has contributed to this. The graph shows that the total numbers of installed compressors has decreased somewhat since 2010, indicating several installations have gone out of business.

Figure 45: Installed base of compressors by application range (Pneurop estimates)



In the table below the stock numbers of the different process gas segments are given. The reference year is 2010, but changes in the installed base are slow.

Table 30: Installed base of compressors in 'process gas' application range

Installed base of process gas compressor, per main type (units)	
Air/nitrogen/noble	
- Turbo	420
- Rotary lobe	265
Other gases	
- Piston	5 250
- Turbo	360
- Screw	380
- Rotary lobe	270

Not shown in the graph above is the installed base of "hobby compressors". Pneurop estimated the sales of hobby compressors with brush motors to be around 500 000 units per year. Assuming a product life of 5 years and constant sales, this results in an installed base of 2 500 000 units.

Although the sales of hobby compressors vastly exceeds that of the other compressors, the Task 3 report shows that hobby compressors remain energetically insignificant, despite their large numbers.

The Pneurop estimate for the installed base of standard air compressors (some 1,1 million units), vastly exceeds the installed base identified by Fraunhofer 1999 for compressed air systems (set at 0,32 million units).

3.6 Sales and stock from 1990 to 2030

There is very little data available in the public domain on the historical development of compressor sales (volume or value) and the forecast for the market.

The sales and stock values for compressors in the standard air application range are based on information retrieved under Task 8 and present the historic and expected future sales for fixed and variable speed screw and vane compressors, and piston compressors.

Sales volume

The data collection exercise (survey) performed between members of the Pneurop Ecodesign JWG for the purpose of Task 6-7-8 allowed an assessment of historical and expected sales for compressors in the standard air application range. For overall consistency the results are repeated here.

Figure 46 Sales of standard air compressors 1990-2030

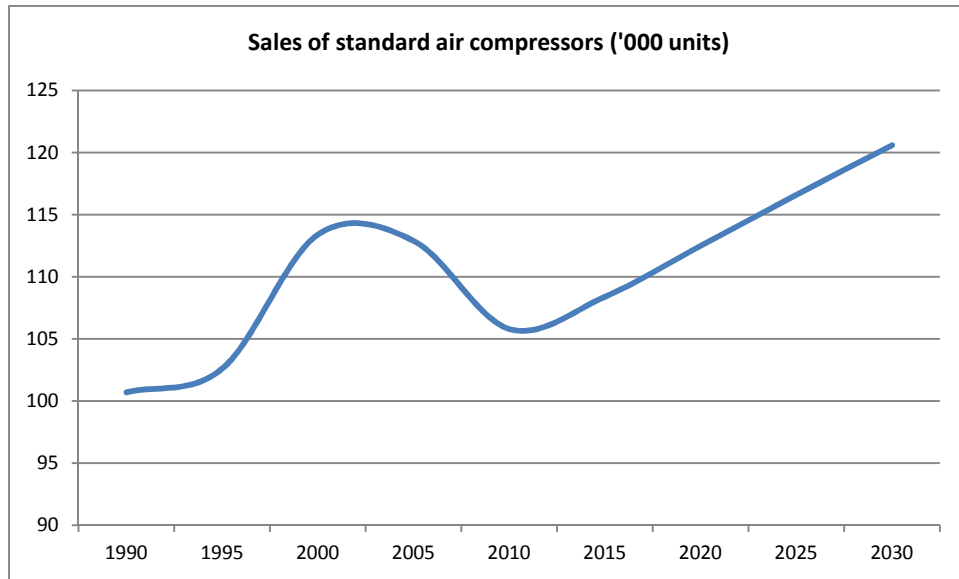


Table 31 Sales of compressors in standard air application range 1990-2030

Sales ('000)									
	1990	1995	2000	2005	2010	2015	2020	2025	2030
fixed speed OIS+OIV	51,2	52,1	56,9	53,9	45,2	42,1	43,1	44,7	46,2
variable speed OIS+OIV	0,0	0,1	0,8	3,5	8,6	13,0	14,1	14,6	15,1
pistons	49,5	50,4	55,7	55,5	52,0	53,3	55,3	57,3	59,3

The current market is still recovering from the effects of the economic crisis started in 2008 and sales are now close to what they were before the economic crisis. The current industry forecasts assume a constant increase in sales volume.

The sales are based upon a combination of economic activity (OECD trends) and expert estimates. The OECD trend is the "industrial production" referred to 2011, averaged on basis of GDP for I/F/D/GB and based on OECD-Data for growth of industrial production in I/F/D/GB

For the other application ranges (oil-free, low pressure and process gas compressors) no such estimates are available. Not in the public domain and not from industry associations. For Low pressure and oil free a similar trend as based on OECD may apply. For process gas compressors the lead times are generally longer and the market less volatile. For these application ranges a constant annual increase of 1 % has been assumed.

The below assessment is therefore a construction of estimated year 2010 sales corrected for OECD activities, with a product life as indicated in the preceding section. Note that the compressors in the standard air application range still represent >85% of sales and stock and are deemed to be reliable.

Table 32 Sales of compressors in other application ranges ('000 units)

Sales ('000 units)	1990	1995	2000	2005	2010	2015	2020	2025	2030	product life (yr)
Low Pressure	9	15	17	15	12	12	13	17	27	15
Oil	1	2	3	2	2	2	2	3	4	20

Free										
Process / inert	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,03	0,03	
type 1	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	30
type 2	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20
process / hazardous	0,16	0,17	0,17	0,18	0,19	0,20	0,20	0,20	0,20	
type 1	0,12	0,13	0,13	0,14	0,15	0,15	0,15	0,15	0,15	35
type 2	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	30
type 3	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20
type 4	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20
type 5	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20

Value

One source did identify a current 2010 market volume of 7,1 billion and predicted growth of 6,4% per year resulting in a market value of 10,2 billion euros in 2015 for "air compressors, reciprocating displacement compressors, refrigeration equipment compressors, rotary displacement compressors, turbo-compressors, other compressors"⁷² but as this value includes compressors for cooling applications (refrigeration and air conditioning, etc.) the actual value for gas (incl. air) compressors is not known.

The above shown sales volume for the standard air application range of almost 106 thousand units represents some 600 million euro (source: Task 8). Assuming a similar cost per kW value as standard air and sales volume and average power as shown in preceding sections, a total market value (including the other compressor application ranges) of close to 1,2 billion can be expected (for which a high error margin applies).

Stock

The stock of the compressors in the standard air application range is calculated on the basis of the sales indicated above (see also Task 8) and the product lives as indicated.

The stock of compressors in the other application ranges are based on the sales identified under the 1st survey (see Task 2) and the assumed product life.

Table 33 Stock of standard air compressors 1990-2030

Stock ('000)									
	1990	1995	2000	2005	2010	2015	2020	2025	2030
fixed speed OIS+OIV	284	532	607	630	615	551	497	495	512
variable speed OIS+OIV	0	0	3	13	46	98	145	168	176
pistons	389	430	460	487	492	478	482	499	517

Table 34 Stock of compressors in other application ranges 1990-2030 ('000 units)

Stock ('000 units)	1990	1995	2000	2005	2010	2015	2020	2025	2030
--------------------	------	------	------	------	------	------	------	------	------

⁷² <http://www.prlog.org/11075455-the-european-demand-for-compressors-is-forecast-to-be-102-bn-euros-in-2015.html>

Low Pressure	48	107	179	221	223	202	188	201	252
Oil Free	8	17	30	40	44	45	41	41	49
Process / inert	0,20	0,52	0,54	0,57	0,60	0,63	0,65	0,67	0,68
type 1	0,00	0,31	0,33	0,34	0,36	0,38	0,39	0,41	0,42
type 2	0,20	0,21	0,22	0,23	0,24	0,25	0,26	0,27	0,27
process / hazardous	0,48	0,77	4,79	5,04	5,30	5,56	5,79	5,97	6,12
type 1	0,00	0,00	3,98	4,19	4,40	4,62	4,81	4,98	5,11
type 2	0,00	0,27	0,28	0,29	0,31	0,32	0,34	0,35	0,36
type 3	0,10	0,10	0,11	0,11	0,12	0,12	0,13	0,13	0,13
type 4	0,18	0,19	0,20	0,21	0,23	0,24	0,24	0,25	0,25
type 5	0,20	0,21	0,22	0,23	0,24	0,26	0,26	0,27	0,27

4 Market trends

This section aims to describe the market structure (actors) and main market trends, on various levels (product technology level, sales/commercial level, corporate level, etc.).

4.1 Market structure

4.1.1 Manufacturers

Leading compressor manufacturers active in the EU are (non-exhaustive overview): Atlas-Copco, Ingersoll Rand, Kaeser, Aerzener, Boge, Siemens, etc.

The following information is compiled using public sources. It may be amended/extended when more information becomes available.

Table 35: general manufacturer information

Name (alphabetically)	Turnover / revenue	Employees	Facilities	Ratio (turnover/employee)	Comments	SME?	HQ
Aerzen	(tbc)	some 1 thousand	(tbc)			No	EU/DE
Atlas Copco	8 400 million	some 33 thousand	Belgium, Germany, USA, China and India	254.545	Founded 1873, Sweden	No	EU/SV
Bauer Kompressoren	140 million	(tbc)	(tbc)	(tbc)		?	EU/DE
Boge	90 million	some 0,5 thousand	Germany (Bielefeld), China (Shanghai)	163.636	Founded 1907, Germany	No	EU/DE
Compair			USA (production in DE, China, USA)				USA
Gardner-Denver	> 650 million (28% of 2.4 billion)	some 7 thousand	global	92.857	Founded 1859 USA, Brand names Gardner-Denver, Champion, Compair	No	USA

Howden	73 million	some 4 thousand globally	39 locations globally		No	USA
Ingersoll Rand	(tbc)	(tbc)	over 100 facilities globally		Founded 1871 USA, 16% of revenue made in EU, 66% in USA	No USA
Kaeser Kompressoren	600 million	some 4 thousand	(tbc)	150.000	Founded 1919, Germany	No EU/DE
Fini NuAirSiemens	73 000 million	(tbc)	(tbc)	(tbc)		No EU/DE

The assessment of a company is an SME or larger company, is based on the following segmentation.

Table 36: Definition of SME according EU Recommendation 2003/361

Company category	Employees	Turnover	Balance sheet total
Medium-sized	< 250	≤ € 50 m	≤ € 43 m
Small	< 50	≤ € 10 m	≤ € 10 m
Micro	< 10	≤ € 2 m	≤ € 2 m

4.1.2 Sales structure

Compressors are placed on the market through a variety of sales channels. These channels can be:

1. Direct sales: This channel covers the direct sales of manufacturer to end-customer. This is a usual form for sales of especially larger equipment (starting from say 150-200 kW input power) up to MW range where guaranteed performance may form part of the sales agreement. Often servicing and maintenance contracts are included in the sales agreement.
2. Independent distributors: These distributors sell multiple brands. They often combine sales with technical and service support.
3. Air centers: These are retail outlets that only sell equipment from a single manufacturer and may be part of the manufacturers sales organisation.
4. Retailers: These channels are managed by manufacturer's representatives, catering to retail chain stores and catalogue houses.

The actual turnover or sales volume per channel is not known (not public information because of confidential nature) but it can be assumed that the largest equipment is usually sold as direct sales, whereas the smallest equipment is more often sold through retailers and dealers. For small equipment it is quite uneconomical to keep a sales force afloat. The type of sales channel is also partly dictated by the compressor technology: For example reciprocating compressors require –in general- more service parts than rotary equipment (reed valves, etc.) and adequate technical and service support is requested.

The buying behaviour can be split up into three main types:

1. Buying large compressors requires presenting detailed specification, high technical expertise, co-ordinated sales effort. The service requirements are more complex and machine failures can be very costly.
2. For medium and small compressors the demand for specifications is less and the behaviour is also less complex. Off-the shelf availability is a priority to meet tight delivery deadlines. Spare parts should preferably be locally available and service for customers is performed without maintenance teams.

3. For small compressors (< 5 hp) the buyer uses the equipment for relatively small jobs. The buyers are mostly reached through retail outlets.

Manufacturers need align the geographic and market segment coverage of various sales channels as they may be active in the same market segment.

4.1.3 Industry organisations / associations

Pneurop is the European committee of manufacturers of compressors, vacuum pumps, pneumatic tools and allied equipment, represented by their national associations. Its members are national associations representing more than 200 manufacturers in 8 EU Member States, in Switzerland and in Turkey.

4.1.3.1 PNEUROP

Pneurop Members are⁷³:

- Association of the Austrian Machinery and Metalware Industries (FMMI)
- Belgium AGORIA
- The Federation of Finnish Technology Industries
- Profluid
- VDMA
- Italy ANIMA
- Sweden TLG
- Switzerland SWISSMEM
- Association of Machine Manufacturers
- UK British Compressed Air Society Limited

These national associations represent more than 200 manufacturers in 8 EU Member States, in Switzerland and Turkey. The European combined market turnover for the businesses represented exceeds 20 billion euro.

The Pneurop association knows several working groups, these being:

- Compressors
- Tools
- Vacuum technology
- Pressure equipment
- Air treatment
- Process compressors

4.1.3.2 ASERCOM

ASERCOM is the Association of European Refrigeration Component manufacturers and its aim is to be the platform in dealing with scientific and technical challenges, promoting standards for performance and safety, focussing on better environment protection, serving the refrigeration and air conditioning industry and its customers. ASERCOM communicates relevant opinions of its members to the industry, the public, governmental bodies and nongovernmental organizations.

ASERCOM⁷⁴ Members are:

⁷³ http://www.pneurop.eu/index.php?pagename=Pneurop_Member_Associations_and_Contacts

⁷⁴ <http://www.asercom.org/asercom-members/>

- Arcelik
- Arctic Circle
- Bitzer
- Danfoss Commercial Compressors
- Danfoss Power Electronics A/S*
- Dorin
- Emerson Climate Technologies
- Emerson Industrial Automation*
- Frascold
- GEA Bock
- GEA Grasso
- Ingersoll Rand
- Johnson Controls International
- KIMO Refrigeration HVAC Ltd*
- Kriwan
- Leroy-Somer*
- Reel*
- Schneider Electric*
- Tecumseh Europe

* Associated member

4.1.3.3 CAGI

CAGI is the USA based Compressed air and gas institute. It's activities are carried out in its separate sections, which are categorized by product scope. Individual member companies may affiliate with one or more of these sections, depending upon their product lines.

Current sections are Air Drying and Filtration, Blower, Centrifugal Compressor, Pneumatic Tool, Rotary Positive Compressor and the Reciprocating Compressor Section.

In addition, (experts from) the Institute also contribute to committees including the Educational and Promotional/Marketing Committee, Standards Committee and Energy Efficiency Committee.

CAGI Members⁷⁵

Air Drying & Filtration Section

- Atlas Copco Compressors LLC
- Beko Technologies Corp.
- Donaldson Co., Inc.
- Ingersoll Rand Industrial Technologies
- Kaeser Compressors, Inc.
- Lectordryer
- Mikropor America, Inc.
- Parker Hannifin Corp.
- Pneumatech LLC
- Pentair Porous Media Corp.
- SMC Corporation of America

⁷⁵ <http://www.cagi.org/membership/>

- SPX Flow Technology
- Walker Filtration, Inc.
- Zeks Compressed Air Solutions

Blowers

- APG-Neuros Inc.
- Atlas Copco Compressors LLC
- Gardner Denver, Inc.
- GE Energy
- Ingersoll Rand Industrial Technologies
- Tuthill Vacuum & Blower Systems

Centrifugal Compressors

- Atlas Copco Compressors LLC
- Cameron
- FS Elliott Co., LLC
- Ingersoll Rand Industrial Technologies

Rotary Positive Compressors

- ALMiG USA Corporation
- Atlas Copco Compressors LLC
- BOGE America
- FS-Curtis
- DV Systems Inc.
- Gardner Denver, Inc.
- Ingersoll Rand Industrial Technologies
- Kaeser Compressors, Inc.
- Mattei Compressors
- Quincy Compressor
- Sullair Corporation
- Sullivan-Palatek, Inc.

Reciprocating Compressor Section

- Atlas Copco Compressors LLC
- FS-Curtis
- DV Systems Inc.
- Gardner Denver, Inc.
- Ingersoll Rand Industrial Technologies
- Quincy Compressor
- Saylor-Beall Manufacturing Co

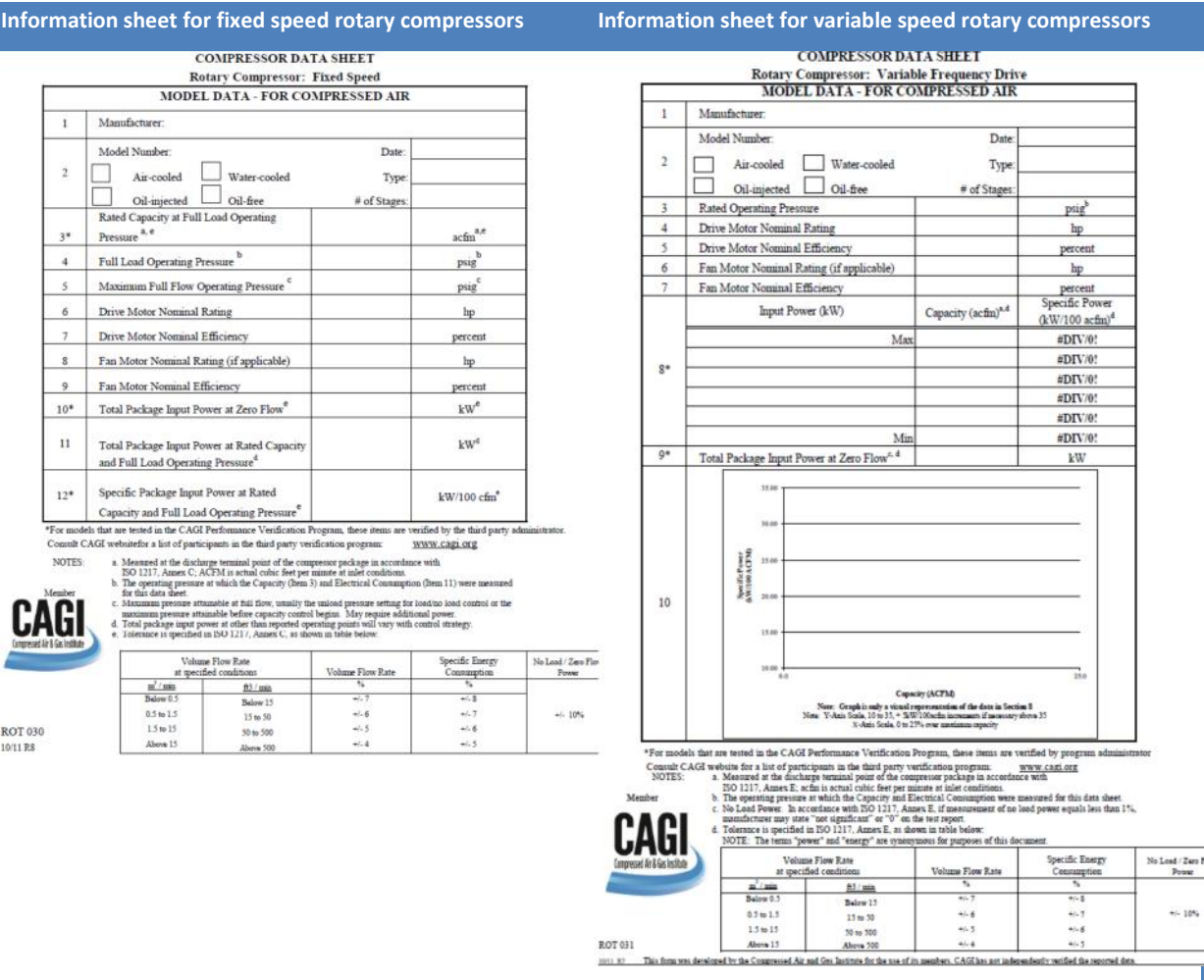
Pneumatic Tools

- Apex Tool Group, LLC
- Chicago Pneumatic Tool Co.
- Florida Pneumatic Manufacturing Corp.
- Ingersoll Rand Industrial Technologies
- Stanley Assembly Technologies
- T.C. Service Co.

CAGI runs its own certification program to which manufacturers can voluntarily sign up to. It involves random checks of equipment.

Manufacturers can show the performance of their products using standardised information sheets.

Figure 47 CAGI data sheets fixed and variable speed rotary



4.1.3.4 Vacuum technology (outside scope)

EVTA - European Vacuum Technology Association (member of ISVT - International Statistic Program on Vacuum Technology). The Pneurop Committee 5 (PN 5) is the responsible committee for the vacuum technology including vacuum pumps.

ISVT is a union of three vacuum industry associations worldwide. ISVT is EVTA (European Vacuum Technology Association), JVIA (Japan Vacuum Industry Association) and AVEM (Association of Vacuum Equipment Manufacturer) in cooperation with SEMI (Semiconductor Equipment Manufacturer International). It is the common goal of the participating vacuum industry associations and their members to gather global statistics on vacuum component sales (by product for each geographic region and market segment) on a regular and frequent basis using a standardized global format.

Worldwide 100 companies join ISVT. They represent 85% of the global sales on vacuum components incl. vacuum pumps.

4.2 Trends in product performance

The following trends in product performance have been identified.

Table 37: Trends in the compressor market

<i>Generic market trends identified</i>	<i>Demand drivers</i>
Energy efficiency and energy recovery – focus on the life-cycle cost of compressed air equipment	Investments in machinery
Increased environmental awareness – energy savings and reduction of CO ₂ emissions	Industrial production
Workplace compressors with low noise levels	Energy costs
Quality Air – air treatment equipment	
Outsourcing of maintenance and monitoring of compressed air installations	
Energy auditing of installations	
New applications for compressed air	
Specialty rental	

Of this, the trend to lower energy costs / increase overall energy efficiency is illustrated by the attention given to part load challenges

In application ranges where the demand for compressed gas fluctuates significantly over a given period (this is generally more often the case for compressed air, then for process gas compressors) efficient part load operation is an important element in the total cost of ownership.

A distinction in addressing part load challenges should be made between:

- 1) Volumetric compressors: Relevant part load challenges relate to use of variable speed drives and system control, and variable displacement (e.g. switching of cylinders, slide valves)
- 2) Dynamic compressors: Relevant part load challenges relate to blow-off, variable in- and outlet guide vanes and other techniques.

The following examples illustrate some of the issues related to part load operation and solutions offered by the market. Note that Task 3 of this study will address part load challenges as well, in the context of real life efficiency or energy consumption and may offer more detail in options available.

Example 1: Use of variable speed drives versus standard driven compressors

Figure 48: Air demand / energy costs over time for standard and VSD option⁷⁶

⁷⁶ Source: Pneurop / Atlas Copco, Oil-injected Rotary Screw Compressors



Over 80% of compressed air systems experience from 40 to 80% fluctuations in air demand.

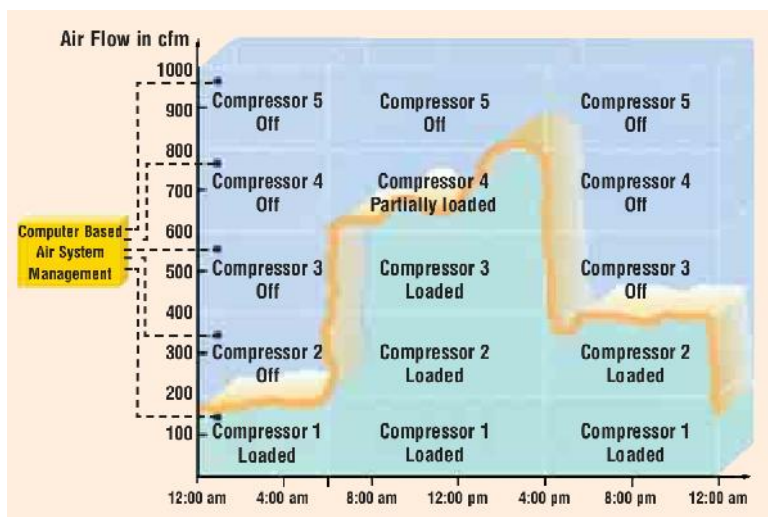
Depending on the actual conditions of use (load distribution and/or profile) using a VSD can reduce energy costs by 35%⁷⁷ or more. For overall life cycle costs (LCC) this means a saving of around 22%.

Example 2: Use of multiple compressors / system control

In case the compressed air demand fluctuates over a wide performance range it is more often an array of multiple compressors that satisfies the demand. These may be combined in a single package, but may also comprise separate compressor units, controlled by a single control unit.

Such packages can combine both single- and variable speed driven compressors in order to achieve the best combination of performance and costs. This provides the most efficient operation over a very wide performance range. An example of such a configuration is provided below.

Figure 49: Optimized Response to Fluctuating Demand⁷⁸



⁷⁷ http://www.atlascopco.com/drivenbyefficiencyus/products/Product_ga/product_ga_history/

⁷⁸ http://us.kaeser.com/Images/USGUIDE3_DesigningYourCompAirSys-tcm9-12601.pdf

5 Consumer expenditure base data

This section aims to describe the total costs of ownership for the compressors within scope.

This comprises information on:

- utility rates (electricity only)
- purchase prices (consumer prices, but if possible also manufacturer selling prices, wholesale margins and retail margins)
- installation costs
- consumables (lubricants, oils, etc.)
- repair and maintenance
- disposal tariffs
- interest and inflation rates

5.1 Utility rates

The energy rates given here are from the MEErP study and are valid for January 2012. For future prices an overall escalation rate of 4% per year will be used (energy price growth rate corrected for inflation).

The analysis in Task 7 shows that the smallest compressor in the standard air application range consumes some 670 kWh (d=20 for smallest piston compressor) to 1.369.815 kWh (for largest variable speed OIS/OIV with d=-5). This is a ratio of around 1:2000, which is very much larger than the average product assessed using the MEErP.

Therefore the assessment in Task 7 shall be based on average EU electricity prices for industrial users. The default MEErP prices will not be used but are shown in this section for comparative purposes.

Table 38 Electricity prices for industrial consumers (Source: Eurostat 2014)

Electricity prices for industrial consumers, from 2007 onwards - bi-annual data [nrg_pc_205]										
Last update	20.12.13									
Extracted on	09.01.14									
Source of data	Eurostat									
CONSOM	2008S2	2009S1	2009S2	2010S1	2010S2	2011S1	2011S2	2012S1	2012S2	2013S1
Band IA : Consumption < 20 MWh	0,1566	0,1588	0,1620	0,1635	0,1723	0,1692	0,1766	0,1747	0,1849	0,1871
Band IB : 20 MWh < Consumption < 500 MWh	0,1194	0,1225	0,1199	0,1221	0,1231	0,1298	0,1316	0,1346	0,1380	0,1416
Band IC : 500 MWh < Consumption < 2 000 MWh	0,1027	0,1067	0,1025	0,1039	0,1052	0,1102	0,1116	0,1153	0,1187	0,1200
GEO	European Union (28 countries)									
PRODUCT	Electrical energy									
UNIT	Kilowatt/hour									
TAX	Excluding VAT and other recoverable taxes and levies									
CURRENCY	Euro (from 1.1.1999)/ECU (up to 31.12.1998)									

Source: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en --> further aggregation by Eurostat/VHK

For completeness of the Task the MEErP values are indicated below.

The MEERp rates for electricity are split up in industry prices and domestic prices.

Energy rates for commercial/industrial users

Table 39: Electricity prices for industry

Electricity prices (kWh)			
	Industry (1)		
	2008	2009	2010
	s1	s1	s1
EU-27	0,10	0,11	0,10
Belgium	0,11	0,11	0,11
Bulgaria	0,06	0,06	0,06
Czech Republic	0,11	0,11	0,10
Denmark	0,09	0,09	0,09
Germany	0,11	0,11	0,11
Estonia	0,06	0,06	0,07
Ireland	0,13	0,12	0,11
Greece	0,09	0,09	0,09
Spain	0,10	0,12	0,12
France	0,07	0,07	0,07
Italy	0,14	0,15	0,14
Cyprus	0,14	0,12	0,15
Latvia	0,07	0,09	0,09
Lithuania	0,08	0,09	0,10
Luxembourg	0,10	0,12	0,10
Hungary	0,11	0,12	:
Malta	0,12	0,15	:
Netherlands	0,10	0,11	0,10
Austria	0,11	:	:
Poland	0,09	0,09	0,10
Portugal	0,09	0,09	0,09
Romania	0,09	0,08	0,09
Slovenia	0,09	0,10	0,10
Slovakia	0,12	0,14	0,12
Finland	0,06	0,07	0,07
Sweden	0,07	0,07	0,08
United Kingdom	0,10	0,11	0,10

(1) Annual consumption: 500 MWh < Consumption < 2 000 MWh

(2) Annual consumption: 10 000 GJ < Consumption < 100 000 GJ

(3) EA11-2000, EA12-2006, EA13-2007, EA15-2008, EA16-2010, EA17

: = not available

Source Eurostat (nrg_pc_205, nrg_pc_203) (MEERp report part 1 page 46)

Table 40: Electricity prices for private households

(for comparison)

Electricity prices (kWh)					
	Domestic (1)				
GEO/TIME	2008	2009	2010	2011	2012
	S1	S1	S1	S1	S1
European Union (27 countries)	0,1177	0,1224	0,1221	0,1281	:
Euro area (2)	0,1169	0,1243	0,1234	0,1286	:
Belgium	0,1500	0,1431	0,1449	0,1572	0,1590
Bulgaria	0,0593	0,0685	0,0675	0,0688	0,0706
Czech Republic	0,1060	0,1102	0,1108	0,1232	0,1235
Denmark	0,1203	0,1239	0,1168	0,1263	0,1314

Germany	0,1299	0,1401	0,1381	0,1406	0,1441
Estonia	0,0639	0,0712	0,0695	0,0704	0,0771
Ireland	0,1559	0,1789	0,1589	0,1584	0,1845
Greece	0,0957	0,1055	0,0975	0,1025	0,1065
Spain	0,1124	0,1294	0,1417	0,1597	:
France	0,0914	0,0908	0,0940	0,0994	0,0986
Italy	:	:	:	0,1397	:
Cyprus	0,1528	0,1336	0,1597	0,1731	:
Latvia	0,0802	0,0957	0,0954	0,0957	0,1138
Lithuania	0,0729	0,0799	0,0955	0,1004	0,1042
Luxembourg	0,1442	0,1619	0,1433	0,1451	0,1468
Hungary	0,1277	0,1227	0,1349	0,1336	:
Malta	0,0945	0,1627	0,1615	0,1615	0,1615
Netherlands	0,1270	0,1440	0,1266	0,1300	:
Austria	0,1271	0,1380	0,1427	0,1442	:
Poland	0,0965	0,0883	0,1049	0,1145	0,1106
Portugal	0,1074	0,1264	0,1093	0,1015	0,1105
Romania	0,0885	0,0814	0,0856	0,0848	0,0795
Slovenia	0,0911	0,1056	0,1057	0,1079	0,1193
Slovakia	0,1194	0,1294	0,1277	0,1372	0,1400
Finland	0,0915	0,0974	0,0998	0,1081	0,1089
Sweden	0,1085	0,1040	0,1195	0,1376	0,1312
United Kingdom	0,1394	0,1399	0,1321	0,1365	0,1603
(1) Annual consumption: 2 500 kWh < Consumption < 5 000 kWh					
(2) EA11-2000, EA12-2006, EA13-2007, EA15-2008, EA16-2010, EA17					
: = not available					
Source Eurostat (nrg_pc_204) extracted 19-10-2012					

Rates for water and fossil fuels are not considered to be relevant.

An escalation rate of 4% will be incorporated for the following years. Note that since the discount factor is also 4% the LCC and payback calculated can be simplified (see Task 7, section 2.3.1).

5.2 Consumer prices

The purchase costs of compressors in the standard air application range have been identified in Task 7. Costs for compressors in other application ranges could not be collected as no information regarding these costs was made available to the study authors.

In order to provide some indicative figures a very simplified approach, based on a generic price per kW is applied. The analysis of Task 7 and some anecdotal data, showed that compressor purchase prices centre around **200 to 400 euro/kW** electric motor power.

Applying the average motor rating of the other application ranges, the purchase cost can be calculated as follows.

Table 41 Indicative prices of compressors in other application ranges than standard air

Application range	Type	Nominal kW	Purchase costs, if ...	
			200 euro/kW	400 euro/kW
Oil free/ non-lubricated air compressor		46	9.200 €	18.400 €
Low pressure compressor		189	37.800 €	75.600 €
Process gas / inert	Turbo	8.039	1.607.800 €	3.215.600 €

	Rotary lobe/air	203	40.600 €	81.200 €
Process gases / hazardous	Piston	314	62.800 €	125.600 €
	Turbo	10.582	2.116.400 €	4.232.800 €
	Screw/ oil free	1.033	206.600 €	413.200 €
	Screw/ oil injected	893	178.600 €	357.200 €
	Rotary lobe	112	22.400 €	44.800 €

The analysis of Task 7 on compressors in the standard air application range show that costs for installation, maintenance and operation can be quite different, even within a rather well defined application area.

That analysis shows that purchase costs maybe be only 6-8% of the overall life cycle costs, installation and maintenance only 10-15% of overall life cycle costs, which leaves some 75-80% share for energy costs.

Downtime

Reliability and availability are important not only for costs but also the safety of the overall process. Downtimes (non-running equipment, due to service, maintenance or other reasons) can also generate secondary energy losses as the start-up of e.g. an ethylene plant takes several days in which production output is zero but its energy consumption is significant.

Downtime costs differ depending on the process and may range e.g. between 30 000 and 500 000 € per day, often forming a significant share of investment costs .

5.3 Interest and inflation rates

Several Ecodesign preparatory studies mention the European Central Bank interest rates. This can be a valuable trend indicator, but for LCC, scenario and sensitivity analysis it is not suitable and the Impact Assessment guidelines of the Commission⁷⁹ require that in economic analyses a discount rate of 4% should be used.

The table below gives an overview of the utility and financial rates based on MEErP 2010.

Table 42: electricity and financial rates EU-27 (1-1-2011) Source: MEErP

	Unit	Domestic incl. VAT	Long term growth per year	Non - domestic excl. VAT
Electricity	€ / kWh	0.18	5%	0.11
Interest		7, 7%		6, 5%
Inflation rate			2,1%	
Discount rate (EU default)			4%	
Energy escalation rate*			4%	
VAT			20%	
*Real inflation corrected				

⁷⁹ European Commission, IMPACT ASSESSMENT GUIDELINES, 15 January 2009, SEC(2009) 92.

Ecodesign Preparatory Study on

Electric motor systems / Compressors

ENER Lot 31

FINAL Report Task 3

Consumer/ User behaviour and local infrastructure



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1 Introduction to Task 3

1.1 Scope

This is the final Task 3 report of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **‘ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives’**.

The aim of this Task 3, in accordance with the tender specifications⁸⁰, is to describe aspects that influence the real life (environmental) performance of products: *"Consumer/user behaviour can - in part- be influenced by product design, but overall it is a very relevant input for the assessment of the environmental impact and the Life Cycle Costs of a product. One aim is to identify barriers and restrictions to possible ecodesign measures, due to social, cultural or infra-structural factors. A second aim is to quantify relevant user-parameters that influence the environmental impact during product life and that are different from the standard test conditions as described in subtask 1.2."*

1.2 Subtasks

The technical tender specifications for the Task 3 subtasks are:

Subtask 3.1 - Real life efficiency

This includes, where relevant:

- Load efficiency (real load vs. nominal capacity);
- Temperature- and/or timer settings;
- Frequency and characteristics of use;
- Identification of use of second hand auxiliary inputs during product life;
- Power management enabling-rate and other use settings;
- Best practise in sustainable product use, amongst others regarding the items above.

Subtask 3.2 – End-of-life behaviour

This task covers identification of actual consumer behaviour (avg. EU) regarding end-of-life aspects. This includes, where relevant:

- Economical product life (=actual time to disposal);
- Repair- and maintenance practise (frequency, spare parts etc.);
- Best practise in facilitating dismantling;
- Present fractions to recycling, re-use and disposal;
- Estimated second hand use, fraction of total and estimated second product life (in practise);
- Best practise in sustainable product use, amongst others regarding the items above.

Subtask 3.3 –Local infrastructure

Description, identification of barriers and opportunities relating to the local infra-structure regarding (where relevant):

- Energy: reliability, availability and nature;
- Telecom (e.g. hot spots, WLAN, etc.);
- Installation, e.g. availability and level of know-how/training of installers;
- Physical environment.

⁸⁰ European Commission, Tender specifications ENER/C3/410-2010, which are the basis for the study.

Not all of these points are fully applicable to the specific product groups of compressors as the above points are based on the general ecodesign study methodology MEEuP, especially where this concerns the real life efficiency.

Therefore the following table indicates which points mentioned under subtask real life efficiency will be further assessed in this task report.

Table 43 Points relevant for real life efficiency

Items according tender specifications	How they are dealt with by this section:
Load efficiency (real load vs. nominal capacity);	<p>Dealt with in Purchase and operation</p> <p>This section will describe the difference between the nominal or rated power of the electric motor, the load factor and aspects of part load operation.</p> <p>Efficiency will also be described but not (yet) linked to compressor energy use (this will be part of coming task 6 and 7)</p>
Temperature- and/or timer settings;	<p>Dealt with in Purchase and operation</p> <p>This section will address the influence of the gas type and quality on overall energy consumption</p>
Frequency and characteristics of use;	<p>Dealt with in Energy use</p> <p>This section will describe the average number operating hours depending on the application range and will describe the 'load factor' applied</p>
Identification of use of second hand auxiliary inputs during product life;	<p>This section will not address this aspect, as is it considered of no significance</p>
Power management enabling-rate and other use settings;	<p>Dealt with in Energy use</p> <p>This section will address part load operation (compressor control options can be considered a form of power management)</p>
Best practise in sustainable product use, amongst others regarding the items above.	<p>Dealt with in Energy use</p> <p>This section will address other relevant aspects in product use.</p> <p>it will also address issues related to purchase as these influence all aspects above.</p>

Other aspects relevant for real life efficiency will be dealt with on a case-by-case basis.

2 Purchase and operation of compressors

Assuming that a decision for the use of electric driven compressors has been made, the client is confronted with a vast array of purchasing options and decisions.

Without trying to be complete, the following aspects are paramount in compressor selection:

- type of gas and quality required;
- quantity or pressures required;
- load profile (variability in flow or pressures required);
- other selection parameters, such as suitability for integration into compressed air systems (CAS);
- etc.

Manufacturers will assist their clients in selecting the best possible configuration or compressor set-up.

2.1 Compressed air needs

Compressed air needs are defined by the air quality, quantity, and level of pressure required by the end uses for industrial plant air. Assessing needs carefully will ensure that a compressed air system is configured properly.

A predominant use of compressed air is as “process enabler” or as “part of the process”, which has little to do with a certain (single) gas quality requirements. To avoid confusion the study writer proposes to identify compressed air as process enabler as process enabler air. The term "process air" is then reserved for applications where air is a core constituent of the process itself.

2.1.1 Air quality

As illustrated in the following table, compressed air quality ranges from plant air to breathing air.

Table 44 Compressed air quality classification

Quality	Applications
Plant air	air tools, general plant air
Instrument air	laboratories, paint spraying, powder coating, climate control
Process enabler air	food and pharmaceutical process air, electronics
Breathing air	hospital air systems, diving tank refill stations, respirators for cleaning and/or grit blasting

Power air

- Power air quality is used for pneumatic tools in plant and workshops
- Filtered separator is normally required
- Refrigerated compressed air dryer and particulate filter may be required where air tools, sand blasting and pneumatic control components are used.

Instrument air

- Instrument air quality is used in pneumatic process control systems, laboratories, powder coating, paint spraying, climate control systems, packing machines etc .
- Refrigerated compressed air dryer and oil removal filter required

Process enabler air

- Process enabler air quality is used in production processes, chemical, pharmaceutical and food processes and laboratories.
- Refrigerated compressed air dryer, oil removal filter and oil vapour absorber may be required
- For outdoor lines in cold climate low dew point desiccant dryer and particulate filter may be required

Breathing air

- Breath air quality is used in hospital air systems, diving, cleaning of breathing equipment
- Often required are an after cooler, coarse pre-filter, and auto draining water trap
- suitable in-line sorbent beds and filters required

Industrial applications typically use one of the first three air quality levels. Quality is determined by the dryness and contaminant level required by the end-uses, and is accomplished with filtering and drying equipment. The higher the quality, the more the air costs to produce. Higher quality air usually requires additional equipment, which not only increases initial capital investment, but also makes the overall system more expensive to operate in terms of energy consumption and maintenance costs.

One of the main factors in determining air quality is whether or not lubricant-free air is required. Lubricant-free air can be produced with either lubricant-free compressors, or with lubricant injected compressors that have additional separation and filtration equipment. Lubricant free rotary screw and reciprocating compressors usually have higher first costs, lower efficiency, and higher maintenance costs than lubricant injected compressors. However, the additional separation and filtration equipment required by lubricant-injected compressors will cause some reduction in efficiency, especially if systems are not properly maintained. Careful consideration should be given to the specific end-use for the lubricant-free air, including the risk and cost associated with product contamination, before selecting a lubricant-free or lubricant-injected compressor.

The three major contaminations in compressed air are solid particles, water and oil. The contamination of compressed air can be categorized by compressed air purity classes. These classes are covered within ISO 8573-1 2010 and shown below.

Particle classes

The particle classes are measured in accordance with ISO 8573-4 and, when required with ISO 8573-8. The defined classes can be seen in the table below, when particle sizes are greater than 5 µm than the classification 1-5 cannot be applied.

Figure 50 Compressed air purity classes for particles Source: ISO 8573-1

Class ^a	Maximum number of particles per cubic metre as a function of particle size, d ^b		
	0.1 < d ≤ 0.5 µm	0.1 < d ≤ 0.5 µm	0.1 < d ≤ 0.5 µm
0	As specified by the equipment user or supplier and more stringent than class 1		
1	≤ 20 000	≤ 400	≤ 10
2	≤ 400 000	≤ 6 000	≤ 100
3	Not specified	≤ 90 000	≤ 1000
4	Not specified	Not specified	≤ 10000
5	Not specified	Not specified	≤ 100000
Class	Mass concentration ^b		
	C _p mg/m ³		
6 ^c	0 < C _p ≤ 5		
7 ^c	5 < C _p ≤ 10		
X	C _p > 10		

- | |
|---|
| a To qualify for a class designation, each size range and particle number within a class shall be met |
| b At reference conditions; see Clause 4. |
| c See A.3.2.2. |

Humidity and liquid water classes

The humidity and liquid water purity classes are measured in accordance with ISO 8573-3 and, when required with ISO 8573-9. The defined classes can be seen in the table below.

Figure 51 Compressor purity classes for humidity and liquid water

Class	Pressure dewpoint °C
0	As specified by the equipment user or supplier and more stringent than class 1
1	≤ -70
2	≤ -40
3	≤ -20
4	≤ 3
5	≤ 7
6	≤ 10
Class	Concentration of liquid water ^a C_w g/m ³
7	$C_w \leq 0.5$
8	$0.5 < C_w \leq 5$
9	$5 < C_w \leq 10$
X	$C_w > 10$
^a At reference conditions; see Clause 4.	

Oil classes

The oil purity classes dealing with liquid oil and aerosols of oil are measured in accordance with ISO 8573-2 and, when required the oil vapour content ISO 8573-5 shall be used. The defined classes can be seen in the table below.

Figure 52 Compressor purity classes for total oil

Class	Concentration of total oil ^a (liquid, aerosol and vapour) mg/m ³
0	As specified by the equipment user or supplier and more stringent than class 1
1	≤ 0.01
2	≤ 0.1
3	≤ 1
4	≤ 5
X	> 5
^a At reference conditions; see Clause 4.	

The air quality required determines to a large degree which compressor types (most obviously: oil-free or lubricated) and ancillary equipment (oil separators, filters, condensers) are needed. This in turn influences overall energy consumption and efficiency.

2.1.2 Packaging materials

2.1.2.1 Quantity, capacity

Required compressed air system capacity is calculated by summing the requirements of the tools and process operations (taking into account load factors) at the site. The total air requirement is not the sum of the maximum requirements for each tool and process, but the sum of the average air consumption of each. High short-term demands should be met by air stored in an air receiver. Systems may have more than one air receiver. Strategically locating air receivers near sources of high demand can also be effective. In most cases, a thorough evaluation of system most cases, demand may result in a control strategy that will meet system demand with reduced overall compressor capacity.

Oversized air compressors are extremely inefficient because most systems use more energy per unit volume of air produced when operating at part-load. In many cases it makes sense to use multiple, smaller compressors with sequencing controls to allow for efficient operation at times when demand is less than peak.

2.1.2.2 Pressure

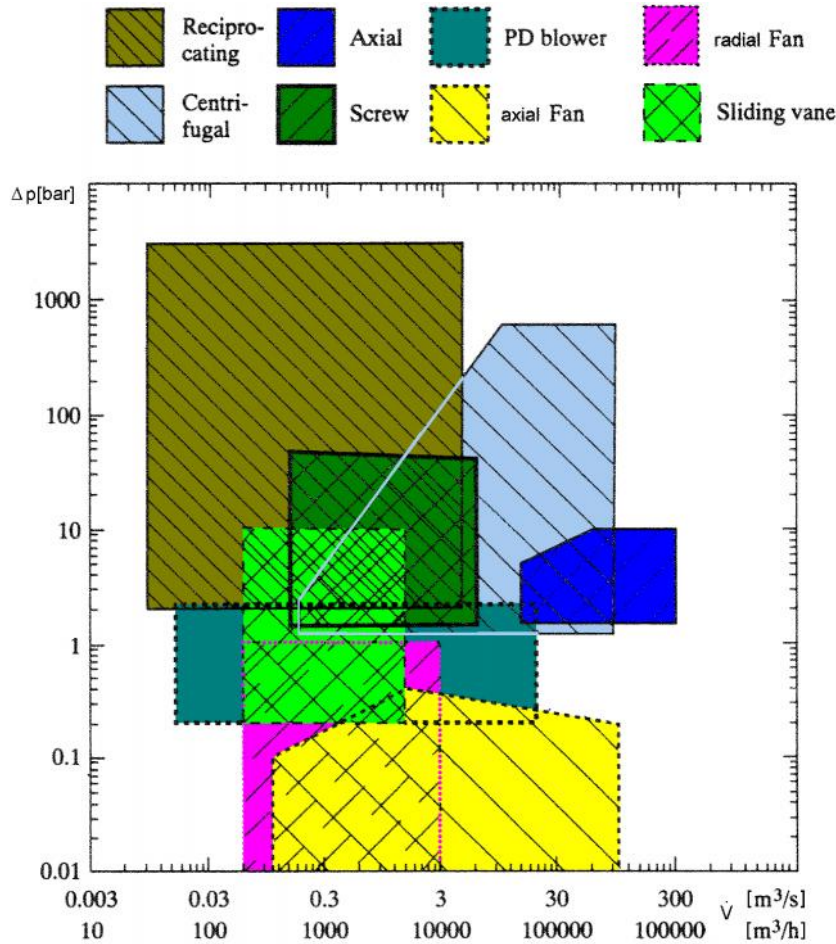
Different tools and process operations require different pressures. Pneumatic tool manufacturer's rate tools for specific pressures and process operation pressure requirements should be specified by the process engineers.

Required pressure levels must take into account system losses from dryers, separators, filters, and piping. A rule of thumb is that every 2 psi (approximately 0.14 bar) increase in operating pressure requires an additional 1% in operating energy costs (1 bar thus results in 7% increase of energy costs, assuming a linear relation).

2.1.2.3 Operating ranges

The range in use of compressors (in terms of pressure and volume flow rate) are so manifold and the subsequent requirements for the compressors are so different that an large variety of compressor types evolved. Figure 2-4 gives an overview over the typical ranges of some generic compressor types. It shows the range in differential pressure between approx. 0.01 bar and 1 000 bar and volume flow rates ranging from approx. 50 m³/h up to 100.000 m³/h (the figure also shows the operating range of an axial and radial fan, which are not compressors).

Figure 53: Ranges of use for different compressor types



Source: Davidson, J.; Bertele, O.v.: Process Fan and Compressor Selection. MechE Guides 1995

Each type of compressor has - in general, exemptions apply- a range within optimal performance is possible. The table below is again a very generic overview of typical operating ranges of various compressor types.

Table 45: General selection criteria for compressors⁸¹

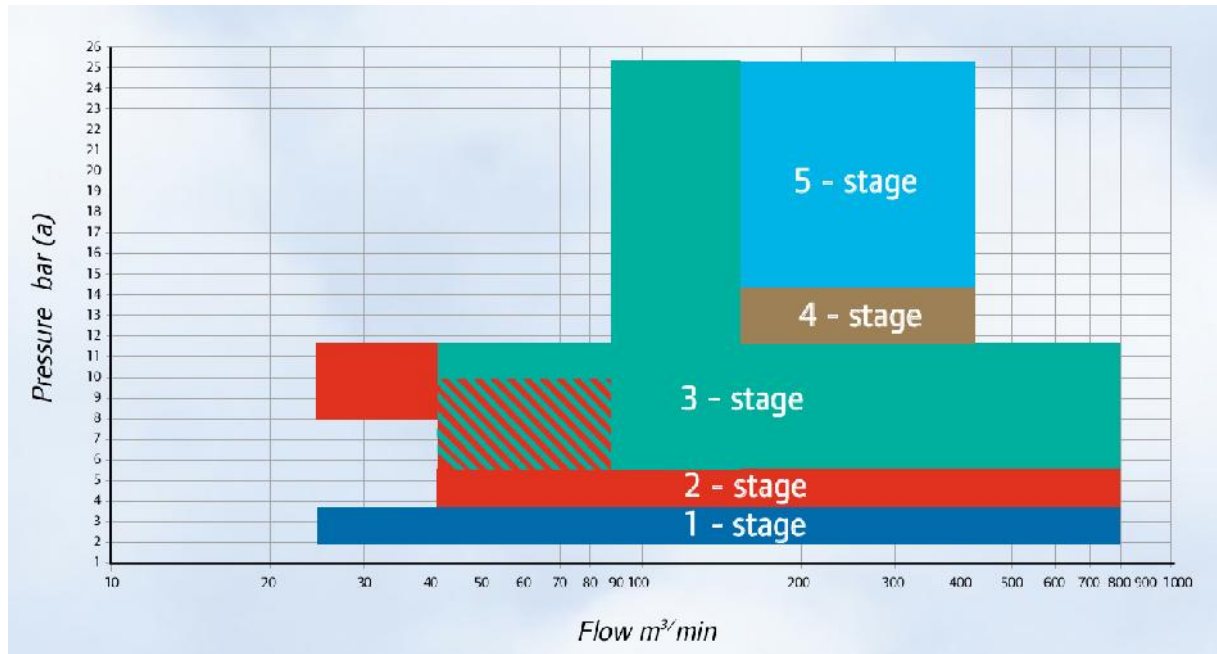
Type of compressor	Capacity (m ³ /h)		Pressure difference (bar)	
	From	To	From	To
Roots blower compressor single stage	100	60 000	0.1	1
Reciprocating				
- Single/two stage	10	12 000	0.8	12
- Multi stage	100	12 000	12	700
Screw				
- Single stage	100	2 400	0.8	13
- Two stage	100	2 200	0.8	24
Centrifugal	600	300 000	0.1	450

⁸¹ <http://www.em-ea.org/Guide%20Books/book-3/Chapter%203.3%20Compressed%20Air%20System.pdf>

The capacities or pressures required not only determine the type of compressor but also its configuration. For certain applications a single large compressors would be a good choice, whereas for other application a multiple compressor set-up would be the best solution.

The selection is made more complicated as compressors are available with single or multifold stages (compression stages), which means the same prime move powers more than one moving member.

Figure 54: Effect of stages on operational range (centrifugal compressor)



Source: Ingersoll-Rand (Centac oil-free)

2.1.3 Demand for compressed air

*[Note: This explanation applies to compressed air **system**. The study however will ultimately focus on options that improve the compressor product as placed on the market]*

Another key to properly designing and operating a compressed air system is assessing a plant's compressed air requirements over time, or load profile. The variation of demand for air over time is a major consideration in system design. Plants with wide variations in air demand need a system that operates efficiently under part-load. Multiple compressors with sequencing controls may provide more economical operation in such case. Plants with a flatter load profile can use simpler control strategies.

Influencing compressed air demand of a site is evidently outside the scope of this study. Still it is worthwhile to give a few examples of how compressed air demand can be influenced and possibly reduced.

Example 1 - Inappropriate uses

Compressed air as a form of energy, may be chosen for applications in which other energy sources are more economical. Inappropriate uses of compressed air include any application that can be done more effectively or more efficiently by a method other than compressed air.

Examples of potentially inappropriate uses of compressed air include:

- Open blowing;
- Sparging;
- Aspirating;

- Atomizing;
- Padding;
- Dilute-phase transport;
- Dense-phase transport;
- Vacuum generation;
- Personnel cooling;
- Open hand-held blowguns or lances;
- Diaphragm pumps;
- Cabinet cooling;
- Vacuum venturis.

Note that the above list is very generic and suitability of compressed air as form of energy requires a case-by-case consideration of alternatives.

Example 2 - Artificial Demand

Artificial demand is defined as the excess volume of air that is required by unregulated end uses as necessary for applications. Flow controllers can help to minimize artificial demand.

2.2 Process gas needs

Ideally a similar approach as described above for compressed air needs could be described for process gases needs. However, as shown in Task 1 section 2.4 on categorisation by application, the needs for process gases are as manifold as its applications and no simple description would do justice to the many different applications realised.

Priorities for process gas needs typically are:

- safety, availability, energy efficiency.

For the moment process gases needs will be treated on a ad-hoc basis, to be amended / supplemented when information becomes available.

Table 46: Process gas compressors – gases (examples)⁸²

Compressed gases	Reciprocating compressors	Centrifugal compressors
Ammonia		x
Argon	x	x
Aliphatic hydrocarbons	x	x
Methane	x	x
Ethane/ Ethylene	x	x
Propane/ Propylene	x	x
Butane	x	x
Pentane	x	x
Hexane	x	x
Acetylene	x	
Biogas	x	x
Water vapour		x
BTX aromatics	x	x

⁸² <http://zm.borsig.de/en/fields-of-application/compressed-gases.html>

Benzene/ Benzol	x	x
Toluene/ Toluol	x	x
Xylene/ Xylol	x	x
Natural gas	x	x
Helium	x	
Hydrogen	x	
Refrigerants	x	x
Carbon dioxide	x	x
Carbon monoxide	x	x
LNG	x	x
LPG	x	x
Process air	x	x
Sulphur dioxide	x	x
Hydrogen sulphide	x	x
Nitrogen, also bone-dry	x	x

Table 47: Process gas compressor applications (examples) ⁸³

Applications	Reciprocating compressors	Centrifugal compressors
Boil off gas technology	x	x
Gas liquefaction, LNG, LPG	x	x
Gas gathering and gas (re)injection	x	
Gas hydrotreatment (HDT)	x	x
Gas hydrodesulphurization (HDS)	x	x
Gas transport	x	x
Hydrogen production units	x	x
Isomerization units	x	
Fertilizer production	x	x
Natural gas lifting and transport	x	x
Natural gas storage	x	x
Gas cylinder filling	x	
Chemical and petrochemical industries	x	x
Refineries	x	x
Oil and gas industries	x	x
Iron and steel industries	x	x
Pharmaceutical industry	x	x
Plastics industry	x	x
Lube oil plants	x	x
Methanol plants	x	x
NH3 synthesis	x	x
GT power plants	x	x
Urea plants	x	x
Flare gas units	x	
Polysilicon production	x	
Cryogenic plants	x	

⁸³ <http://zm.borsig.de/en/field-of-application/applications.html>

In EN 1012-3 is stated that gas compressors (which includes processing of hazardous gases) must avoid hazards caused by reactions of the gas inside the compressor shall be avoided and by minimising the gas dispersal into the environment. The latter shall be achieved by the following measures:

- preventing leakage of harmful or flammable gases;
- providing double sealing with intermediate venting or with a sealing medium;
- using gaskets suitable for the gases processed at prevailing pressures and temperatures;
- neutralizing, diluting to a safe level or venting into a safe area;
- taking precautions for handling polluted lubricants, drainages and deposits.

Therefore, one way to discern process gas compressors from compressors handling only inert gases is that process gas compressors must provide in double sealing with intermediate venting or with a sealing medium.

2.3 Compressor systems

In this study three compressor "product levels" are recognised:

1. the 'bare' compressor;
2. the compressor package (extended product) (also known as **compressor unit**);
3. the compressor system.

Bare compressor

EN 1012⁸⁴ defines a bare compressor as a compressor unit consisting of:

- The compressor;
- A drive system;
- Any component or device which is necessary for operation.

Packaged compressor

Depending on (a.o.) the application and performance required, the compressor purchase may comprise a packaged compressor which may contain the following major components besides the compressor itself:

- Intake Air Filters to prevent dust from entering a compressor.
- Inter-stage Coolers that reduce the temperature of the air before it enters the next stage to reduce the work of compression and increase efficiency.
- After-Coolers with the objective to remove the moisture in the air by reducing the temperature in a water-cooled heat exchanger.
- Air-dryers that remove the remaining traces of moisture after after-cooler as equipment has to be relatively free of any moisture.
- Moisture drain traps that are used for removal of moisture in the compressed air. These traps resemble steam traps.
- Receivers that are provided as storage and smoothening pulsating air output - reducing pressure variations from the compressor.

The package does introduce (unavoidable) energy losses as any type of obstruction, restriction or roughness in the system will cause resistance to air flow and cause pressure drop.

⁸⁴ EN 1012-1:2010 Compressor and vacuum pumps – safety requirements part 1: Air compressors

Outside the scope of this study but nonetheless relevant in saving energy in compressed air systems is the distribution system, where the highest pressure drops usually are found at the points of use, including in undersized or leaking hoses, tubes, disconnects, filters, regulators and lubricators (FRLs). On the supply side of the system, air/lubricant separators, after coolers, moisture separators, dryers and filters are the main items causing significant pressure drops.

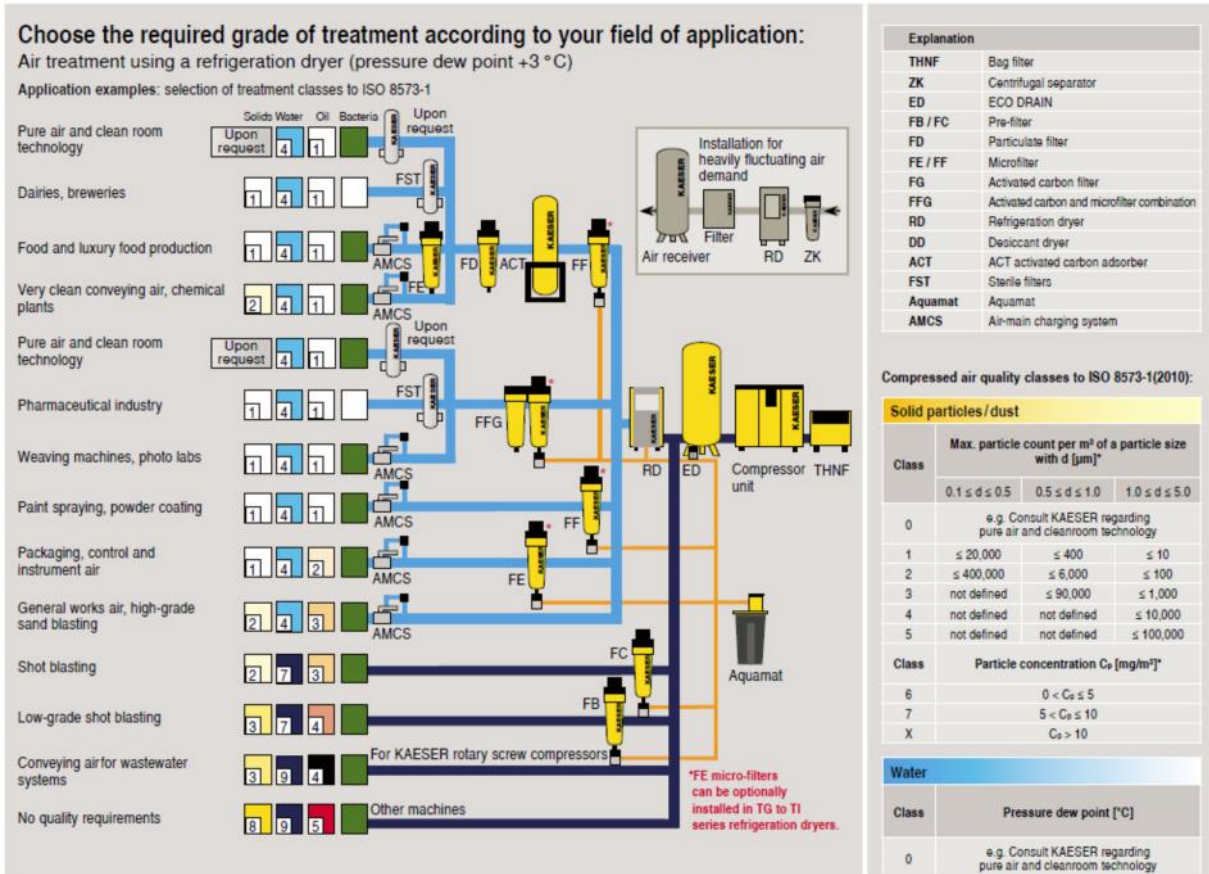
Compressor system

The compressor system includes (in case of a compressed air station) also the piping / distribution and other equipment processing and supplying compressed air, up to the final tools

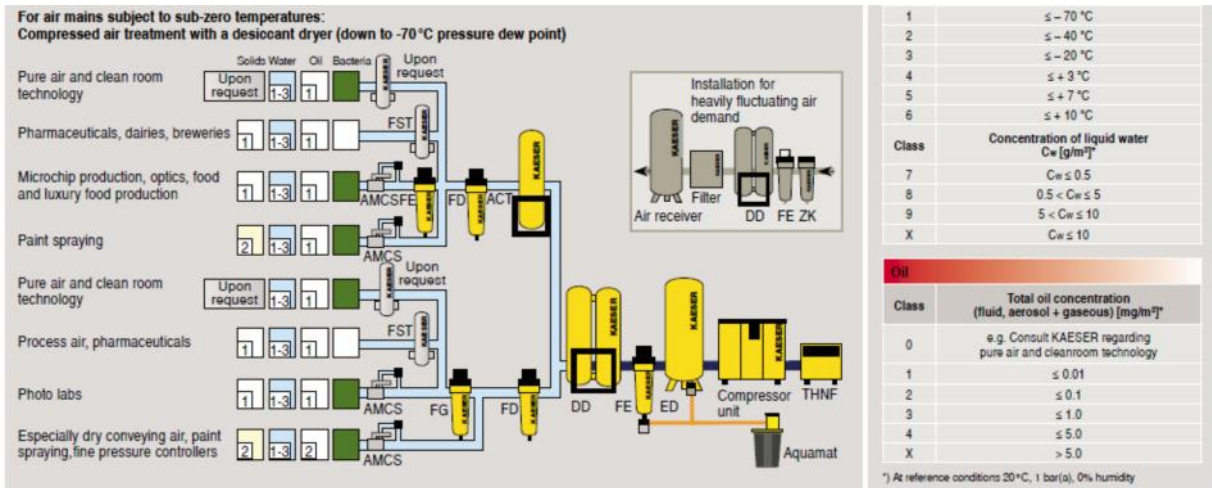
The compressor system is beyond the scope of the 'extended product' and is not subject to further analysis.

Several tools enable specifiers/clients to specify the content of the system. An example of several air treatment options is provided below.

Figure 55: Compressor purchasing tools⁸⁵



⁸⁵ Source: www.kaeser.de



Source: Kaeser Compressors / Rotary Screw Compressors SX-HSD series

2.4 Repair and maintenance practices

During normal economic product life the compressors require servicing (to ensure regular, normal functioning) and repair (in case the product has broken down).

No sources have been identified that quantify the level of material input for servicing and repair, but as some material input undoubtedly will take place an assumption is to be made.

The study did not identify sources that require deviation from the default assumption in the MEEuP 2005 methodology (also applied in MEErP 2011) to allocate 1% of the overall material input in the production phase as inputs during product life, for servicing and repairs.

2.5 Product life

The product life of compressors has been assessed in Task 2, section 3.4.

3 Energy consumption during operation

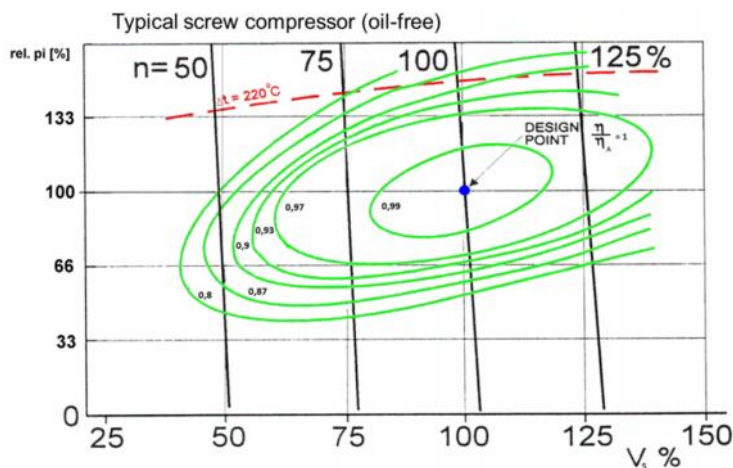
3.1 Standard efficiency

The two main compressor performance standards (ISO 1217 for displacement compressors and ISO 5389 for turbocompressors) allow identification of the compressor isentropic or polytropic efficiency and of other parameters that can be used to establish a specific energy requirement (see Task 1).

ISO 1217 does not mention isentropic or polytropic efficiency, however isentropic efficiency can be calculated on basis of ISO 1217 performance specification (see Task 4).

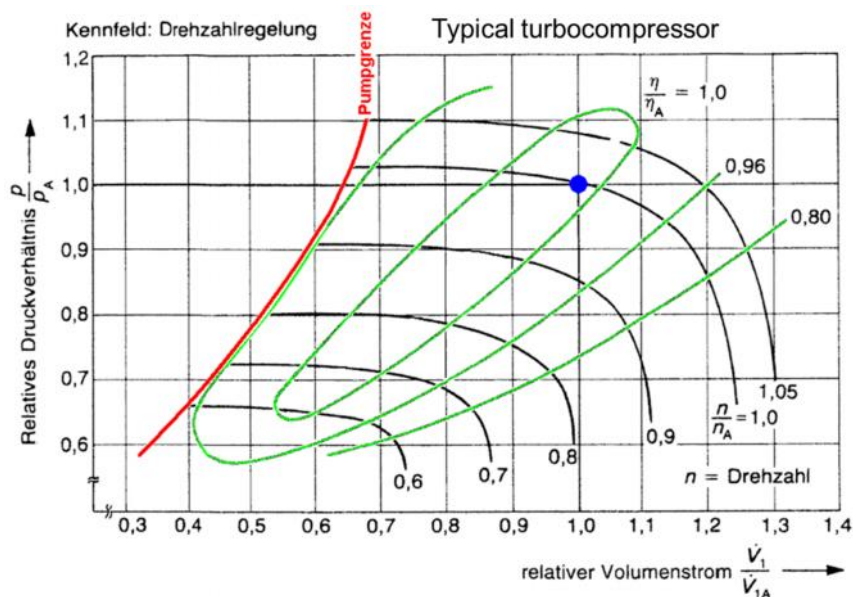
The isentropic efficiency is the measure of the work required for the ideal isentropic compression, divided by the (electric) power input under the same conditions. The efficiency can be calculated for a specific duty point (operation point, to be represented by flow (mass, volume) and differential pressure at that point). When plotted on a volumetric flow/pressure graph, the lines representing a fixed efficiency value will 'radiate' from the single best efficiency point outwards showing a 'circle' of duty points where this efficiency can be achieved.

Figure 56 Displacement compressor efficiency (screw type, oil-free)



Source: Davidson, J.; Bertele, O.v.: Process Fan and Compressor Selection. MechE Guides 1995

Figure 57 Typical turbocompressor efficiency



Source: Bohl, W.: Strömungsmaschinen 1 - Aufbau und Wirkungsweise. 1998

Standard efficiencies are in the range of between 60-90% (polytropic or isentropic).

Turbocompressors can reach a very high efficiency (approx. 85%)⁸⁶ that is little affected by part load running (see " n/n_A " in graph above).

In reality it can be expected that the compressor will not be operating in this best efficiency point, especially if the compressor is required to perform at part load conditions. The real life efficiency therefore is closer to the average operating point.

Besides the volume (or mass) flow rate and the differential pressure and part load condition (achieved by speed control or other throttling mechanisms - see below), other elements that may affect the real-life efficiency may be related to primary and secondary performance parameters, such as the air/gas quality, choice of bearings, sealings, gaskets, operational temperatures, type of lubrication (including oil-free products), choice of cooling method, heat recovery, etc. The equipment for air/gas treatment (filters), cooling, lubrication, etc. included in packaged compressors introduces loss factors as well.

The finalisation of Task 6 led to identification of efficiencies of the complete standard air application range. Please see Task 6 for further information.

3.2 Real life efficiencies

Instead of the isentropic or polytropic efficiencies, the industry also uses the specific energy requirements (e.g. as specified in Annex A-D of ISO 1217). The industry norm for comparison of compressor "efficiency" on specific energy requirement is in terms of $\text{kW}/\text{m}^3/\text{hr}$ (better $\text{W}/\text{m}^3/\text{s}$ as these are SI units) at a given compressor discharge pressure. For example a 317J/liter single-stage lubricant-injected rotary screw compressor will have a rating of approximately $15 \text{ kW}/170 \text{ m}^3/\text{hr}$ ⁸⁷ (referenced to standard inlet conditions and discharge pressure). Users need to remember that performance at site conditions will be different from test data because of differences in factors such as ambient temperature, pressure, and humidity.

Even when accurate, consistent efficiency information is available, it may only be specified for full-load operation (i.e., full capacity and specified full-load discharge pressure). Since most systems operate at part-load much of the time, it is also important to compare part-load efficiencies when evaluating the performance of different compressors. The variety of control methods can, however, make this difficult.

When gathering information on compressor performance and comparing different models, users should make sure the compressors have been tested using the same standard, at the same conditions, and that the data is being reported in a consistent manner. Some situations can lead to a consistent manner. "apples and oranges" comparisons.

For example: Manufacturers may test their compressor under different "standard" conditions. Standard conditions should be at 1 bar (14,5 psia), 20°C (68°F) and dry (0% relative humidity). The actual full-load power required by a typical air compressor package will exceed the nominal nameplate rating of the main drive electric motor. Such motors have a continuous service factor, usually 15%, which allows continuous operation at 15% above the nominal rating. Most manufacturers use up to two thirds of the available service factor, so that full-load power will be 10% above the nominal motor rating. It is therefore important to use the bhp rating, not the motor nameplate hp rating, when comparing efficiency ratings in $\text{hp}/\text{m}^3/\text{s}$. To include the motor efficiency and all package accessories and losses, use a rating in total kW input per m^3/hr to provide more precise data. Inconsistencies between reported data may be due to:

⁸⁶ <http://www.howden.com/en/businesses/howdenhua/products/compressors/turbo/default.htm>

⁸⁷ This value is considered very optimistic by industry and is being reviewed.

- Manufacturers may use a flange-to-flange rating that does not include inlet, discharge, and other package losses. This can affect overall efficiency by 5% or more.
- Energy consumption for accessory components, such as cooling fan motors, may not be treated consistently.
- Manufacturers may apply ranges or tolerances to performance data.
- Performance is usually based on perfect intercooling, which may not be realized under actual operating conditions. Perfect intercooling requires the air inlet temperature at each stage to be the same, requiring a cooling water temperature approximately 9,4 °C below the ambient air temperature. Poor intercooling will adversely affect compressor performance.

As the revised ISO standard and CAGI Compressor Data Sheets become more commonly used, these equipment comparison problems should become less significant.

3.2.1 Part load operation

Few air systems operate at full-load all of the time. Part-load performance is therefore in certain cases critical, and is primarily influenced by compressor type and control strategy.

Part load in this context can mean:

- volume flow lower than maximum;
- operating pressure lower than maximum .

Controlling volume flow is more typical for compressed air applications, as this is influenced by the demand for compressed air. Controlling operating pressure may be less typical for compressed air, and thus more typical for process gas applications.

Adequate part load strategies should differentiate between:

- 1) Rotary volumetric compressors: Relevant part load challenges relate to use of variable speed drives and system control, and variable displacement (e.g. switching of cylinders, slide valves)
- 2) Dynamic machines: Relevant part load challenges relate to blow-off, variable in- and outlet guide vanes and other techniques.

And between individual compressor controls and multiple compressor controls.

The finalisation of Task 6 led to identification of a generic (or better: weighted) efficiency of variable speed compressors in the standard air application range. The weighting comprised 25% of time at 100% volume flow, 50% of time at 70% volume flow and 25% of time at 40% volume flow. Please see Task 6 for further information.

The information collected under Task 3 and 6 includes an estimate of the load factor. The load factor is a correction applicable to compressors to correct for the other than nominal load operating conditions. For variable speed compressors for which the efficiency is already a weighted distribution profile, the load factor can be set to 1, same as for piston compressors that only operate in on/off mode.

3.2.2 Individual compressor control strategies

Over the years, compressor manufacturers have developed a number of different types of control strategies.

Typical Individual compressor controls are:

- 1) Start/ stop or on/off (typical for intermittent duty cycles, typical compressor types involved: reciprocating/piston)
- 2) Load/ unload (idle)
- 3) Modulating controls
 - a) Throttling
 - b) Bypass
 - c) Variable compression ratio
 - d) Multi step control
 - e) Variable speed drives

Controls such as start/stop and load/unload respond to reductions in air demand, increasing compressor discharge pressure by turning the compressor off or unloading it so that it does not deliver air for periods of time. Modulating inlet and multi-step controls allow the compressor to operate at part-load and deliver a reduced amount of air during periods of reduced demand.

Start/Stop

Start/stop is the simplest control available and can be applied to either reciprocating or rotary screw compressors. The motor driving the compressor is turned on or off in response to the discharge pressure of the machine. Typically, a simple pressure switch provides the motor start/stop signal. This type of control should not be used in an application that has frequent cycling because repeated starts will cause the motor to overheat and other compressor components to require more frequent maintenance. This control scheme is typically only used for applications with very low duty cycles (intermittent or sporadic use).

Load/Unload

Load/unload control, also known as constant speed control, allows the motor to run continuously ('idle mode'), but unloads the compressor when the discharge pressure is adequate. Compressor manufacturers use different strategies for unloading a compressor, but in most cases, an unloaded rotary screw compressor will consume 15-35% of full-load horsepower while delivering no useful work. As a result, some load/unload control schemes can be inefficient.

Throttling

Modulating (throttling) inlet control allows the output of a compressor to be varied to meet flow requirements. Throttling is usually accomplished by closing down the inlet valve (suction side), thereby restricting inlet air to the compressor. This control scheme is applied to centrifugal and rotary screw compressors. This control method, when applied to displacement compressors, is an inefficient means of varying compressor output. When used on centrifugal compressors, more efficient results are obtained, particularly with the use of inlet guide vanes which direct the air in the same direction as the impeller inlet. The amount of capacity reduction is limited by the potential for surge and minimum throttling capacity.

Certain piston compressors allow complete closure of the suction side of one or more cylinders, (DE: "Zylinderabschaltung") thereby unloading the cylinder.

Bypass

A bypass involves an external, controllable connection between pressure and suction side.

Variable compression ratio

Some rotary screw compressors can vary their compression volumes (ratio) using sliding or turn valves. These are generally applied in conjunction with modulating inlet valves to provide more accurate pressure control with improved part-load efficiency.

Some piston compressors can allow manipulation of the compressible volume by increasing the 'dead volume' (DE: "Schadlichen Raum"). Other piston-compressor related controls relate to the opening and closure of valves.

Multi-step controls

Some compressors are designed to operate in two or more partially-loaded conditions. With such a control scheme, output pressure can be closely controlled without requiring the compressor to the compressor to start/stop or load/unload.

Reciprocating compressors are designed as two-step (start/stop or load/unload), three- step (0%, 50%, 100%) or five-step (0%, 25%, 50%, 75%, 100%) control. These control schemes generally exhibit an almost direct relationship between motor power consumption and loaded capacity.

Variable frequency drives

Historically, the use of variable frequency drives (VFDs - same as variable speed drives) for industrial air compressors has been rare, because the high initial cost of a VFD could not justify the efficiency gain over other control schemes. Cost is no longer a major issue and VSD compressors are presently well established, reliable and efficient.

Blow-off

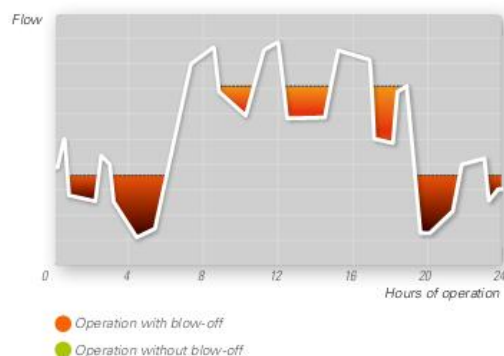
More typical for dynamic machines is the use of blow-off. In case the compressor set-up cannot completely match a reduced load, in many cases the excess pressure is relieved by a blow-off valve.

The example below shows further options to reduce losses introduced by blow-offs, which may involve use of multiple compressors or use of a variable speed drive.

Figure 58: Reduction of blow off⁸⁸

Reduced blow-off

While turbo compressors are very efficient in turndown, a lot of energy is wasted during blow-off by expanding part of the compressed air into the blow-off valve and silencer. By combining two turbo compressors in an erratically varying air demand, the expensive blow-off is reduced but not completely eliminated.



Eliminated blow-off

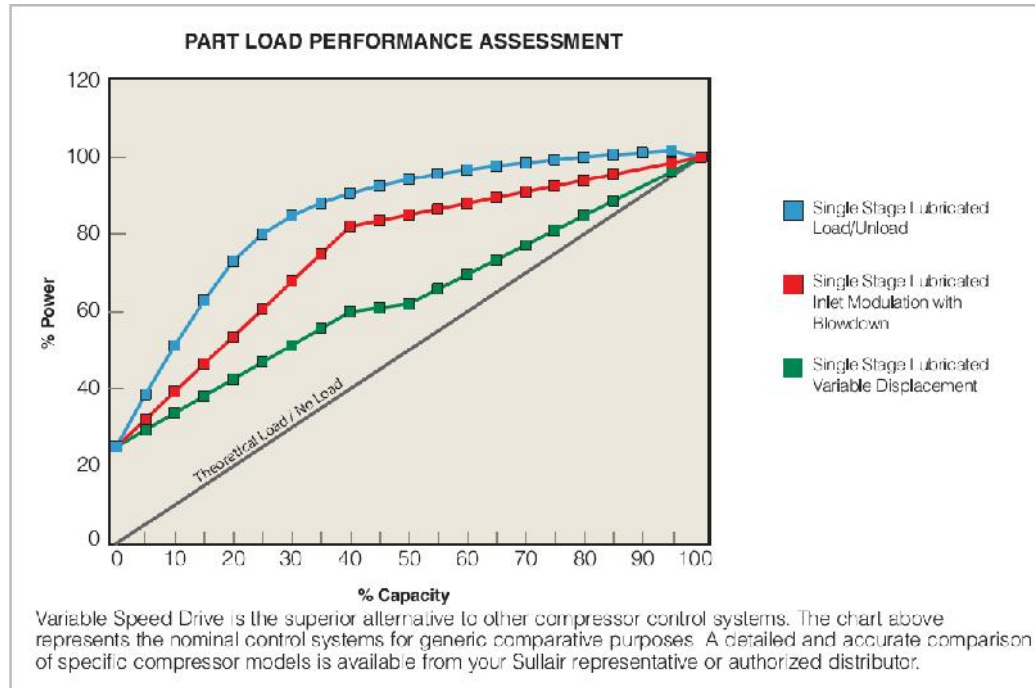
Atlas Copco's unique Variable Speed Drive (VSD) technology closely follows the air demand by automatically adjusting the motor speed. When combining the ZH+ turbo compressor and the ZR screw compressor with VSD, the highest efficiency is achieved by completely eliminating blow-off.



⁸⁸ Atlas Copco, Oil-free centrifugal compressors, ZH 4000-26000, 400-2750 kW/500-3500 hp

Each control strategy has its own advantages and disadvantages and should be optimised for the compressor application, type and duty cycle. The energy savings achieved by various control options therefore also differentiate as shown in the figure below.

Figure 59 Various types of part load control, capacity plotted against power



Source: http://www.aimcompanies.com/public/userfiles/files/S-energy_Single-Stage_Air_Compressors_25-100_HP.pdf

3.2.3 Multiple compressor controls

Multiple compressor controls are:

- Network controls, use make use of the compressor controls' microprocessors linked together to form a chain of communication that makes decisions to stop/start, load/unload modulate, vary displacement and vary speed.
- System master controls, is a central box that regulates the operation of the compressor system by making critical lead/lag and load/unload decisions. The controller continuously studies system air pressure, the direction to or from set point and the rate of pressure change, resulting in tight control to set point with the correct number of compressors running in order to achieve the best overall efficiency. It is possible to have different range compressors.⁸⁹
- Pressure/Flow Controllers (P/FC) are system pressure controls that can be used in conjunction with the multiple compressor controls.

System/master controllers

An example of how a system controller acts is shown below.

Figure 60 Sample demand flow profile⁹⁰

⁸⁹ http://www.centurycontrols.com/Pdf/CenturyControls_CC6000%20Brochure.pdf

⁹⁰ <http://www.airbestpractices.com/technology/air-compressors/applying-variable-speed-compressors-multiple-applications-application-suc>

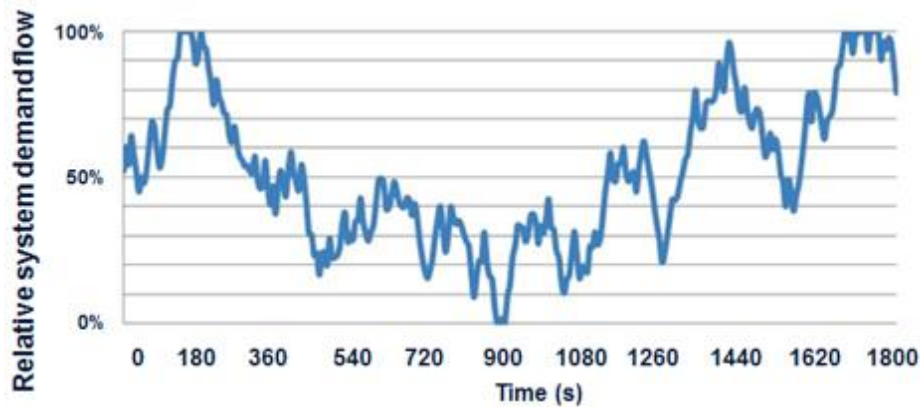


Figure 61 Multiple compressor system operated by a master controller

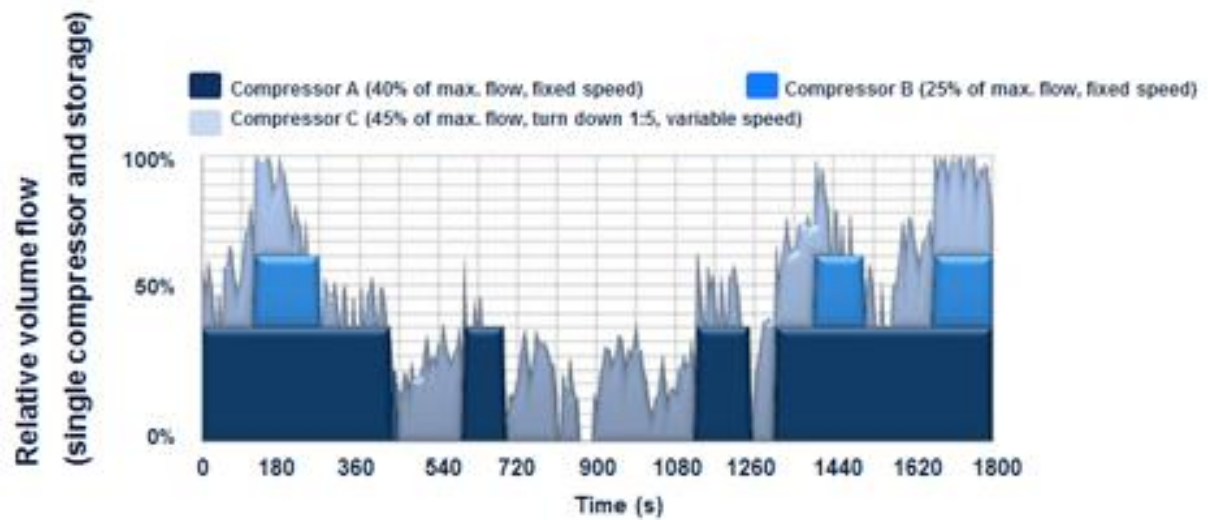
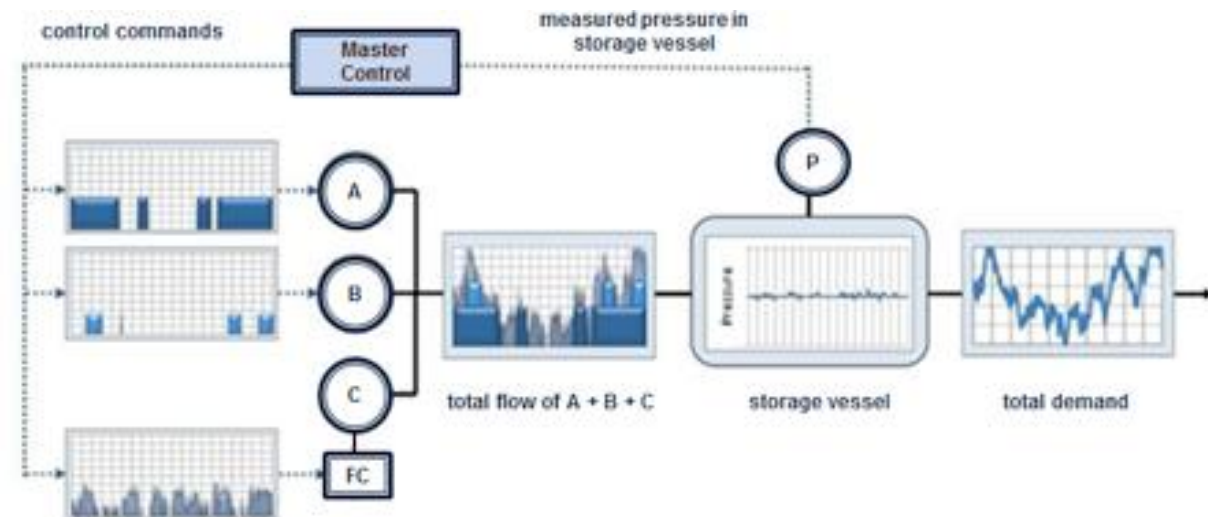


Figure 62 Characteristics of a compressed air system master controller



Flow Controllers

Flow controllers are system pressure or density controls used in conjunction with the individual compressor or system controls described previously. A flow controller does not directly control a compressor and is generally not included as part of a compressor package. A flow controller is a

device that serves to separate the supply side of a compressor system from the demand side. This allows compressors to be operated at or near their optimum pressures for maximum efficiency while the pressure on the demand side can be reduced to minimize actual usage requirements. Storage, sized to meet anticipated fluctuations in demand, is an essential part of this control strategy. Higher pressure supply air enters a storage tank at a predetermined rate and is available to reliably meet fluctuations in demand at a constant, lower pressure level. A well designed and managed system integrates control strategy, demand control, signal locations, differentials, compressor controls, and storage. The goal is to operate demand at the lowest possible pressure, support transient events as much as possible with stored air, and take as long as possible to replenish storage. This should result in the lowest possible energy consumption.

Electronic equipment, such as variable speed drives, do introduce additional electric losses. These losses will be addressed in oncoming study Tasks 6 and 7.

3.2.4 Load factors

Load factors represent the difference between the nominal capacity of a driver and the assumed actual load (= power input) of the driver. It is assumed that the average compressor runs at less than nominal capacity (or put it the other way around, the motor is specified at a somewhat higher capacity than required for average load conditions).

This does not mean the motor is never used at nominal load or even at 'overload' conditions (most motor designs allow running at higher capacities for a limited time). The load factor only indicates that 'on average' the load condition is below the nominal load.

The *load factor* represents two effects:

1. full nominal power (full volume flow, max. pressure) is usually not the representative (nominal point + time average) operating condition;
2. the real electrical input power is the shaft power divided by motor efficiency plus electrical power of auxiliary equipment.

Experts from Pneurop have estimated average load factors for each of the application ranges identified in Task 2. These load factors are provided below.

Table 48 Load factors for typical application ranges

	Compressor class (nominal driver power kW)	Load factor
Standard air compressor	10	0,8
1a. Fixed OIS/OIV compressor	25,9	0,85
1b. Variable OIS/OIV compressor	35,4	1,0
1c. Piston compressor	4,4	1,0
Low pressure compressor	46	0,8
Oilfree/ non-lubricated air compressor	189	0,8
Process/air-nitro-noble		
turbo	8.039	0,8
rotary lobe / air	203	0,8
Process/other gases		
piston	314	0,8

	turbo	10.582	0,8
	screw/oil-free	1.033	0,67
	screw/oil-injected	893	0,67
	Rotary lobe / other gas	112	0,8
HOBBY	Hobby compressor	1,25	0,8

3.2.5 Losses of the primary driver

The electric motor that drives the bare compressor has efficiencies of -on average- between 85% to over 95%. Motors of higher power have higher nominal efficiencies. The actual efficiency will depend on the actual load placed on the motor.

Of course the efficiency, like all moving/rotating equipment, changes if the duty point changes. The losses by electric motors will be addressed in oncoming study Tasks 6 and 7.

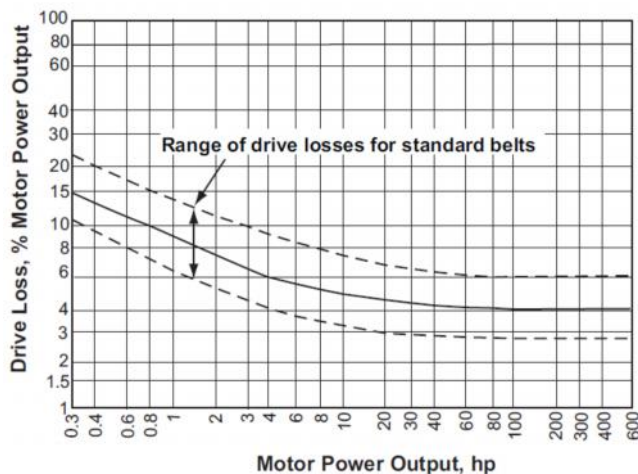
[section to expand using input from Lot 30 - electric motors]

3.2.6 Losses of transmission or coupling

The transmission can be a direct coupling of motor to compressor drive shaft, flexible couplings, clutched (slip) couplings.

Other transmissions may also incur a change in rotational speeds (not necessarily though). Such transmissions are belt drives, gears, etc. All types of transmission introduce losses. An example is provided below.

Figure 63: Transmission losses



The losses by transmissions will be addressed in oncoming study Tasks 6 and 7.

3.2.7 Combined losses of the extended product

The combination of the bare compressor (air end), the primary driver (electric motor), a transmission (belt, where applicable) and possibly the use of electronic controls (like variable speed drives) make up the 'extended product'.

The efficiency of the extended product can be calculated by combining the efficiencies (or correcting for the losses introduced) by the various components. The combined losses of the extended product will be addressed in oncoming study Tasks 6 and 7.

3.2.8 Losses and gains at system level

Apart from the energy losses of the packaged product, there are also significant losses (or improvement options) at system level. There is a watershed in information on system losses and savings potential for compressed air systems and for other (process gas) applications.

Process gas applications are in many cases unique applications that are very client specific. Some of the below remarks on reducing system energy losses can be applicable to process gas applications as well, but it has to be understood that the savings are much more confined as the freedom in options is limited by the specific application. At the moment no other general rules, specifically applicable to process gas applications, could be identified.

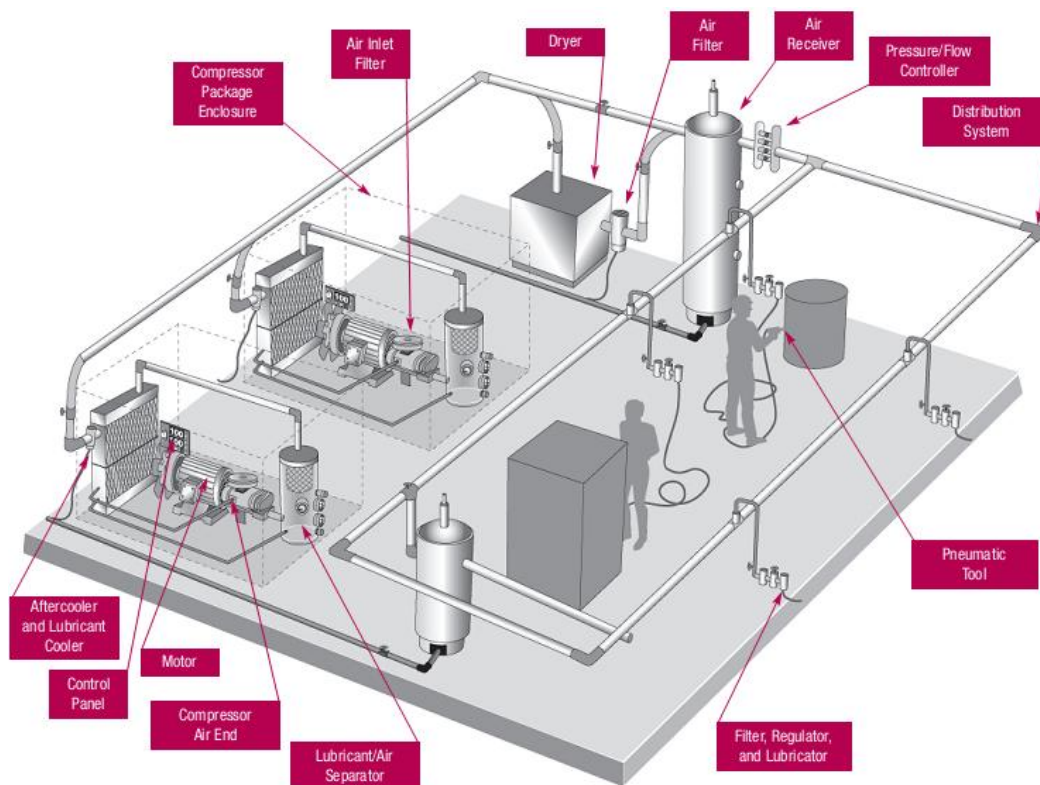
The below paragraphs focus on compressed air systems.

Compressed air systems

When looking at compressed air systems (typical plant air applications) the system is understood as the product system from air intake to 'point-of-use', and thus includes distribution (piping) networks and end-use equipment (e.g. pneumatic tools).

The figure below presents a typical compressed air system, but it needs to be stated that modern compressor systems use compressor packages with integrated functions, monitoring and system controllers, combining one or more of the separate systems parts of the figure below.

Figure 64: Components of a typical industrial compressed air system⁹¹



⁹¹ Source: Improving compressed air system performance: a sourcebook for industry U.S. Department of Energy, Energy Efficiency and Renewable Energy. Figure is said to be out-dated as these functions are more often combined in compressor packages with integrated functions, monitoring and system controls.

Explanation of compressed air system parts:

Air receiver

An air receiver is a buffer and a storage medium between the compressor and the consumption system. Receivers are especially effective for systems with widely varying compressed air flow requirements

After cooler

After coolers are installed after the final stage of compression in order to reduce the temperature of the compressed air. After coolers use either air or water to remove moisture from compressed air.

Dryer

Compressed air leaving the after cooler consist of moisture this can cause problems like corrosion in the piping and system. A compressed air dryer is a device for removing water vapour from compressed air. The higher the temperature of the air the more moisture it can contain. "Relative humidity"⁹² is the term used to express the moisture content.

Most commonly used dryers:

- refrigerant dryer;
- regenerative-desiccants-type dryers;
- deliquescent-type dryers;
- heat of compression dryers;
- membrane technology dryers.

Motor --> power range

- 375 kW is a natural barrier between low and medium voltage.
- with high power machines, the client is normally aware of a significant energy use and purchases accordingly.
- as lower end 16A 3,6kW 2-3phase. The natural barrier in the lower end of the scope can be the changeover from 1 (2) to 3 phase motors (around 2-5 kW);
- the 3 phase low voltage motors

Motors can generally only be improved by 0,1/0,2 % and therefore have a smaller impact on total system improvements. From user perspective it could be more worthwhile to look at them together with VSD's to establish whether higher savings can be reached.

Filters⁹³

Removal of oil, water, and solids from compressed air and other gases. Types of compressed air filters:

- Compressor intake filters
- Compressor air/ oil separator
- Coalescing filter (Interception filter suitable for hard and oil particles up to 0,1 micron in diameter.)
- Particulate filter
- High particulate filter
- Vapour filter (charcoal filter)

⁹² Technical correct term for relative humidity is relative vapour pressure.

⁹³ <http://www.ecompressedair.com/library-pages/compressed-air-filters.aspx>

The ISO 12500 defines a universal method for manufacturers to test and rate compressed air filters.

ISO 12500-1:2007 specifies the test layout and test procedures required for testing coalescing filters used in compressed-air systems to determine their effectiveness in removing oil aerosols.

ISO 12500-2:2007 specifies the test layout and test procedures required for testing hydrocarbon vapour adsorbent filters used in compressed air systems to determine their effectiveness in removing hydrocarbon vapours. The performance characteristics to be identified are the adsorptive capacity and the pressure drop.

ISO 12500-3:2009 provides a guide for choosing an appropriate method of determining the solid particulate removal efficiency rating by particle size of filters used in compressed air systems.

The test method described in ISO 12500-4:2009 is designed to determine the water-removal efficiency and operational pressure drop of any device designed for water removal from compressed air described as wall flow in accordance with ISO 3857-4⁹⁴

Control panel

Compressed air system controls match the compressed air supply with system demand (although not always in real-time) and are one of the most important determinants of overall system energy efficiency.

Lubrication

Lubricants are designed to cool, seal and lubricate moving parts in order to enhance performance and extend their lifetime.

An overview of possible energy savings measures for typical compressed air systems is shown in the table below.

Table 49: Energy savings potential Compressed air systems⁹⁵

Energy savings measure	Applicability (1)	Gains (2)	Potential contribution (3)		Comments
	%	%	TWh/a	%	
System installation or renewal					
Improvement of drives (high efficiency motors)	25%	2%	0,40	0,50%	Most cost effective in small (<10 kW) systems
Improvement of drives (speed control)	25%	15%	3,00	3,80%	Applicable to variable load systems. In multi-machine installations, only one machine should be fitted with a variable speed drive. The estimated gain is for overall improvement of systems, be they mono or multi-machine
Upgrading of compressor (for instance, to 2 stage compressor)	30%	7%	1,68	2,10%	
Use of sophisticated control systems	20%	12%	1,92	2,40%	
Recovering waste heat or use in other functions	20%	20%	3,20	4,00%	Note that the gain is in terms of energy, not of electricity consumption, since electricity is converted to useful heat

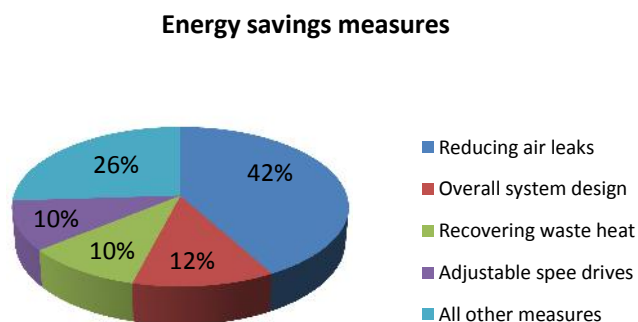
⁹⁴ ISO 3857-4 " Compressors, pneumatic tools and machines — Vocabulary — Part 4: Air treatment".

⁹⁵ Compressed air systems in the European Union, Fraunhofer 2009, based on data by Radgen et al, 2001.

Energy savings measure	Applicability (1)	Gains (2)	Potential contribution (3)		Comments
Improved cooling, drying and filtering	10%	5%	0,40	0,50%	This does not include more frequent filter replacement (see below)
Overall system design including multi-pressure systems	50%	9%	3,60	4,50%	
Reducing frictional losses (for example by increasing pipe diameter)	50%	3%	1,20	1,50%	
Optimising certain end use devices	5%	40%	1,60	2,00%	
System operation and maintenance					
Reducing air leaks	80%	20%	12,80	16,00%	Largest potential gain
More frequent filter replacement	40%	2%	0,64	0,80%	
Total⁹⁶				32,90%	
(1) % of compressed air systems where this measure is applicable and cost effective					
(2) % reduction in annual energy consumption					
(3) Potential contribution = applicability * reduction					

The total savings for the compressed air system (beyond the scope of the extended product) as calculated in the table above is 32,9%.

Figure 65 Energy savings at system level



Source: Fraunhofer 1999

The following procedure helps to minimize losses from compressed air systems. It consists of four steps:

1. *Avoid leakage*

⁹⁶ Note the potential for savings, 32,9%, is less than the sum of the savings for individual measures. The total possible savings must be calculated as a product of efficiency gains. $ES = GEC * IEF * CasF * (1 - \prod_i (1 - EGF_i * MPF_i))$

One of the most fundamental ways in which the efficiency of any compressed air installation can be improved is by reducing leakage. While every effort should be made to keep a compressed air system leak-tight, all systems will have some leakage. There are however, several ways of reducing opportunities for leaks.

Where to look for leaks: Condensate traps, fittings and pipework, flanges, manifolds, filters, cylinders, flexible hoses, instrumentation, tools and drainage points. One leak of 2mm in diameter reduces losses by 17,3 m³/h saved (at 7 bars) (Source: Pneurop website). 1 bar saved = 7% energy saved;

Figure 66: Leakage loss in typical plant air compressor station (Source: Radgen study)

Leakage size		Leakage volume at 8 bar _g	Losses	
[mm]	Size		Energy [kW]	Money [€/J]
1	•	75	0,6	315,-
1,5	•	150	1,3	683,-
2	•	260	2,0	1051,-
3	•	600	4,4	2312,-
4	•	1100	8,8	4625,-
5	•	1700	13,2	6938,-

Money values for:

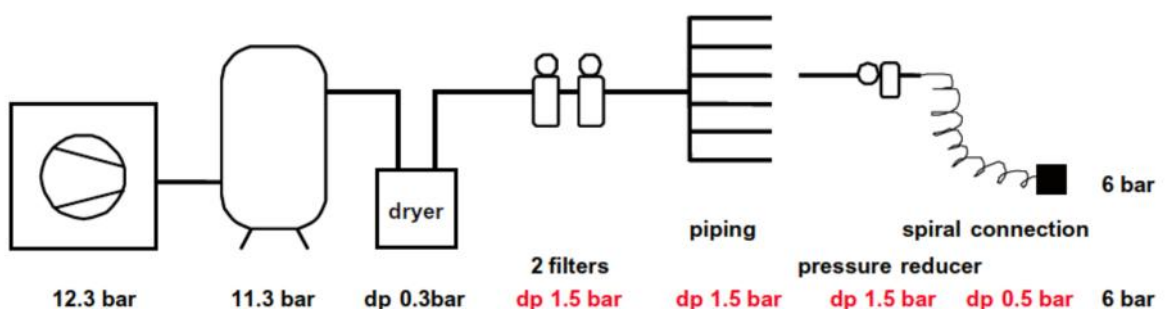
Electricity costs 0,06€/kWh

Leakage time 8.760 h/a

2. *Don't generate at a higher pressure than necessary - the higher the pressure, the more air that will escape through a given-size hole.*

Pressures can be reduced by optimising the system, reducing pressure drop losses.

Figure 67: Pressure drops in typical plant air compressor system



3. *Don't keep your whole system pressurised during non-productive hours just because a few items of machinery require a constant supply of compressed air.*

Isolate parts of the system that require air at different times. Isolation valves can be operated manually or automatically using simple control devices like time switches or interlocks, or they can be controlled using your building energy management system, if you have one.

4. *Apply heat recovery*

As much as 80-93% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a properly designed heat recovery unit can recover anywhere from 50- 90% of this available thermal energy and put it to useful work heating air or water. It is addressed in more detail in the following section.

3.2.9 Heat recovery

As much as 80-93% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a properly designed heat recovery unit can recover anywhere from 50-90% of this available thermal energy and put it to useful work heating air or water.

Typical uses for recovered heat include supplemental space heating, industrial process heating, water heating, makeup air heating, and boiler makeup water preheating. Recoverable heat from a compressed air system is not, however, normally hot enough to be used to produce steam directly.

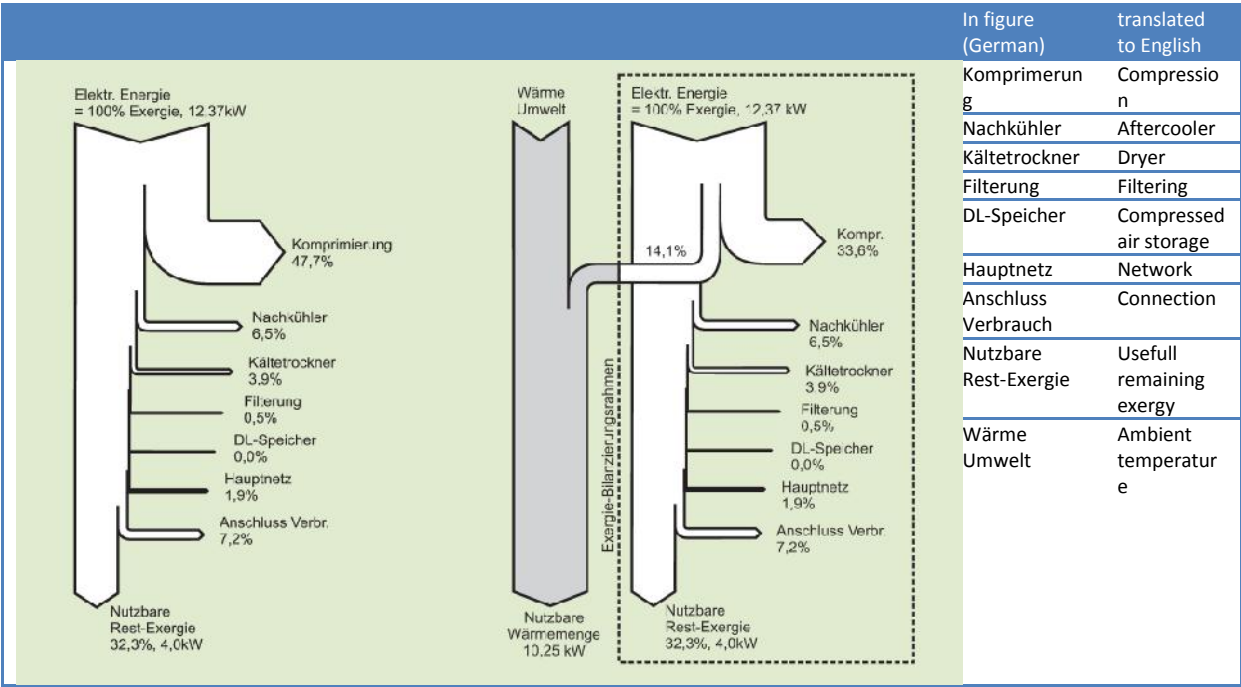
Heat recovery systems are available for both air and water-cooled compressors.

For air-cooled displacement compressors (screw): As a rule of thumb, approximately 50.000 Btu/hour (approximately 15 kW) of energy is available for each 100 cfm (approximately 2,8 m³) of capacity (at full-load). Air temperatures of 30 to 40 F (17 to 22 °C) above the cooling air inlet temperature can be obtained. Recovery efficiencies of 80-90% are common.

For water-cooled equipment recovery rates are somewhat lower as usually a heat exchanger is needed between the two fluids. Recovery efficiencies of 50-60% are typical.

The figure below shows the exergy⁹⁷ flow (and losses) of a compressor and related equipment during compression, when used without and with heat recovery⁹⁸.

Figure 68: Exergy flow of compressor system

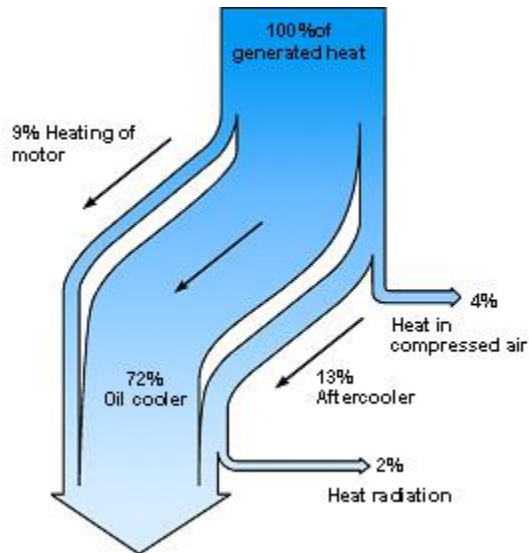


⁹⁷ Exergy is the maximum useful work that is possible in a system before reaching equilibrium. Exergy is that part of the energy that can be completely converted into another form of energy.

⁹⁸ Source: EnEffAH-Projektkonsortium 2012: EnEffAH, Energieeffizienz in der Produktion im Bereich Antriebs- und Handhabungstechnik - Grundlagen und Maßnahmen (figure received from Pneupop).

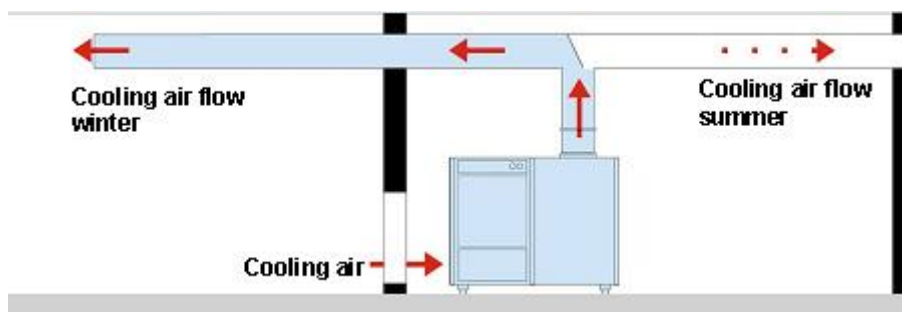
The figure below shows the different streams of heat out of an air cooled oil injected screw compressor. The heat from the drive motor, the oil cooler and the air after cooler leaves the compressor in one stream of warm air, taking out 94 % of the generated heat. This cooling air flow can be used to heat rooms or production facilities. What is needed is an air duct connected to the compressor cooling air outlet.

Figure 69 Compression heat in a screw compressor



The figure below shows an example installation. This is the simplest method of heat recovery, immediately saving energy which otherwise would have to be used to heat the building.

Figure 70 Example installation of heat recovery from cooling air



Another possible way for heat recovery is to take the heat from the oil circuit in the compressor with a heat exchanger. The advantage is that heat is then taken from the place where it is generated and from the hottest medium. Hot water with a temperature of up to 70°C can be generated which can be used in other places. This way of heat recovery is independent from the type of compressor cooling. One possible application would again be to supplement a central heating system whereby a significant amount of oil or gas for the heater can be saved.

Figure 71 Saving potential for heat recovery

Drive rate [kW]	Discharged power [kW/h]	Usable heat amount [MJ/h]	Saving potential at 1,000 op.h [€]
22	17,7	63,7	1,118
30	24,4	87,8	1,540
37	30,3	109,0	1,912
45	37,7	135,7	2,381
55	45,5	163,8	2,874
65	54,9	197,6	3,467
75	63,1	227,1	3,984
90	74,0	266,4	4,674
110	90,0	324,0	5,684
132	110,5	397,0	6,965
160	133,5	480,6	8,432
200	168,3	605,8	10,628
250	208,9	752,0	13,193

(calculated at a price of 0.50 €/l for heating oil)

The figure above shows a table with possible saving potential when heat recovery is used. The saving potential is calculated for a single shift operation (2.000 operating hours) and heat recovery only done during half of the year (1.000 operating hours).

In an application where the recovered heat is used in a three shift operation throughout the year, the saving potential is even six times bigger. In most cases the return on investment for heat recovery installations is very short. When building a new compressor station heat recovery should always be considered. That would also include choosing the compressor location as near as possible to a heat consumer.⁹⁹

3.3 Operating hours

For each specific application the average annual operating hours (at average load, which is represented by the nominal load * load factor) have been estimated by Pneurop experts.

These values are to be interpreted as average operating hours and it should be noted that each real world application of a compressor may have very different operating hours, even if the compressor is in the same application range. The operating hours presented below serve to provide input values for a generic calculation of overall compressor energy consumption.

Table 50: Operation hours per application range (Source: Pneurop)

Application range		Operating hours per year
Standard air compressor		See Task 6
	Reciprocating piston compressors	700
	Oil injected vane/ screw	2350
Low pressure air compressor		6 000
Oil free/non-lubricated air compressors		5 800
Process – air/inert	Piston	5 300
	Turbo	8 000
Process – other gases	screw/rotary lobe	5 800
	rotary lobe w/o inner compressors	5 800
Hobby compressors		20

⁹⁹ <http://www.boge.com/us/artikel/en/Effektiv/HRC.jsp?msf=400>

In case more details are available of the specific application then the operating hours can be estimated in more detail.

3.4 Energy consumption

The analysis of the energy consumption is structured on the basis of the application ranges identified in Task 1.

The calculation starts with the real motor power calculated as the **nominal power usage** (of the compressor class) multiplied by the **load factor**.

To calculate the energy consumption of the compressors per unit the real motor power (kW) is multiplied by the average operating hours (Pneurop data).

Multiplying the energy consumption with the average sales and the lifetime (also possible to multiply the sales with lifetime in accordance to get the stock) results in the total energy consumption (in the field, stock) of the compressor class.

Combining the information from the Pneurop estimates 2012 on sales of products (see also Task 2), average product life (Task 2) and installed base (Task2) with information on average nominal power consumption (Task 2), load factor and operating hours (Task 3) allows a first estimation of the overall energy consumption of (electrically driven) compressors in the EU27 of the sold volume (market) and the installed base (stock). The data refer roughly to year 2010-2011.

Based on the 1st survey results and assumed average power for compressors in the standard air application range the overall EU energy consumption of these compressors was estimated to be some 42 TWh in 2010.

However the results from the second survey (see Task 6) resulted in different sales and power estimates. The revised calculation of energy consumption (see Task 8) resulted in an EU energy consumption of compressors in the standard air application range of some 60 TWh/yr.

Combining this revised value with the first estimates for compressors in the other application ranges gives as overall estimate of energy consumption of all electric driven compressors some 188 TWh/a, representative for 2010.

Other estimates

The Fraunhofer study from 1999 identified an electricity consumption of the stock of air compressors of around 80 TWh per year¹⁰⁰. This is based on assumed average operating hours of 3500 hours/year and an average power electric power input of 71 kW.

Table 51: Electricity consumption for compressed air systems in 1999

Country	Total	10-110 kW	110-300 kW
France	12	9	3
Germany	14	11	4
Greece + Spain + Portugal	9	7	2
Italy	12	9	3
United Kingdom	10	8	3
Rest of the EU	23	17	6
Total	80	60	20

¹⁰⁰ Fraunhofer study compressed air systems in the EU

This value corresponds with the estimates by Pneurop for standard air and low pressure air compressors. Based on the Pneurop assumptions these compressor types make up roughly 99% of the installed base (excluding hobby air compressors) but only almost 50% of the EU27 compressor electricity consumption. The major difference between the Fraunhofer and Pneurop assessment is the inclusion of process gas compressors and oil free/non-lubricated compressors in the latter assessment.

Table 52 Energy consumption by typical compressor application ranges

Application range	Compressor nominal drive	Load factor	Average operating hours per year	Energy per unit	Sales (eu-27)	Energy consumption, put on market	Electricity costs	Average life time (from survey)	Installed base	Energy consumption, in the field (
	kW	[-]	hrs/yr	kWh/yr	units	TWh/yr	EUR/unit/yr	yrs	units	TWh/yr
Standard air compressor					105 900	4.9			1 153 000	59
- for fixed speed OIS/OIV	25.9	0.8	4312.5	89 355	45 000	4.04	See Task 8	12	615 000	48.8 *
- for variable speed OIS/OIV	35	1	2 350	69 560	46 708	0.72	See Task 8	12	46 000	8.9 *
- for piston	4.3	1	800	2 368	76 654	0.12	See Task 8	10	492 000	1.5 *
Low pressure compressor	46	0.8	6 000	218.750	12 800	2.80	24.063	15	192 000	42,0
Oilfree/ non-lubricated air compressor	189	0.8	5 800	875.000	2 000	1.75	96.250	20	40 000	35.0
Process gases/air-nitrogen-noble										
turbo	8 039	0.8	8 000	51 452 381	14.0	0.72	5 659 762	30	420	21.6
rotary lobe / air	203	0.8	5 800	943 396	13.3	0.013	103 774	20	265	0.25
Process gases /other gases										
piston	314	0.8	5 300	1 333 333	150.0	0.20	146 667	35	5 250	7.0
turbo	10 582	0.8	8 000	67 722 222	12.0	0.81	7 449 444	30	360	24.4
screw/oil-free	1 033	0.67	5 800	4 015 385	6.5	0.026	441 692	20	130	0.5
screw/oil-injected	893	0.67	5 800	3 472 000	12.5	0.043	381 920	20	250	0.9
rotary lobe / other gas	112	0.67	5 800	518 519	13.5	0.007	57 037	20	270	0.1
Hobby compressor	1	0.5	20	10	500 000	0.005	2	5	2 500 000	1.25
TOTALS (excl. hobby)					638 385	9.2			4.589.375	188

*= based on stock model, described in Task 8

4 End-of-life practises

This section will cover the following items as specified in the technical specifications:

Items according tender specifications	How they are dealt with by this section:
Economical product life (=actual time to disposal);	This is addressed under 'Product life'
Repair- and maintenance practice (frequency, spare parts etc.);	This is addressed under 'Repair and maintenance practices'
Best practice in facilitating dismantling;	This is addressed under 'Disposal'
Present fractions to recycling, re-use and disposal;	
Estimated second hand use, fraction of total and estimated second product life (in practice);	
Best practice in sustainable product use, amongst others regarding the items above.	

4.1 Regulatory context

The EU's Waste framework Directive (75/442/EEC, as amended by 91/156/EEC) requires that waste management is applied, following a hierarchy of waste treatment options: First is waste prevention, followed by recovery (includes material recycling), incineration with energy recovery and lastly, incineration without energy recover and disposal (landfill).

The Waste Incineration Directive 2000/76/EC ensures that facilities meet adequate requirements as regards permits and emissions. The Landfill Directive (1999/31/EC) requires that only waste subject to treatment may be landfilled.

Compressors are not covered specifically by WEEE Directive nor by the RoHS Directive.

The WEEE Directive 2012/19/EU excludes from its scope:

- (b) large-scale stationary industrial tools;
- (c) large-scale fixed installations, except any equipment which is not specifically designed and installed as part of those installations;

Whereby these are defined as:

(b) 'large-scale stationary industrial tools' means a large size assembly of machines, equipment, and/or components, functioning together for a specific application, permanently installed and de-installed by professionals at a given place, and used and maintained by professionals in an industrial manufacturing facility or research and development facility;

(c) 'large-scale fixed installation' means a large-size combination of several types of apparatus and, where applicable, other devices, which:

- (i) are assembled, installed and de-installed by professionals;
- (ii) are intended to be used permanently as part of a building or a structure at a pre-defined and dedicated location; and
- (iii) can only be replaced by the same specifically designed equipment;

DIRECTIVE 2012/19/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast)

Annex I

Categories of EEE covered by this Directive during the transitional period as provided for in Article 2(1)(a)

1. Large household appliances
2. Small household appliances
3. IT and telecommunications equipment
4. Consumer equipment and photovoltaic panels
5. Lighting equipment
6. Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
7. Toys, leisure and sports equipment
8. Medical devices (with the exception of all implanted and infected products)
9. Monitoring and control instruments
10. Automatic dispensers

DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast)

Categories of EEE covered by this Directive

1. Large household appliances.
2. Small household appliances.
3. IT and telecommunications equipment.
4. Consumer equipment.
5. Lighting equipment.
6. Electrical and electronic tools.
7. Toys, leisure and sports equipment.
8. Medical devices.
9. Monitoring and control instruments including industrial monitoring and control instruments.
10. Automatic dispensers.
11. Other EEE not covered by any of the categories above.

Electric driven compressors meet the generic definition of 'electrical and electronic equipment' or 'EEE' referred to in the RoHS Directive 2011/65/EU as it means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current;

The RoHS Directive excludes large-scale fixed installations from its scope (article 2, 4, b) which are defined as: 'large-scale fixed installation' means a large-scale combination of several types of apparatus and, where applicable, other devices, which are assembled and installed by professionals,

intended to be used permanently in a pre-defined and dedicated location, and de-installed by professionals; (article 3.4)

This 'large-scale' definition could cover most commercial and industrial applications of compressors, except the smallest ones, where - for instance - a pressure vessel is part of the package and the required connections are simple to perform. This description would fit most of the piston compressor standard air application range.

4.2 Product life extension

No factual information is available on extension of product life of compressors inside or outside the EU. For certain capital goods (e.g. buses, manufacturing tools) it is known that the product life is extended outside the EU borders.

It can be expected that this extension of product life after discarding in the EU applies to (certain types of) compressors as well. There are however no sources indicating the level of extension of product life and this (potential) effect could therefore not be quantified.

4.3 Disposal

Product disposal is most often left to the owner's discretion. It can be assumed that most EU users of compressors dispose of their products through appropriate channels after the economic life has been reached.

This is assumed because of the very high metal content of these products (see Task 4) which results in considerable scrap value. As over 80% of the material composition (see also Task 4) of electric driven compressors are metals (mostly steel, but also aluminium and copper) it can be assumed that these materials will enter the metal recycling loop. Whether this is inside or outside the EU is not known.

The plastics fraction can in practice follow various scenarios: it can be recycled in similar or higher grade applications (up cycling), or recycled in low-grade applications (down cycling), or burned with thermal recovery, or burned without thermal recovery or landfilled. The plastics fraction (on weight basis) in most compressors is however minute compared to the overall weight.

At the moment no recycling programs have been identified to ensure product take-back of products after end-of-life. Therefore the fraction of plastics to be up cycled is assumed to be zero. For plastics it is assumed that the fraction is most likely to end up in a waste incineration facility with energy recovery.

It is assumed that dismantling takes place to sort the various metal fractions and to obtain the highest possible scrap values (stainless steel apart from normal steel, etc.). During this it is assumed that major non-ferrous fractions (e.g. the electric motors that contain a high copper content) are separated from metallic ferrous and send to separate disposal routes as they should be, as otherwise the (precious and/or non-ferro) metal content is 'lost' in generic metal recycling routes¹⁰¹.

Electronics are assumed to be dismantled and send to specialist electronics recyclers as these also represent economic value (presence of precious metals).

Still it can be assumed that many more specialty metals are lost due to inadequate recycling facilities and or activities (Beryllium for instance, is applied in copper alloys, but during recycling often diluted or ends up in slag). The problem is however not limited to (electric) compressors alone, and should best be addressed through a horizontal initiative (as introduced under the flag of the "Resource Efficient Europe").

¹⁰¹ See also <http://www.bir.org/industry/non-ferrous-metals/>

5 Local infrastructure

This section concerns the local infrastructure of compressors and how this affects selection of compressors, operation conditions and other elements attributing to real-life efficiency of compressors.

According the technical specifications this section shall cover the reliability, availability and nature of the energy form involved, and other infrastructural items such as telecom (e.g. hot spots, WLAN, etc.), installation, e.g. availability and level of know-how/training of installers and other aspects of the physical environment.

As the scope of this study is limited to electric compressors only, the influence of the energy infrastructure is limited.

As the scope addresses industrial products mainly:

- the relevance of telecom facilities is deemed adequate, especially if networked products are used;
- compressor installation is performed by trained personnel and also the main users are trained personnel. The hobby compressors may be bought and used by lay-persons but their energetic relevance is deemed insignificant.

Of course the local infrastructure does affect options for heat recovery and or energy saving in the compressor system, but these options exceed the scope of that of even the extended product. More information on the applicability of ecodesign options is provided in Task 6 and 7.

Ecodesign Preparatory Study on

Electric motor systems / Compressors

ENER Lot 31

FINAL Report Task 4

Technical analysis existing products



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Final Report Lot 31 Task 4

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1 Introduction to Task 4

1.1 Scope and subtasks

This is the final Task 4 report of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **‘ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives’**.

The aim of this Task 4, in accordance with the tender specifications¹⁰², is to describe aspects that determine the environmental performance of the products within the scope, covering the complete life cycle.

1.2 Subtasks for Task 4

The technical specifications underlying this study require addressing the following points.

Subtask 4.1 Production phase

The following input data are required:

- Avg. EU product weight and Bill-of-Materials, distinguishing materials fractions (weight) at the level of the EuP EcoReport Unit Indicators as proposed in the MEEuP report.
- This includes packaging materials and an assessment of the primary scrap production during sheet metal manufacturing (avg. EU).

Subtask 4.2 Distribution phase

This section describes the volume and weight of the packaged product as placed on the EU market (average product).

Subtask 4.3 Use-phase (product)

- Annual resources consumption (energy, water) and direct emissions¹⁰³ during product life according to the test standard defined in task 1.2;
- Assessment of resource consumption (energy, water) and direct emissions during product life in off-standard conditions. i.e. variable load.

Subtask 4.4 Use-phase (system)

This paragraph identifies and describes the functional compressor system and identifies and attempts to quantify those product features that can reduce the environmental impact not only of the product but of the system as a whole.

The scope of the system analysis is restricted only to issues that can be influenced by technical features of the compressor. This paragraph is an addition to the more traditional product-specific analysis in paragraph 4.3, i.e. to design product-specific legislation (if any) in such a way that it would not make system-oriented innovations impossible.

Subtask 4.5 End-of-life phase

Considerations regarding end-of-life of materials flow¹⁰⁴ for:

¹⁰² European Commission, Tender specifications ENER/C3/410-2010, which are the basis for the study.

¹⁰³ This relates to product specific emissions during product-life, e.g. ozone for certain imaging equipment, radiation for certain televisions etc.

- Handling as pure waste (landfill, pyrolytic incineration);
- Heat recovery (non-hazardous incineration optimized for energy recovery)
- Re-use or closed-loop recycling

Subtask 4.6 Recommendations on mandates

This section shall include recommendations for the content of possible mandates to be issued by the European Commission to the European standardization organisations on (measurement) standards for compressors. → This subtask is transferred to Task 8, in the section dealing with recommendations.

The application ranges identified in Task 1 and 2 are used in this section as guidance for structuring the information provided. They are the predecessors of the base cases that are defined in Task 5 and beyond.

.

¹⁰⁴ At least for plastics and electronics, as defined in the EuP EcoReport. For metals and glass this may also be indicated if the recycling percentage is less than 95%.

2 Production phase

The application ranges include all of the most common types of compressors for which the following input data are required:

Avg. EU product weight and Bill-of-Materials, distinguishing materials fractions (weight) at the level of the EuP EcoReport Unit Indicators as proposed in the MEEuP report. This includes packaging materials and an assessment of the primary scrap production during sheet metal manufacturing (avg. EU).

2.1 Bill-of-materials

Very few data on the bill-of-materials (BOMs) for compressors have been found in the public domain. So far, the single available BOMs specifically for compressors relate to the following types:

- 4 kW reciprocating piston compressor (source: Pneurop);
- 90 kW oil injected screw compressor (source: Pneurop).
- 200 kW turbo compressor (source: public website, Siemens STC-DO 5SF-A);
- 6.2 MW turbo compressor (source: public website, Siemens STC-ECO) (this product is not representative, but will be mentioned due to very few data on BOMs.).

This means an information gap exists for other compressor types, such as rotary lobe.

Other BOM's for products similar to compressors, such as the 7.9 MW Gas turbine (Siemens SGT-300), 175 MW steam turbine (Siemens SST-700), do not fill the current gap in compressor bill-of-materials.

The available BOMs give the following split-up per material input class.

Table 53: Material inputs based on public BOMs

	90 kW oil injected screw compressor	4kW reciprocating piston compressor	200 kW turbo compressor	6.2 MW turbo compressor	7.9 MW Gas turbine	175 MW steam turbine
			Siemens STC- DO 5SF-A	Siemens STC- ECO	Siemens SGT-300	Siemens SST-700
high alloy steel	0.5%		3%	15%	7%	21%
low alloy steel	53.7%	2%	3%	27%	17%	47%
unalloyed steel	0.2%	64%	44%	53%	58%	32%
cast iron	29.4%	7%	22%	3%	9%	
aluminium	5.3%	10%	9%		3%	
copper	3.9%	3%	3%	2%	5%	
plastics	1.2%	4%	2%			
insulation material	0.0%		10%			
electronics	0.0%		2%			
others	5.7%	8%	2%		0.5%	0.4%
energy	5 000 MWh	12-39 MWh			3 344 GWh	3 000 GWh

	90 kW oil injected screw compressor	4kW reciprocating piston compressor	200 kW turbo compressor	6.2 MW turbo compressor	7.9 MW Gas turbine	175 MW steam turbine
	(lifetime)	(lifetime)				
product life	12	10			20	20
operating hrs	4 000	250-800			8 000	3 000

The above generic BOM's have been scaled on the basis of the input power, to be more proportional of the inputs expected for the other application ranges.

Table 54 Generic BOMS used for application ranges

Generic description	"generic rotary compressor"	"generic reciprocating compressor"	"generic turbo compressor < 1 MW"	"generic turbo compressor > 1 MW"
(actual source of data)				
Application range / for base case	90 kW oil injected screw compressor	4kW reciprocating piston compressor	200 kW turbo compressor	6.2 MW turbo compressor
Standard air compressor				
- for fixed speed OIS/OIV	V			
- for variable speed OIS/OIV	V			
- for piston		V		
Low pressure compressor	V			
Oilfree compressor			V	
Process gases/air-nitrogen-noble				
- turbo				V
- rotary lobe			V	
Process gases /other gases				
- piston		V		
- turbo				V
- screw/oil-free	V			
- screw/oil-injected	V			
- rotary lobe / other gas	V			

2.1.1 Scrap metal

No data regarding average scrap metal rates (as % of total metal input) have been identified. Therefore, the average scrap metal rate as assumed in the Ecoreport shall be used (25% of sheet metal input added to production phase and 100% recycled).

2.1.2 Packaging materials

No data regarding average packaging materials for compressors specifically have been identified.

As packaging materials are estimated to be of minor relevance considering the significance of other resource inputs, especially metals, the authors have chosen to neglect packaging materials as inputs¹⁰⁵.

2.2 Product weight

As the compressors covered by the application ranges differ in nominal input power, pressure ranges and also in auxiliary equipment included, the overall product weight and therefore the material inputs also differ significantly.

However, it has proven not to be possible to identify one single typical real life product to signify the average in the application range. In the approach described below an average weight to power ratio has been identified for several products in a manufacturer's line up of products (see example below).

Table 55: Weight by power ratio

Manufacturer 'A': Screw compressor belt drive		
Nominal motor power (kW)	Weight (kg)	Ratio (kg/kW)
4	190	48
5,5	190	35
7,5	205	27
11	220	20
15	235	16
15	435	29
18,5	450	24
22	485	22
30	580	19
37	595	16
37	880	24
45	1 070	24
55	1 170	21
75	1 180	16
75	2 000	27
90	2 100	23
110	2 200	20
132	2 700	20
132	3 600	27
160	3 750	23
200	3 950	20
200	3 900	20
250	4 100	16
Average ratio		23

¹⁰⁵ In other product groups, packaging may be a very relevant resource use parameter and should not be neglected.

The above table shows the kg/kW ratio is (on average) highest for smaller products (can be above 40 kg/kW) and (on average) smaller for larger capacity products (below 20 kg/kW).

Indeed, this is a very rigid simplification of the real world situation where the actual weight is not only determined by the nominal motor power but also by the compressor type and a range of features. Taking all these elements into account would however require access to a database with all these compressor characteristics. Such database however does not yet exist.

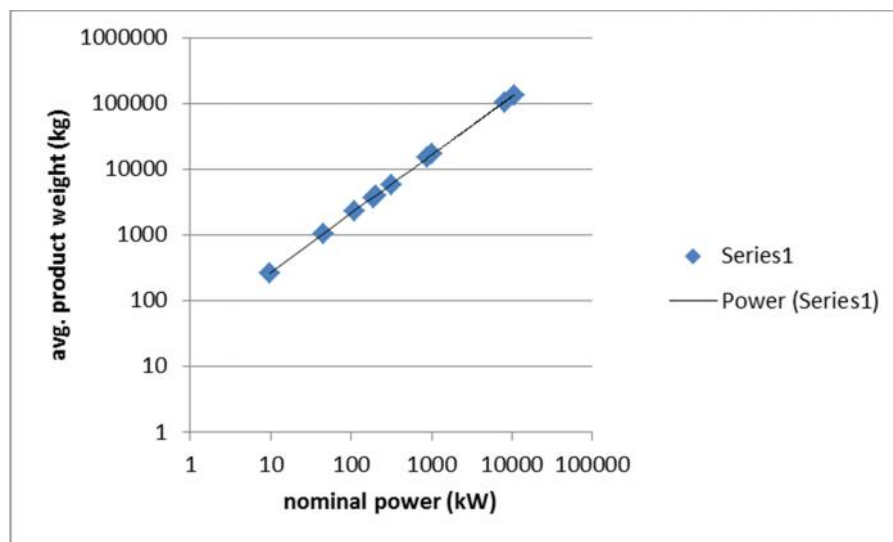
Based on the anecdotal dataset above and assumptions regarding the expected product weight of larger capacity products, the average product weight of the typical product in the given application range is estimated by the formula: $m = 35 \cdot (P_{nom}^{-0,11})$, where:

m = product weight (kg)

P_{nom} = nominal motor power (kW)

The relation is visualised in the graph below (note: X and Y-axis are logarithmic)

Figure 72: Weight by power (indicative)



2.3 Overview production phase inputs

The above collected information on type of materials used (section 2.1) and the amount of materials (section 2.2) combined gives an indicative resource consumption for the compressors within the given application ranges. An overview table is presented on the following page.

The input "other" has been subdivided into inputs related to powder coating, rubbers/elastomers and Cr-plating. For powder coating and elastomers a share of 1/10 of 'others' has been assumed. For Cr-plating a share of 1/10 000 of 'others'.

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This results in the product weights as presented below.

Table 56: Material inputs by base case / application range

Base cases	Standard air	low pressure	Oilfree/ non-lubricated	Process gases /air-nitro-noble		Process gases /other gases					
type					rotary lobe / air	piston	turbo	screw / oil-free	screw / oil-inj.	Rotary lobe / other gas	Ecoreport unit indicator
kW	10	46	189	8039	203	314	10582	1033	893	112	
kg/kW ratio	27,3	23,0	19,7	13,0	19,5	18,6	12,6	16,3	16,6	20,8	kW
Weight	265	1048	3709	104645	3966	5847	133635	16855	14809	2328	kg
MATERIALS Extraction & Production											
high alloy steel	8	31	111	15697	119	175	20045	506	444	70	26
low alloy steel	8	31	111	28254	119	175	36081	506	444	70	23
unalloyed steel	116	461	1632	55462	1745	2573	70826	7416	6516	1024	22
cast iron	58	231	816	3139	873	1286	4009	3708	3258	512	24
aluminium	24	94	334	0	357	526	0	1517	1333	210	27
copper	8	31	111	2093	119	175	2673	506	444	70	29
plastics	5	21	74	0	79	117	0	337	296	47	11
insulation material	26	105	371	0	397	585	0	1685	1481	233	16
electronics	5	21	74	0	79	117	0	337	296	47	98
others	5	21	74	0	79	117	0	337	296	47	
assumed powder coating	1	2	7	0	8	12	0	34	30	5	40
assumed rubbers	1	2	7	0	8	12	0	34	30	5	17
assumed Cr-plating	0,0005	0,0021	0,0074	0,0000	0,0079	0,0117	0,0000	0,0337	0,0296	0,0047	41

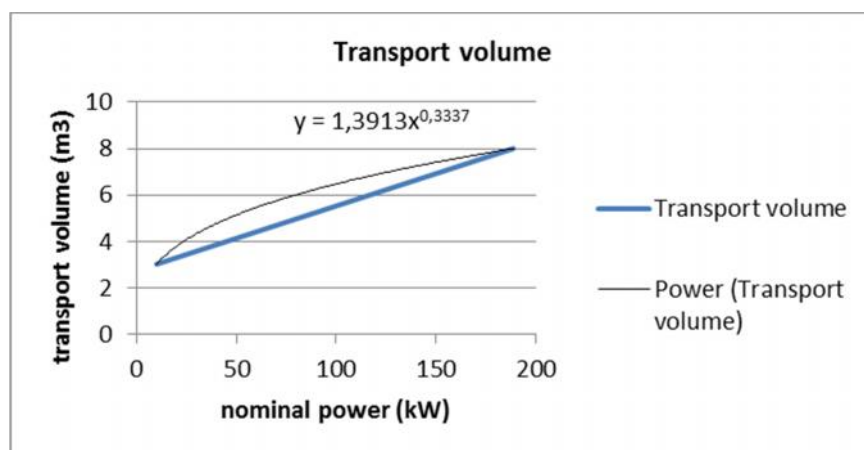
3 Distribution phase

This section describes the volume and weight of the packaged product as placed on the EU market (average product).

3.1 Transport volume

The average transport volume has been estimated on the basis of anecdotal information on size of compressor packages using the formula below (see "power equation" in graph).

Figure 73: Transport volume by power (indicative)



In the analysis a simplified formula was used: $V = 1,5 * (P_{nom}^{0,25})$, where:

V = transport volume (m³)

P_{nom} = nominal power (kW)

Table 57: Transport volume by application range (indicative)

Base cases	Standard			Low pressure	Oilfree / non-lubricated	PROCESS/air-nitrogen		PROCESS/other gases					
type	Fix OIS/OIV	Var OIS/OIV	Piston			turbo	rotary lobe / air	piston	turb o	screw/oil-free	screw/oil - injected	Rotary lobe / other gas	
Transport volume	3	4	2	4	6	14	6	6	15	9	8	5	m³

3.2 Transport distance

As most of the compressor sales will occur in the countries (or regions) with the highest degree of industrialisation, it is assumed that production occurs in mid Germany and use (on average) occurs over a distance of 3 000 km (e.g. Scandinavia, Italy, Spain).

It should be noted that the EU has a significant export (and import) of compressors, which may mean that a significant share of compressors produced in the EU as well as compressors imported to the EU have considerable transportation distances (overseas). However, as the exact number of imports and exports could not be determined, this analysis assumes distribution within the EU only.

4 Use-phase (product)

This section addresses the following aspects of compressor usage:

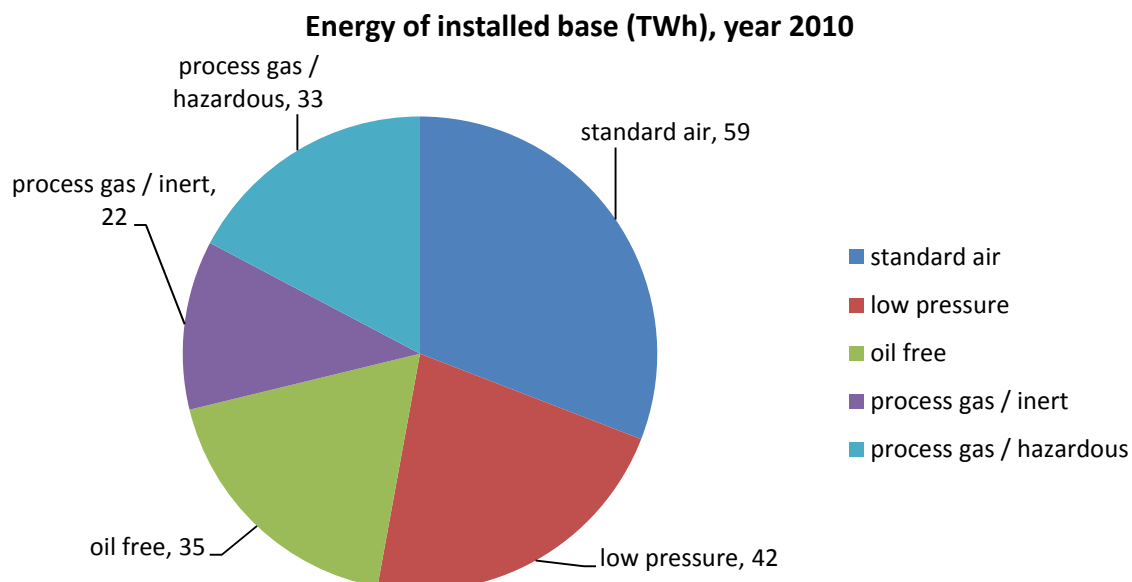
- Resources consumption (energy and other consumables) and direct emissions¹⁰⁶ during product life. It should be noted that the energy consumption cannot be established using a test standard, but is purely based on assumptions regarding actual power (nominal power corrected by load factor), operating hours and product life. The test standards described in Task 1 can only be used to differentiate on energy efficiency (isentropic or polytropic);
- The above means that resource consumption (energy) in non-nominal load conditions (part load etc.) are included in the calculation, but are not made more specific. Available information on energy savings for part load operation is provided where available.

4.1 Energy consumption

The total annual energy consumption of the compressors in the scope of this study is calculated to be around 188 TWh. The calculation of this energy consumption is explained in Task 8 report.

The graph below does not include "hobby air compressors, which comprise at maximum some 1,25 TWh or 0, 1% of the total energy consumption.

Figure 74: Energy consumption of compressors by application range, (data based on Pneurop estimates 2012)



¹⁰⁶ This relates to product specific emissions during product-life, e.g. ozone for certain imaging equipment, radiation for certain televisions etc.

4.2 Other consumables

The main consumables for compressor operation are limited to oil consumption (except when 'oil-free') and (air) filter paper.

Oil consumption

Oil-free compressors do not emit oil in the gas stream and such emissions are therefore zero by default. For standard air compressors the choice for oil-injected or oil-free systems depends on the requirements of the client as regards the quality and application of the compressed air, and also the requirements as regards running costs, purchase costs, types of use, etc. Oil consumption may be required to meet lubrication, cooling and sealing needs although other purposes may also apply. In general most of the oil is recovered from the compressed air. Only a very small fraction is dispersed through air and needs to be replenished.

Oil consumption by oil-injected/lubricated compressors should be split up into:

- 1) Oil consumption related to oil change (including used oil in exchanged filters)
- 2) Oil consumption related to oil-carry over, to be split into
 - a) oil "washed out" with condensate in air-after cooler / refrigerated air dryer
 - b) oil remaining in compressed air after basic air treatment

In general, the oil consumption is split into 1) oil change and 2) oil carry-over into compressed air. In addition a large percentage of oil carry (aerosol + vapour) is "washed out" together with condensate in air after-coolers and refrigerated air dryer and removed in filters. Only a minor percentage of the oil consumption of an oil-injected compressor is "dispersed into plant air".

To give an estimation of the amount of oil dispersed in plant air: Sources¹⁰⁷ identify a range of 1-3 mg/m³ to 0.7 mg/m³. The emissions not only depend on compressor but also on oil characteristics. Reportedly some oil may reduce emissions (lower value of range indicated above).

Table 58: Indicative oil emissions in air

By application	volume flow			oil %	
	kW	m ³ /min	m ³ /yr	mg/m ³	kg/year
Plant air					
Standard air compressor	9,7	1	261 514	1,3	0,3
Low pressure compressor	46				
Oilfree/ non-lubricated air compressor	189				
Process gas					
turbo	8 039	1 223	587 228 261	1)	
rotary lobe / air	203	31	10 767 022	6,3	68
piston	314	48	15 217 391	2)	
turbo	10 582	1 610	772 916 667	1)	
screw/oil-free	1 033				
screw/oil-injected	893	136	47 314 731	11,3	535
Rotary lobe / other gas	112	17	5 917 874	12,3	73

Comment 1): turbocompressors are typically "oil-free" meaning no oil is emitted in the medium

Comment 2): it is assumed that oil or grease is used for bearings, but oil does not come in contact with the medium

¹⁰⁷ <http://www.boge.com/en/artikel/en/Produkte/How-It-Works.jsp?msf=200,100,100,050&switchlang=en>

With oil-injected/oil-lubricated screw or vane compressors ("standard air") and rotary lobe compressors oil may be present in the medium.

Anecdotal data suggests that oil (and grease) consumption (not emissions per se) can be reduced by product design in specific applications, by specifying air bearings or magnetic bearings.

The need for lubrication oil for bearings and gears in compressors producing oil free air or gas does not mean this oil (or grease) is present in the medium. The above example therefore relates to oil consumption mainly and not to emissions of oil in the medium.

Air filter consumption

The air filter usually is a dry type paper filter with replaceable elements. No data has been found on average consumption.

4.3 Other emissions

Inherent to the functioning of a compressor is the possibility of leakage of the gas being compressed. For standard air compressors, any leakage represents an energetic loss (indirect impact), but not a direct environmental impact.

For inert gases like nitrogen or 'noble' gases any leakage is again an energetic loss, and also an economic loss, as the leaked gas represents an economic value, and a direct environmental impact (which depends on the type of gas that escapes and its environmental properties).

For other process gases, which may be hazardous, toxic, flammable etc., the same energetic and economic losses apply, but the direct environmental impact may also be significant. Methane for instance is a gas that is many times a more potent greenhouse gas than carbon dioxide. Leakage through sealings may represent direct environmental impacts. Opportunities exist to reduce this leakage by applying tighter sealings and bearings.

As an example the EPD of the STC-ECO 6.2 MW turbo compressor states:

"This compressor is hermetically sealed and canned as it is designed for compressing hazardous and toxic gases. All pressure barriers towards environment are established over double sealing elements which are highly resistant towards explosive decompression. This concept results in zero process gas emissions. Compared with a single-shaft compressor with conventional sealing technology and flaring of propane and methane, the STC-ECO avoids the emission of 27,200t of CO₂ over its lifetime¹⁰⁸"

The quantification of such direct losses however could not be completed as too little information exists on the exact number of plants, the gases they process and the leakage that may be allocated to these plants. It may be possible to extract this kind of information for specific sites, but an overall picture could not be produced.

4.4 Transport during use

During use a number of annual service and maintenance visits are assumed. No data sources have been identified that describe average transport distances for service and maintenance.

Therefore, an annual transport distance of 3000 km is assumed. This is to be multiplied with the product life to get the total life transport distance.

¹⁰⁸ Based on 6.2MW model, 25 years assumed lifetime

5 Use-phase (system)

This paragraph is to identify and describe the functional compressor system and to identify and possibly quantify those products features that can reduce the environmental impact not only of the product but of the system as a whole. The scope of the system analysis is restricted only to issues that can be influenced by technical features of the compressor.

Note that the electric motor, transmission and motor control (including variable speed drive or similar) are included in the definition of the compressor, as well as equipment included in the package as placed on the market (may include inlet/outlet valves, inter/final cooling, oil/water separators, etc.). The product is therefore an 'extended product' according the interpretation in the study tender specifications.

The system as intended in this section extends beyond the (extended) product and includes the remaining compressed air (process gas) system. The latter remark means that compressor control options are included, but that other compressor system aspects not influenced by the compressor design itself, are not included.

In Task 7, indicative savings at system level are presented.

6 End-of-life phase

This section aims to describe considerations regarding end-of-life of materials flow¹⁰⁹ for:

- Handling as pure waste (landfill, pyrolytic incineration);
- Heat recovery (non-hazardous incineration optimized for energy recovery)
- Re-use or closed-loop recycling

Section 2 of this Task 4 shows that some 80% to over 90% of the compressor material composition are metals, some of which representing high scrap values (copper, high alloy steel). In Task 3 it is therefore assumed that compressors will most likely end-up in metal scrap dealers because of the economic value of the scrap.

It is assumed that some dismantling takes place to sort the various metal fractions and obtain the highest possible scrap values. During this it is assumed that non-metal fractions are separated from metallic fractions and send to separate disposal routes: for plastics it is assumed that the fraction is most likely to end up in a waste incineration facility with energy recovery.

Electronics are assumed to be dismantled and send to specialist electronics recyclers as these also represent economic value (presence of precious metals).

Following the conclusions of Task 3, section 4, it is assumed that:

- the metal fraction (ferrous and non-ferrous) is recycled for 99%;
- the plastics fraction is incinerated with heat recovery for 50% and without heat recovery for 50%;
- other inert materials like ceramics (stone or glass wool for insulation) are landfilled;
- special fractions like electronics are assumed to be dismantled and are incinerated without heat recovery.

¹⁰⁹ At least for plastics and electronics, as defined in the EuP EcoReport. For metals and glass this may also be indicated if the recycling percentage is less than 95%.

Ecodesign Preparatory Study on

Electric motor systems / Compressors

ENER Lot 31

FINAL Report Task 5

Definition of Base-cases



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Prepared *for the European Commission*

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1 Introduction to Task 5

1.1 Scope

This is the final report of Task 5 of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **‘ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives’.**

The aim of this Task 5, in accordance with the tender specifications¹¹⁰, is to describe the (environmental) impacts of products.

1.2 Subtasks for Task 5

The definition of the base cases in this study requires addressing the following points.

Subtask 5.1 – Product specific inputs

This includes, where relevant:

- Avg. EU product weight and Bill-of-Materials (BOM), distinguishing materials fractions (weight) at the level of the EuP EcoReport Unit Indicators as proposed in the MEEuP report, this includes packaging materials;
- Primary scrap production during sheet metal manufacturing (avg. EU);¹¹¹
- Volume and weight of the packaged product avg. EU;
- Annual resources consumption (energy, water) and direct emissions¹¹² during product life according to the test standard defined in subtask 1.2;
- Annual resources consumption (energy, water) and direct emissions during product life according to the real-life situation as defined in subtask 3.2;
- Selected EU scenario at end-of-life of materials flow¹¹³ is:
 - Disposal (landfill, pyrolytic incineration);
 - Thermal recycling (non-hazardous incineration optimised for energy recovery)
 - Re-use or Closed-loop recycling.

Note: the above information has been collected under Task 4.

Subtask 5.2 – Base-case Environmental Impact Assessment

Using the VHK EuP EcoReport indicates the environmental impact analysis, specifying:

- Emissions/ resources categories as mentioned in the MEEuP report and other significant aspects not addressed in the EcoReport such as noise;

For:

- Raw materials use and manufacturing;

¹¹⁰ European Commission, Tender specifications ENER/C3/410-2010, which are the basis for the study.

¹¹¹ Necessary input into the EuP EcoReport

¹¹² This only relates to emissions that are not already taken into account in the VHK EcoReport Unit Indicators

¹¹³ At least for plastics and electronics, as defined in the EuP EcoReport. For metals and glass this may also be indicated if recycling percentage is less than 95%.

- Distribution;
- Use;
- and End-of-Life phase.

Subtask 5.3 Base-Case life Cycle Costs

Combining the results from Task 2 and 3 in order to define the life cycle costs.

Note: The Life Cycle Costs calculation is presented in Task 7 (product level) and Task 8 (EU level)..

Subtask 5.4 – EU totals

Aggregate the real-life base-case environmental impact data (Subtask 5.2) and the life cycle costs data (Subtask 5.3) to EU-27 level, using stock and market data from task 2, indicating:

- A. The life cycle environmental impact and total LCC of the new products designed in 2005 (this relates to a period of 2005 up to 2005 + product life)
- B. The annual (2005) impact of production, use and (estimated) disposal of the product group, assuming post-RoHS and post-WEEE conditions.¹¹⁴

Subtask 5.5 – EU-27 Total systems impact

Using the estimates of task 4 to estimate the total environmental impact of the product system and compare with outputs from input/ output analysis.

¹¹⁴ BAU scenario to be based on this assumption

2 Product specific inputs

2.1 Definition of the base cases

This section describes the inputs for the base cases that form the reference for the environmental and technical/ economical improvements to be identified in Task 6, 7 and 8.

According the MEeRP¹¹⁵ (the methodology underlying the preparatory study) Task 5 requires that one or more average EU product (s) have to be defined or a representative product category as the “Base-case” for the whole of the EU-27 has to be chosen. On this Base-Case most of the environmental and Life Cycle Cost analyses will be built throughout the rest of the study. The Base-Case is a conscious abstraction of reality, necessary one for practical reasons. Having said that, the question if this abstraction leads to inadmissible conclusions for certain market segments will be addressed in the impact- and sensitivity analysis.

Anticipating subtask 5.2 and in line with Task 2, this chapter will make the assessment for the following BaseCases.

Table 59: Overview of base cases

Application range	base case	Typical technology	BOM based on:	base case
Standard air compressor	average fixed speed compressor	screw, vane	Generic rotary compressor	BC1_A
	average variable speed compressor	screw, vane	Generic rotary compressor	BC1_B
	average piston compressor	piston	Generic reciprocating compressor	BC1_C
Low pressure compressor	Low pressure compressor	lobe, turbo, screw, etc.	Generic rotary compressor	BC2
Oilfree/ non-lubricated air compressor	Oilfree/ non-lubricated air compressor	turbo, piston, screw	Generic rotary compressor	BC3
process gas / inert gases	Turbo (Nitro/ air) compressor	turbo	Generic turbo compressor	BC4
	Rotary lobe / air compressor	lobe	Generic rotary compressor	BC5
Process gas / hazardous gases	Piston compressor	piston	Generic reciprocating compressor	BC6
	turbo (Other gasses) compressor	turbo	Generic turbo compressor	BC7
	Screw/oil-free compressor	screw	Generic rotary compressor	BC8
	Screw/oil-injected compressor	screw	Generic rotary compressor	BC9
	Rotary lobe / other gas compressor	lobe	Generic rotary compressor	BC10

2.2 Manufacturing phase (BOMs)

The material composition is described by the 'bill of materials' (BOM). The BOMs are constructed on the basis of the data supplied in previous tasks and supplementary data from PNEUROP. The table on the landscape pages following these sections give the inputs that will be used for the environmental impact assessment, and EU Totals.

¹¹⁵ See http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/index_en.htm

The material inputs do not present information on the use of 'critical raw materials' by compressors, as such information has not been shown to be available during the course of the study.

However, it is known that (an unknown percentage of) compressors may use high efficiency electric motors, among which permanent magnet motors. The use of such motors is often associated with the use of critical raw materials such as dysprosium and neodymium¹¹⁶, but the actual quantities of the materials used by compressors could not be assessed.

2.3 Manufacturing phase

The inputs required to assess the environmental impacts for the manufacturing phase are generated by default by the EcoReport. As metal scrap percentage we use the default 25%. Note that for plastics the manufacturing impacts are included in the materials.

2.4 Distribution phase

The EcoReport requires the product volume as an input for transportation and warehouse impacts. These have been estimated as follows.

2.5 Use phase

The environmental impacts in the use phase consist of:

- Electricity consumption
- Consumables (oil, filters), with possible result oil in medium;

Of these inputs during the use phase only energy consumption could be quantified as not enough data is gathered/available to quantify the other effects.

Indeed heat recovery would affect/reduce the energy consumption of related energy systems, such as energy for space heating or water heating. At the moment recovery of heat is not quantified in this assessment due to lack of data.

Material inputs related to maintenance and servicing have been included in the production phase. Energy inputs for maintenance and servicing have been neglected.

2.5.1 Noise

Compressors emit significant levels of noise. Most, if not all, compressors covered by the application ranges considered are machinery, and manufacturers have an obligation, following the Machinery Directive 2006/42/EC, to reduce the noise levels as much as feasible.

Directive 2006/42/EC Annex I, Item 1.5.8. states: *"Machinery must be designed and constructed in such a way that risks resulting from the emission of airborne noise are reduced to the lowest level, taking account of technical progress and the availability of means of reducing noise, in particular at source"*.

2.6 End-of-life phase

For the End-of-Life the EcoReport default scenario is assumed, as no indications have been received to alter the default values. Commercial and industrial compressors are not mentioned in the scope of RoHS or WEEE

Table 60: Default EOL scenario

Landfill (not recovered)	9% of total weight
--------------------------	--------------------

¹¹⁶ Several sources, among which:
http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall-2011/_html_en/raw-materials.html

Incinerated	3% of total weight
EoL mass fraction to re-use, in %	1% of plastics fraction
EoL mass fraction to (materials) recycling, in %	85 % of plastics fraction
EoL mass fraction to (heat) recovery, in %	2 % of plastics fraction
Metals & Misc.	95% recycled (value already incorporated)

The total combined Ecoreport inputs are shown below.

Table 61: Life cycle inputs for all base cases

Base cases	Unit	1. Standard air / Fixed speed OIS/OIV	1. Standard air / Variable speed OIS/OIV	1. Standard air / Piston	2. Low pressure compressor	3. Oilfree	4. Process-inert / Turbo	5. 4. Process-inert / Rotary lobe	6. Process-other/ Piston	7. 6. Process-other/ Turbo	8. 6. Process-other/ Screw/oil-free	9 Process-other/. Screw/oil-6. injected	10. process-other/ Rotary lobe
Material inputs													
Steel	kg	314	430	98	524	1.854	99.4 13	1.983	2.923	126.95 3	8.427	7.405	1.164
Iron	kg	171	233	11	231	816	3.13 9	873	1.286	4.009	3.708	3.258	512
Aluminium	kg	31	42	15	94	334	-	357	526	-	1.517	1.333	210
Copper	kg	29	40	5	31	111	2.09 3	119	175	2.673	506	444	70
Bulk plastics (LDPE/PP/PVC/ABS)	kg	1	1	6	21	74	-	79	117	-	337	296	47
Electronics	kg	0	0	0	21	74	-	79	117	-	337	296	47
Other	kg	34	46	12	25	89	-	95	140	-	405	355	56
Total	kg	579	792	147	1.052	3.724	104. 645	3.982	5.870	133.63 5	16.922	14.868	2.337
Manufacturing phase													
OEM Plastics Manufacturing (fixed)	kg	7,0	9,5	6,3	128	452	0	484	713	0	2056	1807	284
Foundries Fe/Cu/Zn (fixed)	kg	196,8	268,9	11,4	231	816	3139	873	1286	4009	3708	3258	512
Foundries Al/Mg (fixed)	kg	7,1	9,7	15,3	0	0	0	0	0	0	0	0	0
Sheet metal Manufacturing (fixed)	kg	308,7	421,9	95,6	587	2077	7115 9	2221	3274	90871	9439	8293	1304
PWB Manufacturing (fixed)	kg	0,2	0,3	0,0	0	0	0	0	0	0	0	0	0
Other materials (Manufacturing already included)	kg	60,0	82,0	19,1	107	378	3034 7	405	596	38754	1719	1511	237

Base cases	Unit	1. Standard air / Fixed speed OIS/OIV	1. Standard air / Variable speed OIS/OIV	1. Standard air / Piston	2. Low pressure compressor	3. Oilfree	4. Process-inert / Turbo	5. 4. Process-inert / Rotary lobe	6. Process-other/ Piston	7. 6. Process-other/ Turbo	8. 6. Process-other/ Screw/oil-free	9 Process-other/. Screw/oil-6. injected	10. process-other/ Rotary lobe
Sheet metal Scrap	kg	77,2	105,5	23,9	147	519	1779 0	555	819	22718	2360	2073	326
Distribution phase													
Is it an ICT or Cons. Electr. Product< 15kg?	-	No	No	No	No	No	No	No	No	No	No	No	No
Is it an installed appliance?	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Volume of packaged final product	-	3	4	2	4	6	14	6	6	15	9	8	5
Use phase													
Product life	yrs	12	12.5	10	15	20	30	20	35	30	20	20	20
Power input	kW	25.9	35.4	4.4	46	189	8039	203	314	10582	1033	893	112
Operating hours (corrected load factor and sales segments applied)	hrs/a (corrected)	3450	2250	650	4800	4640	6400	4640	4240	6400	3886	3886	3886
Energy consumption	kWh/yr	89355	79650	2860	218750	875000	5145 2381	943396	133333 3	67722 222	40153 85	34720 00	51851 9
End-of-life phase													
Disposal													
Landfill	kg	52,2	71,3	13,3	94,3	333,8	9418	356,9	526,2	12027, 1	1516,9	1332,8	209,5
Incineration	Kg	17,4	23,8	4,4	31,4	111,3	3139	119,0	175,4	4009	505,6	444,3	69,8
Re-use, Recycling Benefit													
EoL mass fraction to reuse	Kg	5,8	7,9	1,5	10,5	37,1	1047	39,7	58,5	1336,3	168,5	148,1	23,3
EoL mass fraction to (materials) recycling	Kg	492,7	673,4	125,5	890,7	3152,6	8894 8	3371,0	4969,7	11358 9,3	14326, 7	12587, 7	1978,9
EoL mass fraction to (heat) recovery	kg	11,6	15,8	3,0	21,0	74,2	2093	79,3	116,9	2672,7	337,1	296,2	46,6

3 Base-Case environmental impact assessment

3.1 Environmental impact base cases

Ecoreports for all ten Base Cases were calculated, using the inputs given in the previous chapters. The table below summarizes the outcome for all the base cases.

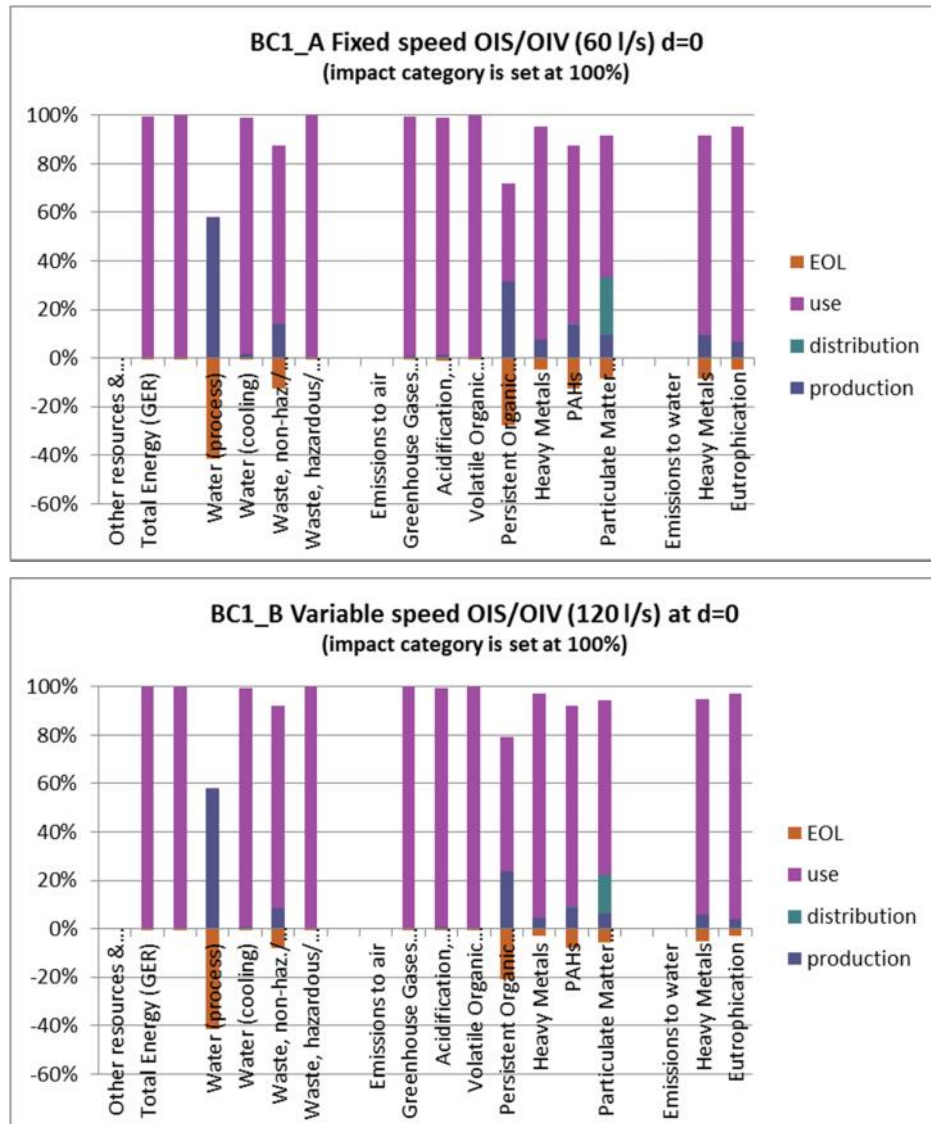
Table 62: Environmental impact base case units over lifetime per unit

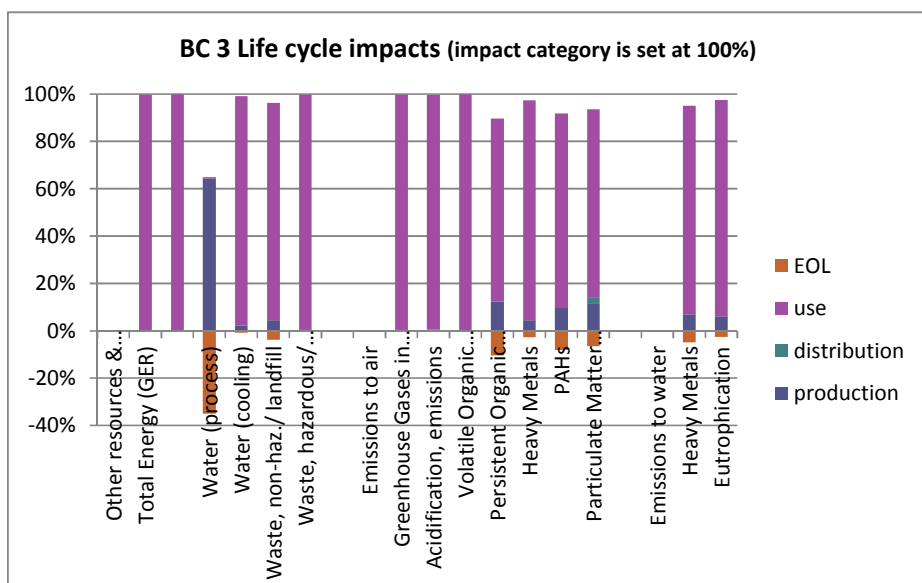
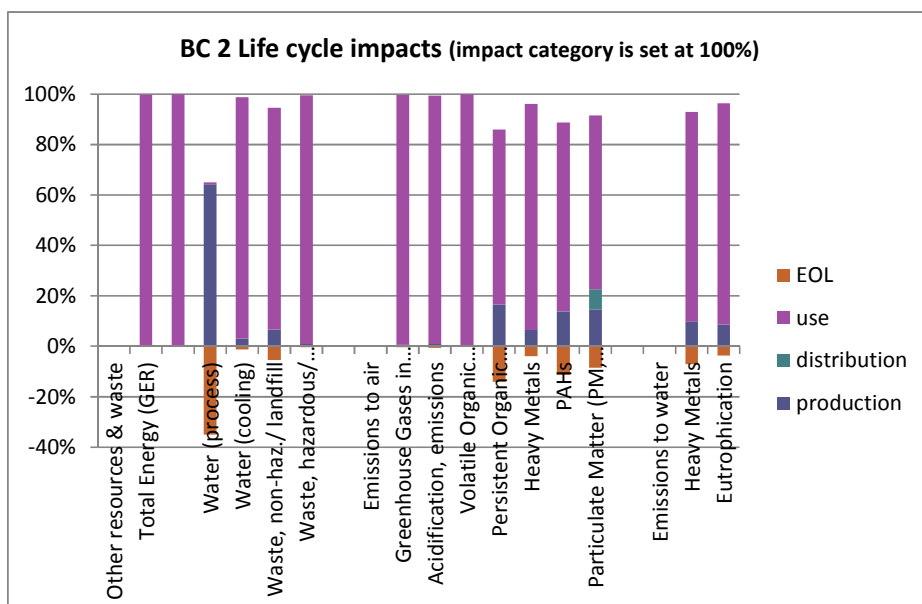
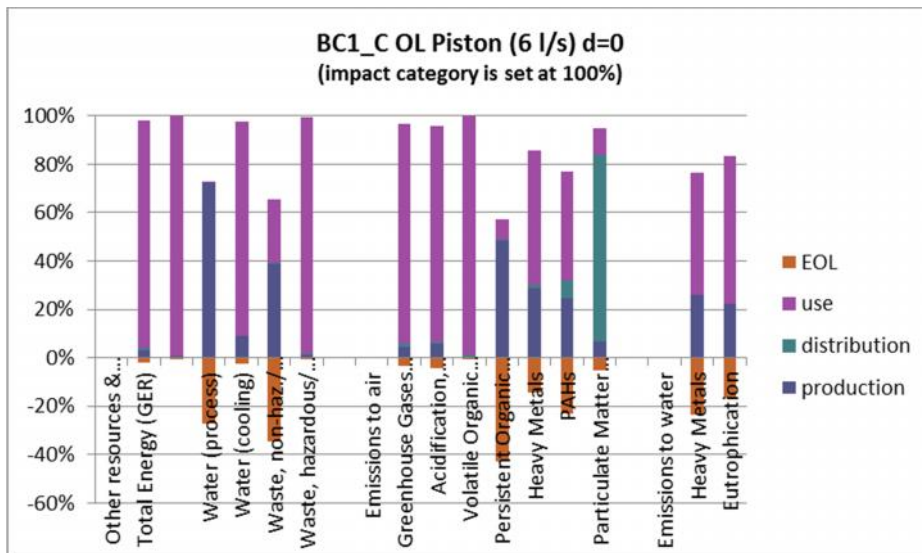
Base cases	Unit	1. Standard air / Fixed speed Oils/OIV	1. Standard air / Variable speed Oils/OIV	1. Standard air / Piston	2. Low pressure compressor	3. Oilfree	4. Process-inert / Turbo	5. 4. Process-inert / Rotary lobe	6. Process-other / Piston	7. 6. Process-other / Turbo	8. 6. Process-other / Screw/oil-free	9 Process-other / Screw/oil-6. injected	10. process-other / Rotary lobe
Resource consumption													
Total	kg	544,2	792,2	147,7	1.048	3.709	104.645	3.966	5.847	133.635	16.855	14.809	2.328
to disposal	kg	34,2	46,7	13,9	126	445	12.557	476	702	16.036	2.023	1.777	279
to recycling	kg	510,1	753,5	135,0	922	3.264	92.088	3.490	5.145	117.598	14.832	13.032	2.049
Other Resources & Waste													
Total Energy (GER)	GJ	9.661,8	9.374,5	262,4	29.588	157.692	13.893.695	170.016	420.300	18.286.980	723.626	625.712	93.455
of which, electricity (in primary GJ)	GJ	9.654,2	9.364,2	258,7	29.561	157.605	13.892.907	169.924	420.166	18.285.976	723.249	625.381	93.400
Water (process)	ltr	294,7	402,8	50,8	8.487	30.040	81.386	32.121	47.353	103.932	136.511	119.940	18.856
Water (cooling)	ltr	431.543,3	419.557,4	12.232,3	1.338.109	7.090.641	617.744.881	7.644.091	18.809.549	813.070.602	32.534.984	28.137.908	4.205.044
Waste, non-haz./ landfill	kg	5.048,7	4.926,2	156,4	15.416	81.859	7.175.307	88.251	217.532	9.443.585	375.612	324.826	48.534
Waste, hazardous/ incinerated	kg	152,5	148,0	4,1	468	2.494	219.188	2.688	6.640	288.498	11.442	9.895	1.478
Emissions (Air)													

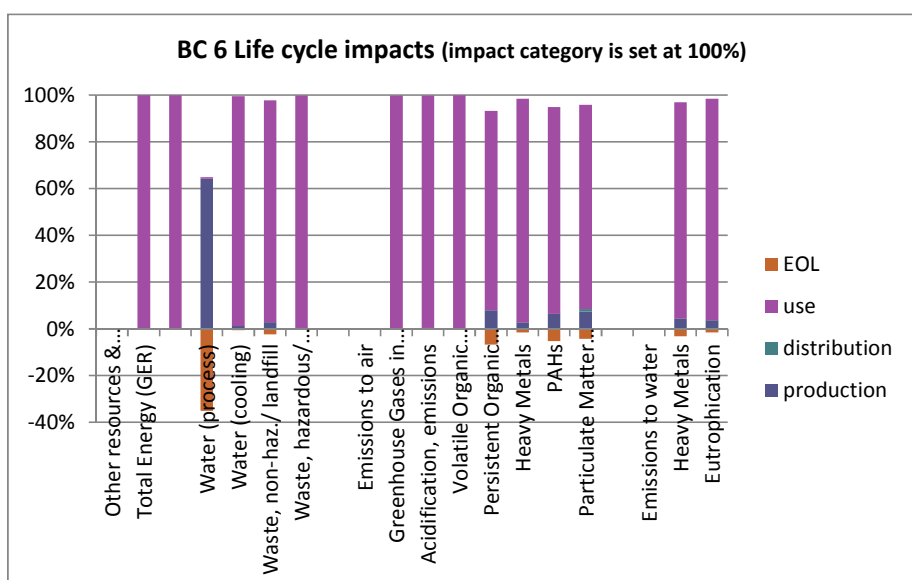
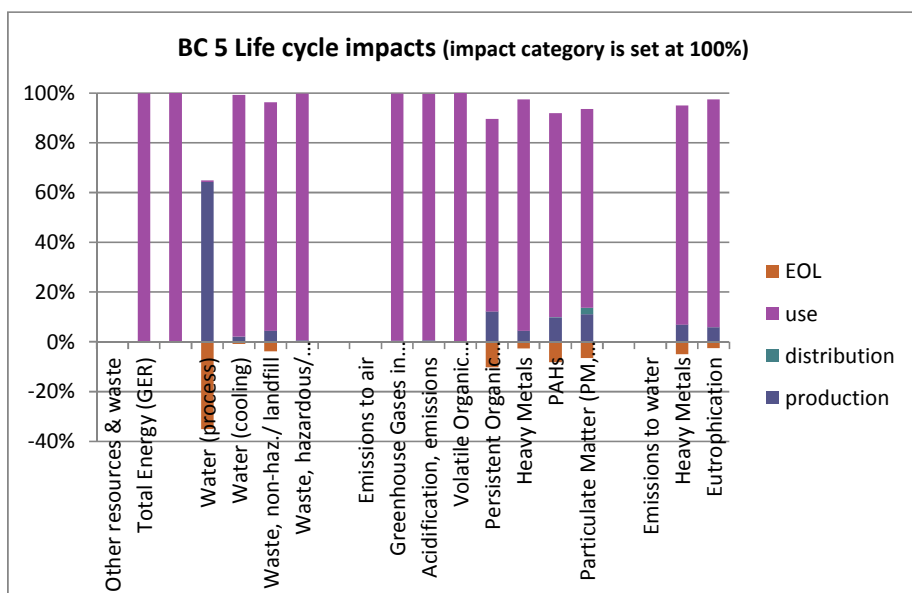
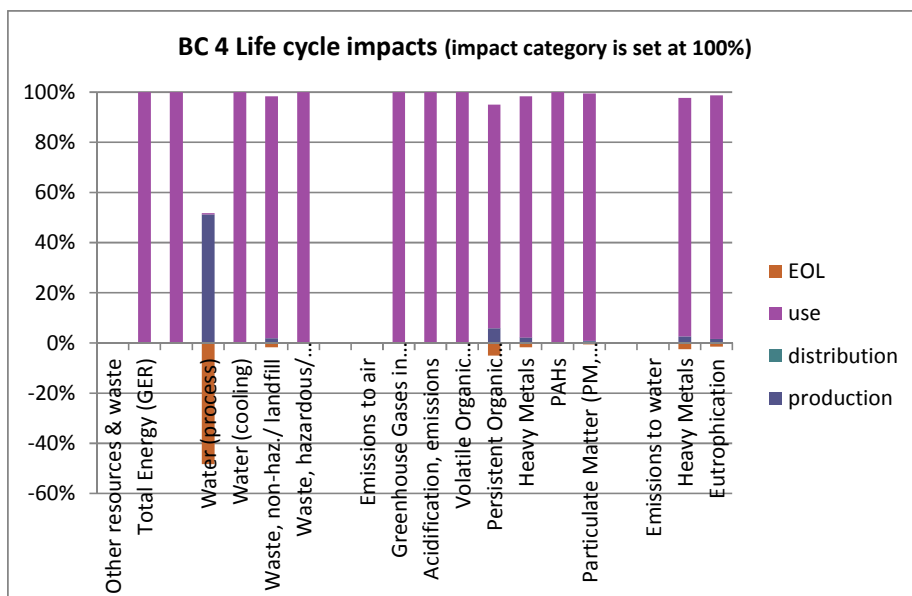
Base cases	Unit	1. Standard air / Fixed speed OIS/OIV	1. Standard air / Variable speed OIS/OIV	1. Standard air / Piston	2. Low pressure compressor	3. Oilfree	4. Process- inert / Turbo	5. 4. Process- inert / Rotary lobe	6. Process- other / Piston	7. 6. Process- other / Turbo	8. 6. Process- other / Screw/oil- free	9 Process- other / Screw/oil-6. injected	10. process- other / Rotary lobe
Greenhouse Gases in GWP100	kg CO ₂ eq.	412.627,5	400.429,8	11.280,6	1.263.597	6.733.242	593.102.240	7.259.443	17.944.066	780.644.188	30.897.263	26.716.700	3.990.506
Acidification, emissions	kg SO ₂ eq.	1.825,9	1.771,9	49,7	5.597	29.815	2.624.521	32.145	79.435	3.454.407	136.816	118.305	17.671
Volatile Organic Compounds (VOC)	kg	215,6	209,1	5,8	660	3.518	310.261	3.793	9.381	408.368	16.143	13.959	2.085
Persistent Organic Pollutants (POP)	ng i-Teq	23.992,8	23.853,6	1.052,0	71.494	376.636	32.723.139	405.994	994.393	43.058.494	1.727.932	1.494.677	223.516
Heavy Metals	g Ni eq.	99,8	97,7	3,3	307	1.624	141.078	1.750	4.296	185.665	7.449	6.443	963
PAHs	g Ni eq.	22,9	22,3	0,7	71	376	32.417	405	993	42.668	1.725	1.492	223
Particulate Matter (PM, dust)	kg	49,4	51,8	8,0	143	689	55.690	741	1.761	73.285	3.098	2.682	415
Emissions (Water)													
Heavy Metals	mg Hg/20	41.873,3	40.740,6	1.168,8	131.441	693.260	59.911.954	747.313	1.832.021	78.852.417	3.180.680	2.751.221	411.358
Eutrophication	g PO ₄	1.850,9	1.806,1	52,8	5.895	30.870	2.628.350	33.273	81.098	3.459.297	141.611	122.519	18.333

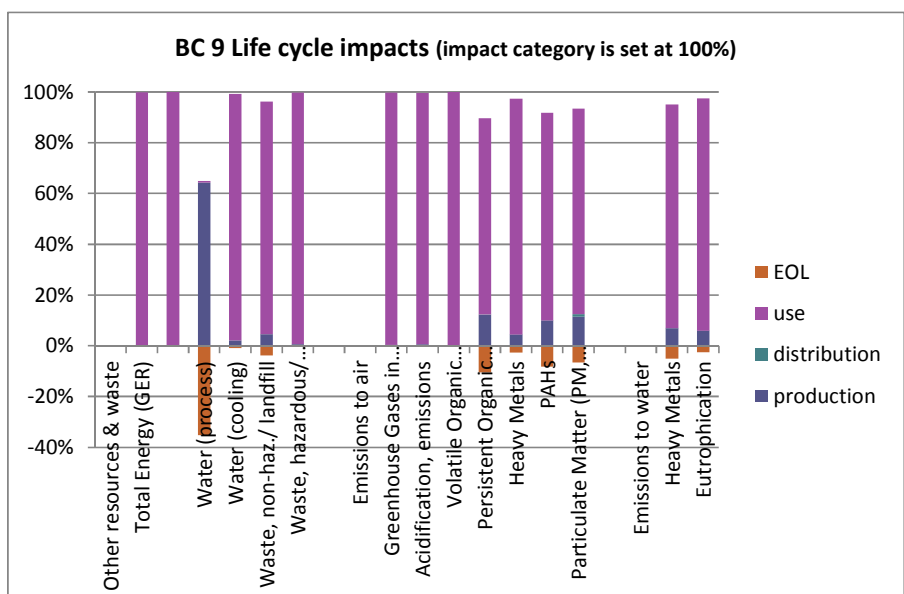
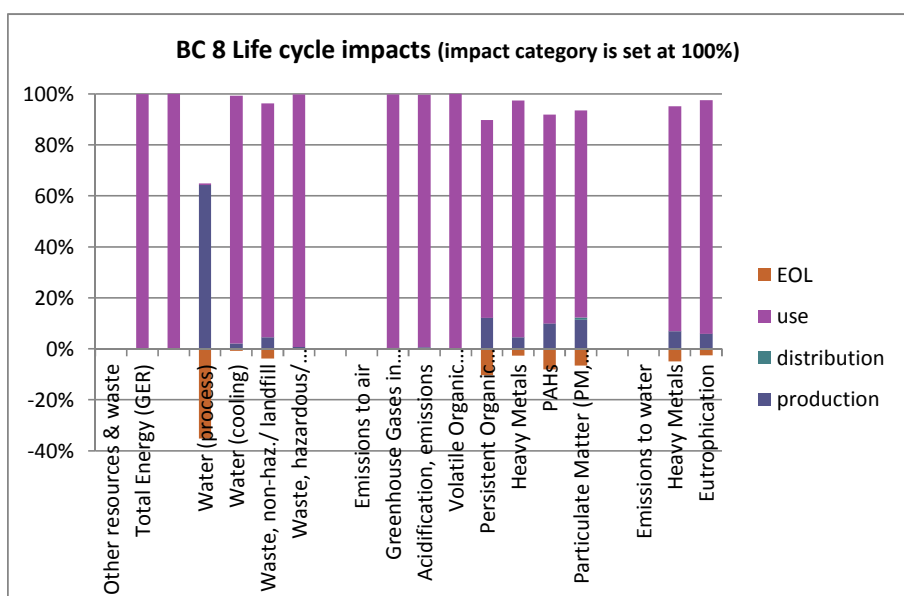
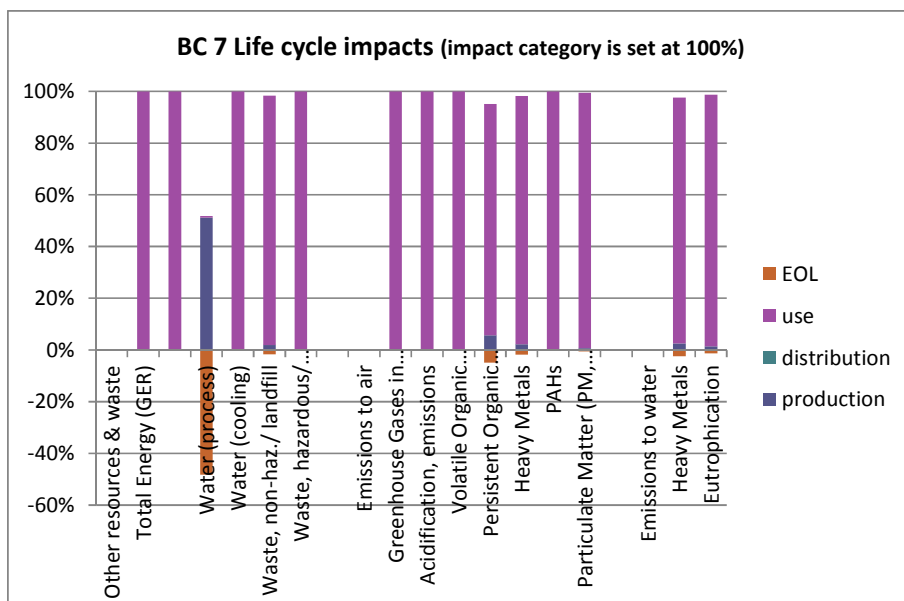
The figures below present the same information in graphic charts, whereby the impact category total is set to 100% (if expressed per life cycle phase means negative value is possible, if the net effect is a reduction of the impact).

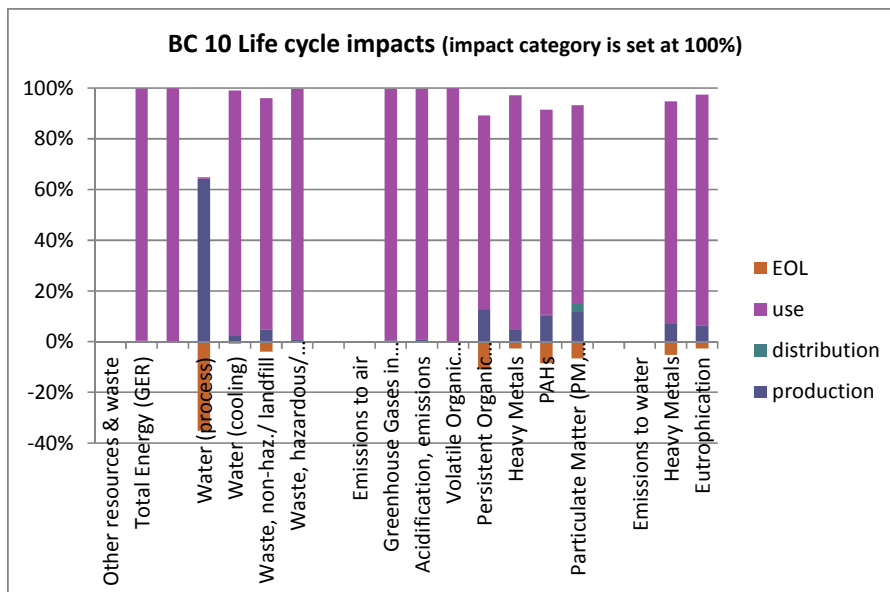
Figure 75: Life cycle impacts per base case











3.2 Sensitivity analysis of main base cases

For the single most important application range 'standard air' a sensitivity analysis has been performed to investigate the robustness of conclusions in case major parameters are changed.

This sensitivity analysis is performed at the level of the three sub-base cases:

- fixed speed OIS/OIV;
- variable speed OIS/OIV;
- OL pistons.

The parameters that are varied are:

- Size: for each sub-base case a smaller and larger product is assessed (needless to say that product life and energy consumption vary as well, because of the size change)
- Product life: for each of the three sub-base cases a variant assuming longer product life has been calculated.

The following figures show the sensitivity of these sub-base cases regarding size

3.2.1 Sensitivity of sub-base case regarding size

Table 63 Sensitivity of fixed speed OIS/OIV regarding size

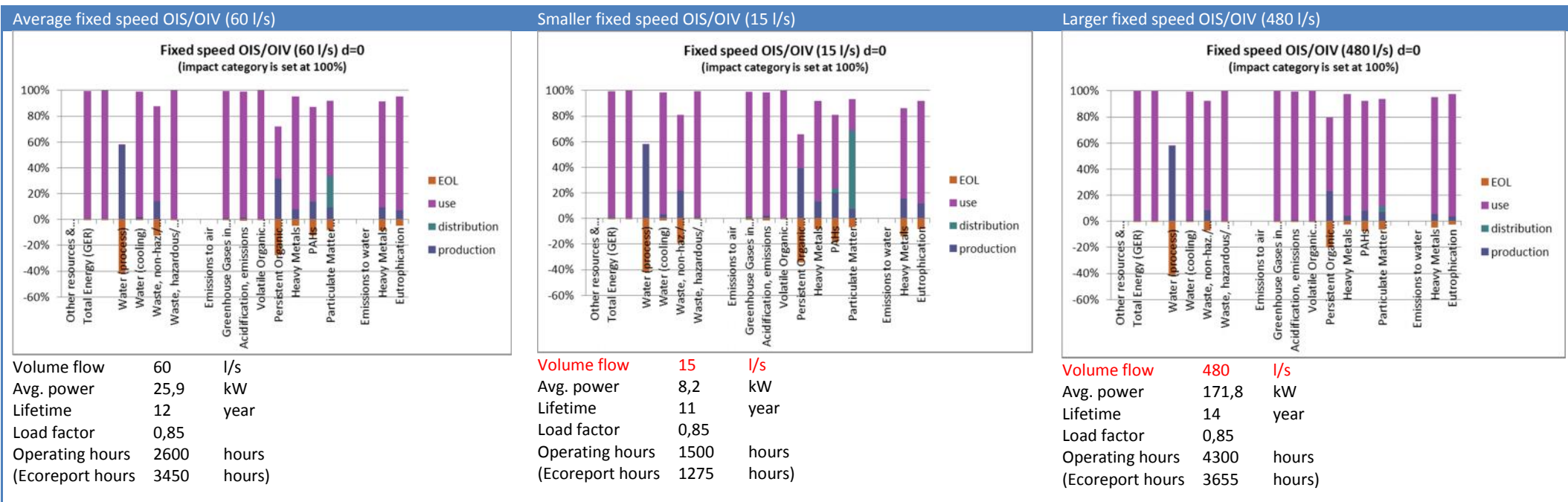
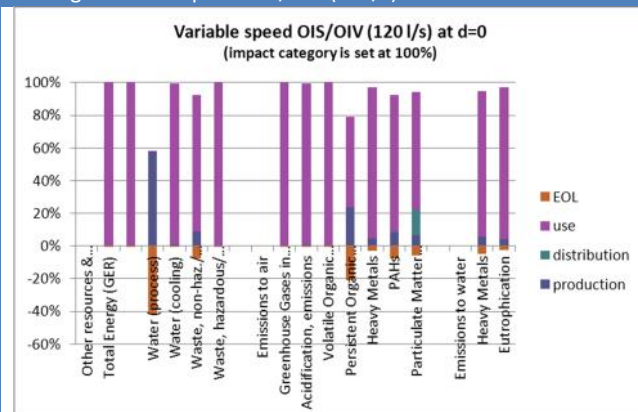


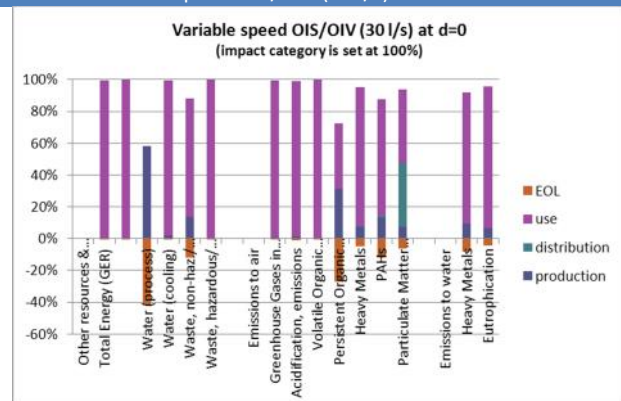
Table 64 Sensitivity of variable speed OIS/OIV regarding size

Average variable speed OIS/OIV (60 l/s)



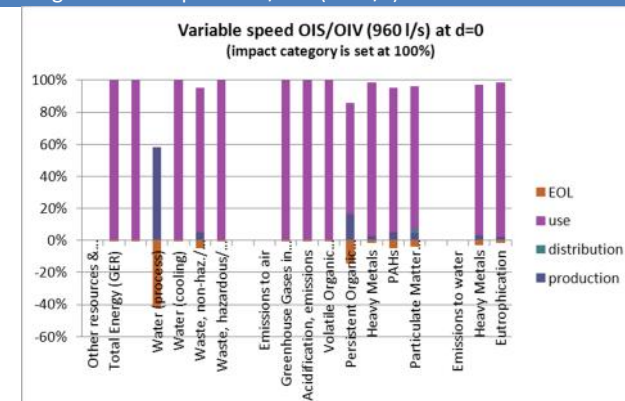
Volume flow 120 l/s
 Avg. power 35.4 kW
 Lifetime 12.5 year
 Load factor 1
 Operating hours 3900 hours
 (Ecoreport hours 2350 hours)

Smaller variable speed OIS/OIV (15 l/s)



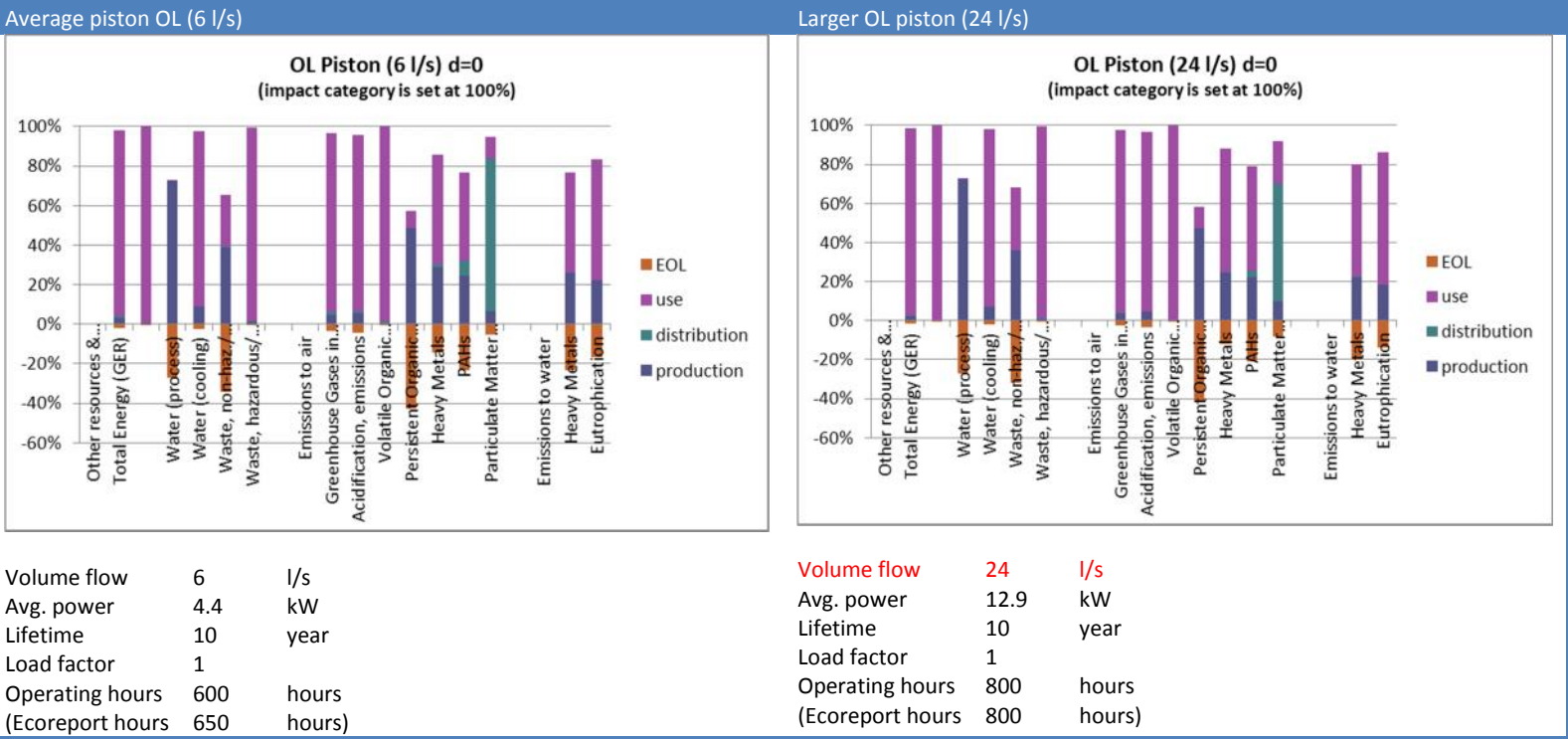
Volume flow 30 l/s
 Avg. power 11.8 kW
 Lifetime 11.5 year
 Load factor 1
 Operating hours 2400 hours
 (Ecoreport hours 2400 hours)

Larger variable speed OIS/OIV (480 l/s)



Volume flow 960 l/s
 Avg. power 221.1 kW
 Lifetime 14.5 year
 Load factor 1
 Operating hours 6000 hours
 (Ecoreport hours 6000 hours)

Table 65 Sensitivity of OL piston regarding size



3.2.2 Sensitivity of sub-base case regarding product life

Table 66 Sensitivity of fixed speed OIS/OIV regarding size

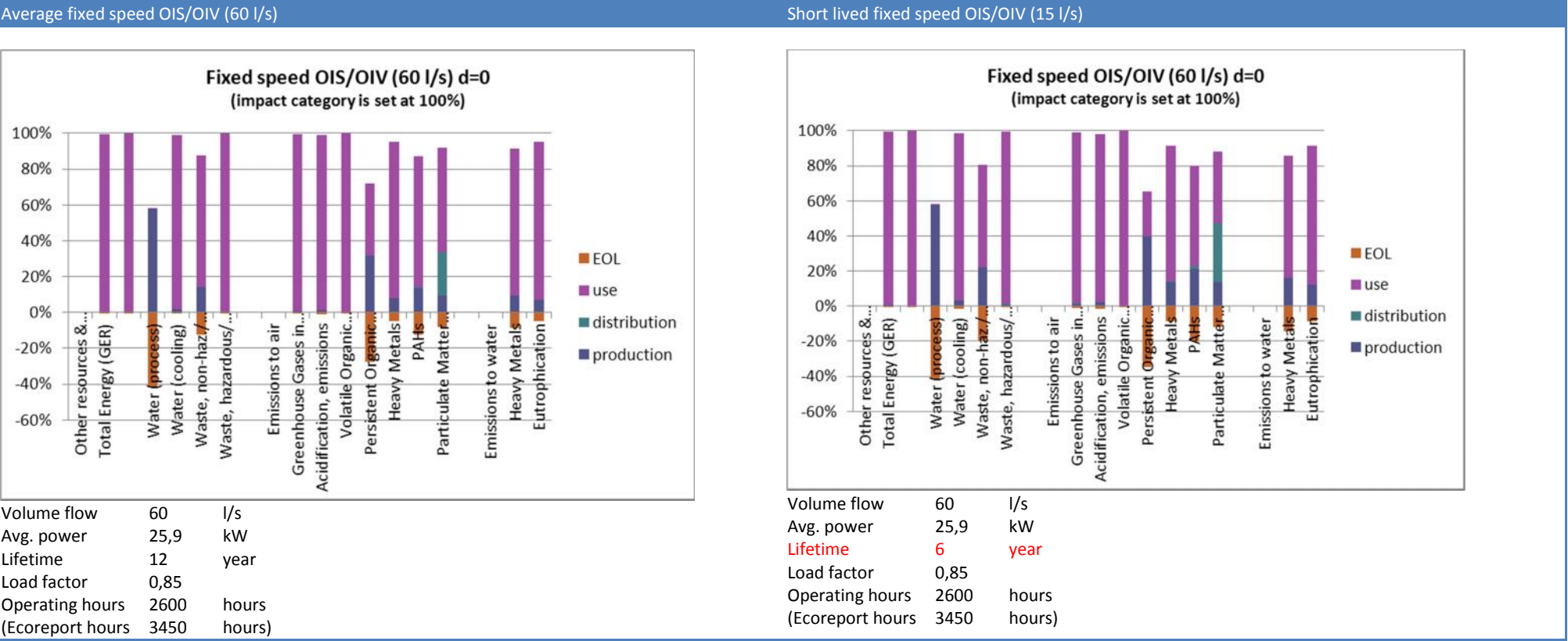


Table 67 Sensitivity of variable speed OIS/OIV regarding size

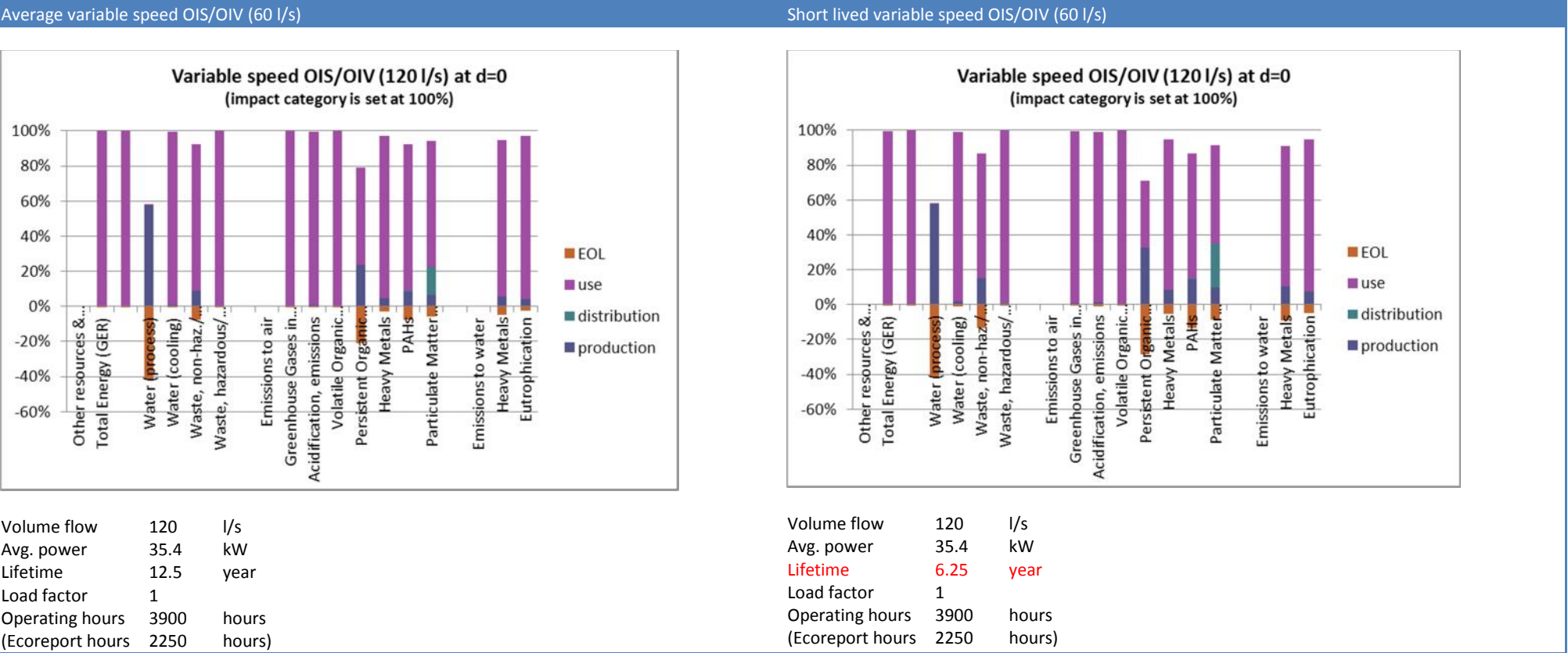
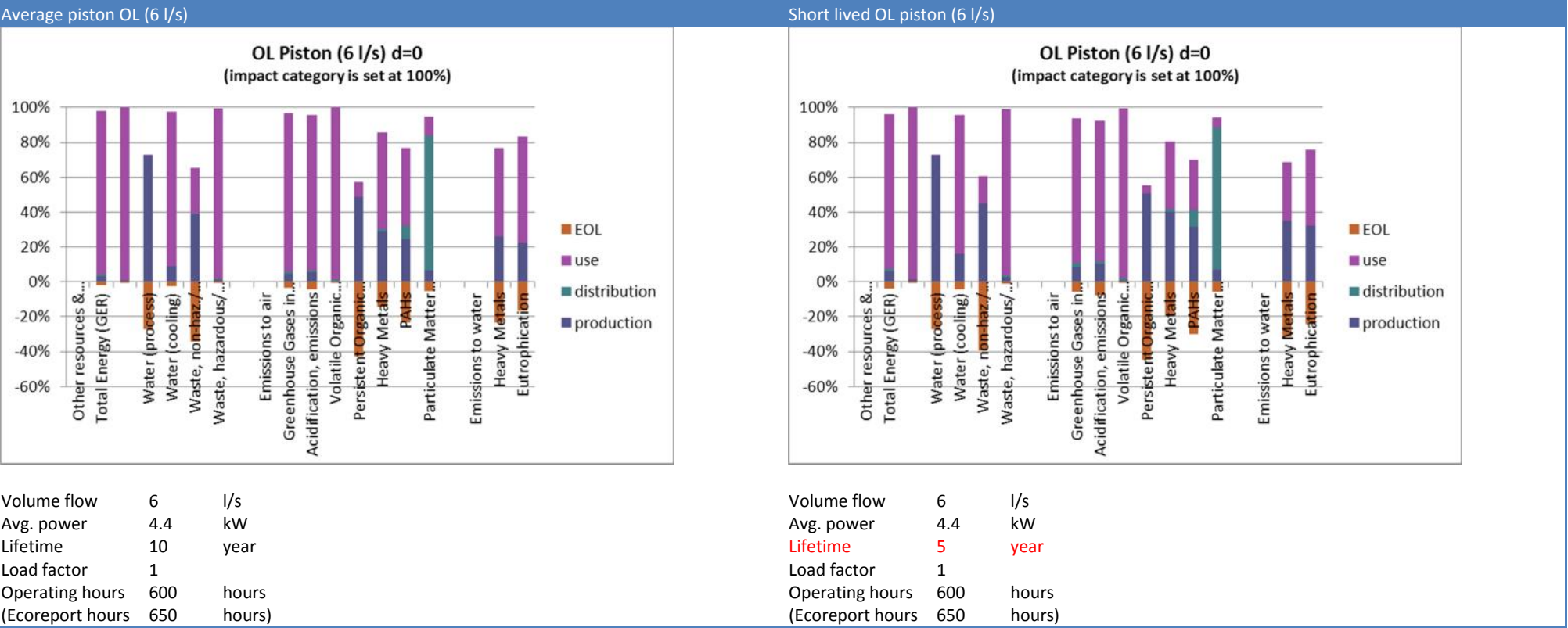


Table 68 Sensitivity of OL piston regarding product life



3.3 Conclusions on environmental impact

The above assessment shows that the main life cycle impact of the products occurs during the use phase, and is associated with the **energy consumption during use**. The main relevant product parameter is therefore the energy efficiency of the product.

Impacts related to production can be traced back to the extensive use of (alloyed and unalloyed) steel and non-ferro metals in these products. The relevant product parameter is the use of such materials.

The distribution phase has an impact on particulate matter, as transport is assumed to occur by means of diesel-driven trucks mainly. The relevant product parameter is the mass and volume of the shipment.

The end-of-life phase shows (positive) impacts in categories where production phase has large impacts as well, signifying the relevance of recovery and recycling. The relevant product parameter is the use of such materials and their recovery/recycling.

Considering the above, it is decided to focus the Task 6, 7 and 8 analysis on improving the energy efficiency of the product.

The sensitivity analysis shows that this conclusion is robust for both changes in compressor size (smaller and larger) and changes in product life (for reduced product life): The sensitivity analysis confirms the dominance of the energy consumption in the use-phase in the overall environmental impacts of products.

Although the sensitivity analysis is only performed for sub-base cases in the standard air application range, it is expected that the same conclusion would apply to products in the other application ranges.

Aspects not captured in above assessment

The above environmental assessment does not include a quantitative assessment of use of **critical raw materials** or **hazardous substances** possibly present in the products.

Certain stakeholders to this study have presented or pointed towards information that discuss issues related to use of critical raw materials and/or hazardous substances. The information, although being very informative, does not allow a quantitative assessment of these aspects applied when to compressors. As said before, no bill-of-materials could be produced that contained this level of detail (at level of substance analysis).

This does not mean the issue should be ignored. However, instead of making the use of critical raw materials and/or hazardous substances a focal point of the subsequent improvement option analysis, it is recommended to cover the issues related to use of critical raw materials and/or hazardous substances at a horizontal level, and not confine it to electric driven compressors only, as the issue is just as relevant for other motor driven , electric/electronic equipment. This horizontal approach is already applied by various measures (REACH, RoHS and WEEE).

3 Base-Case Life Cycle Costs

The base case life cycle costs for the standard air application range have been reported under Task 7 (product level) and Task 8 (EU level)

4 EU Totals

This section describes the impacts of the base cases at EU level.

4.1 New products

For all compressors put on the market and active in the installed base the following energy consumption has been calculated.

Table 69: Life cycle impacts of new products place on market

	SALES (EU-27)	Stock	Energy consumption, Sales (TWh)	Energy consumption, stock (TWh)
1. Standard air compressor	105 800	1153000	4,9	60
Fixed speed OIS/OIV	45.200	615.000	4,04	48
Variable speed OIS/OIV	8.600	46.000	0,75	9
Piston	52.000	492.000	0,12	1,5
2. Low pressure compressor	12 800	192 000	2.800	42,0
3. Oil free/ non-lubricated air compressor	2 000	40 000	1.750	35,0
PROCESS/air-nitro-noble				
4. Turbo	14	420	0,720	21,6
5. Rotary lobe / air	13,3	265	0,013	0,25
PROCESS/other gases				
6. Piston	150	5 250	0,200	7,0
7. Turbo	12	360	0,813	24,4
8. Screw/oil-free	6,5	130	0,026	0,5
9. Screw/oil-injected	12,5	250	0,043	0,9
10. Rotary lobe / other gas	13,5	270	0,007	0,1
Total	138 384	2 089 375	11,3	190

The total life cycle impacts of base cases placed on the market as new products is as presented in the table below.

Table 70: Life cycle impacts of NEW products placed on the market

Materials	unit	1A Fixed OIS/OIV compressor	1B Var OIS/OIV compressor	1C Piston compressor	2. Low pressure compressor	3. Oilfree/ non-lubricated air compressor	4. Turbo (Air/nitro)
Total	kt	26,4	6,9	7,7	13	7	1
of which							
Disposal	kt	1,5	0,4	0,7	2	1	0
Recycled	kt	24,9	6,5	7	12	6	1
Other Resources & Waste							
Total Energy (GER)	PJ	436,71	80,62	13,65	380	316	195
of which, electricity (in primary PJ)	PJ	436,37	80,53	13,45	379	315	195

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Water (process)	mln. m ³	0,01	0	0	0	0	0
Water (cooling)	mln. m ³	19,51	3,61	0,64	17	14	9
Waste, non-haz./ landfill	kt	228,2	42,37	8,13	209	170	102
Waste, hazardous/ incinerated	kt	6,89	1,27	0,21	6	5	3
Emissions (Air)							
Greenhouse Gases in GWP100	Mt CO ₂ eq.	18,65	3,44	0,59	16	13	8
Acidification, emissions	kt SO ₂ eq.	82,53	15,24	2,59	72	60	37
Volatile Organic Compounds (VOC)	kt	9,75	1,8	0,3	8	7	4
Persistent Organic Pollutants (POP)	g i-Teq	1,08	0,21	0,05	1	1	0
Heavy Metals	ton Ni eq.	4,51	0,84	0,17	4	3	2
PAHs	ton Ni eq.	1,03	0,19	0,04	1	1	0
Particulate Matter (PM, dust)	kt	2,23	0,45	0,42	2	1	1
Emissions (Water)							
Heavy Metals	ton Hg/20	1,89	0,35	0,06	2	1	1
Eutrophication	kt PO ₄	0,08	0,02	0	0	0	0

(continued)

Materials	unit	5. Rotary lobe / air	6. Piston	7. Turbo (other gasses)	8. Screw/oil-free	9. Screw/oil-injected	10. Rotary lobe / other gas
Total	kt	0,05	1	2	0,1	0,2	0,03
of which							
Disposal	kt	0	0	0	0	0	0
Recycled	kt	0,05	1	2	0,1	0,2	0,03
Other Resources & Waste							
Total Energy (GER)	PJ	2	63	219	5	8	1
of which, electricity (in primary PJ)	PJ	2	63	219	5	8	1
Water (process)	mln. m ³	0	0	0	0	0	0
Water (cooling)	mln. m ³	0	3	10	0	0	0
Waste, non-haz./ landfill	kt	1	33	115	3	4	1
Waste, hazardous/ incinerated	kt	0	1	3	0	0	0
Emissions (Air)							
Greenhouse Gases in GWP100	Mt CO ₂ eq.	0	3	9	0	0	0
Acidification, emissions	kt SO ₂ eq.	0	12	41	1	1	0
Volatile Organic Compounds (VOC)	kt	0	1	5	0	0	0
Persistent Organic Pollutants (POP)	g i-Teq	0	0	1	0	0	0
Heavy Metals	ton Ni eq.	0	1	2	0	0	0
PAHs	ton Ni eq.	0	0	1	0	0	0
Particulate Matter (PM, dust)	kt	0	0	1	0	0	0

Emissions (Water)							
Heavy Metals	ton Hg/20	0	0	1	0	0	0
Eutrophication	kt PO ₄	0	0	0	0	0	0

4.2 Annual impact of production

The overall combined environmental impact for the products placed on the market as indicated below. It describes the production phase impacts of all products placed on the market (value similar to that presented for new products, combined with the impacts from energy consumption of not only the new products but also the other products already present in the field (installed base or stock energy consumption). It therefore represents the annual impacts of the complete product group, new and existing on the market.

Table 71: Annual impacts of all products NEW and EXISTING on the market

Materials	unit	1A Fixed OIS/OIV compressor	1B Var OIS/OIV compressor	1C Piston compressor	2. Low pressure compressor	3. Oilfree/ non-lubricated air compressor	4. Turbo (Air/nitro)
Total	kt	26,4	6,9	7,7	13	7	1
of which							
Disposal	kt	1,5	0,4	0,7	2	1	0
Recycled	kt	24,9	6,5	7	12	6	1
Other Resources & Waste							
Total Energy (GER)	PJ	437,65	80,86	13,91	380	316	195
of which, electricity (in primary PJ)	PJ	436,42	80,54	13,47	379	315	195
Water (process)	mln. m ³	0,05	0,01	0	0	0	0
Water (cooling)	mln. m ³	19,61	3,64	0,65	17	14	9
Waste, non-haz./ landfill	kt	252,76	48,75	16,57	209	170	102
Waste, hazardous/ incinerated	kt	6,91	1,28	0,21	6	5	3
Emissions (Air)							
Greenhouse Gases in GWP100	Mt CO ₂ eq.	18,72	3,46	0,61	16	13	8
Acidification, emissions	kt SO ₂ eq.	83,02	15,37	2,7	72	60	37
Volatile Organic Compounds (VOC)	kt	9,75	1,8	0,3	8	7	4
Persistent Organic Pollutants (POP)	g i-Teq	1,54	0,32	0,21	1	1	0
Heavy Metals	ton Ni eq.	4,67	0,88	0,2	4	3	2
PAHs	ton Ni eq.	1,15	0,22	0,05	1	1	0
Particulate Matter (PM, dust)	kt	2,39	0,49	0,44	2	1	1
Emissions (Water)							
Heavy Metals	ton Hg/20	2,02	0,38	0,09	2	1	1
Eutrophication	kt PO ₄	0,09	0,02	0	0	0	0

(continued)

Materials	unit	5. Rotary lobe / air	6. Piston	7. Turbo (other gasses)	8.Screw/oil-free	9. Screw/oil-injected	10. Rotary lobe / other gas
Total	kt	0,05	1	2	0,1	0,2	0,03
of which							
Disposal	kt	0	0	0	0	0	0
Recycled	kt	0,05	1	2	0,1	0,2	0,03
Other Resources & Waste							
Total Energy (GER)	PJ	2	63	219	5	8	1
of which, electricity (in primary PJ)	PJ	2	63	219	5	8	1
Water (process)	mln. m ³	0	0	0	0	0	0
Water (cooling)	mln. m ³	0	3	10	0	0	0
Waste, non-haz./ landfill	kt	1	33	115	3	4	1
Waste, hazardous/ incinerated	kt	0	1	3	0	0	0
Emissions (Air)							
Greenhouse Gases in GWP100	Mt CO ₂ eq.	0	3	9	0	0	0
Acidification, emissions	kt SO ₂ eq.	0	12	41	1	1	0
Volatile Organic Compounds (VOC)	kt	0	1	5	0	0	0
Persistent Organic Pollutants (POP)	g i-Teq	0	0	1	0	0	0
Heavy Metals	ton Ni eq.	0	1	2	0	0	0
PAHs	ton Ni eq.	0	0	1	0	0	0
Particulate Matter (PM, dust)	kt	0	0	1	0	0	0
Emissions (Water)							
Heavy Metals	ton Hg/20	0	0	1	0	0	0
Eutrophication	kt PO ₄	0	0	0	0	0	0

5 EU-27 total system impact

This section presents the total impacts of the product as a fraction of the EU-27 impacts. For this the normalisation factors as shown in the table below are used.

Table 72: Impacts for EU total (based on MEErP 2010)

Main life cycle indicators	EU totals	unit	Reference
Materials			
Plastics	48	Mt	Ref: Plastics Europe (demand by EU converters) [1]
Ferrous metals	206	Mt	Ref: Iron & Steel Statistics Bureau [1]
Non-ferrous metals	20	Mt	Ref: www.eaa.net et al. (Al 12,5+Cu 4,7 + Zn 0,8 + Pb 0,8 + Ni 0,3)
Other resources & waste			
Total Energy (GER)	75.697	PJ	Eurostat, Gross Inland Consumption EU-27, 2007, in Net Calorific Value
of which, electricity	2.800	TWh	Final end-use. Ref: Eurostat
Water (process)*	247.000	mln.m ³	Ref: http://ec.europa.eu/environment/water/quantity/pdf/exec_summary.pdf [1]
Waste, non-haz./ landfill*	2.947	Mt	Ref: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=Generation_of_waste,_total_arising_and_by_selected_economic_activities .
Waste, hazardous/ incinerated*	89	kton	
Emissions (Air)			
Greenhouse Gases in GWP100	5.054	mt CO ₂ eq.	Ref: EEA3 (CO ₂ 4187 + CH ₄ 416 + N ₂ O 374 + HFCs 63 + PFCs 4 + SF ₆ 10)
Acidifying agents (AP)	22.432	kt SO ₂ eq.	Ref: EEA1 (NO _x 11 151 + SO _x 7 339 + NH ₃ 3 876)
Volatile Org. Compounds (VOC)	8.951	kt	Ref: EEA1
Persistent Org. Pollutants (POP)	2.212	g i-Teq.	Ref: EEA1 (dioxins and furans only)
Heavy Metals (HM)	5.903	ton Ni eq.	Ref: EEA1 (Cd 118 + Hg 89 + Pb 2157 t); EEA2 (As 337 + Ni 2843 t); CML (Cr 517 + Cu 589 + Zn 6510 t)
PAHs	1.369	ton Ni eq.	Ref: EEA1
Particulate Matter (PM, dust)	3.522	kt	Ref: EEA1 (1400 kt PM _{2,5} + 2122 kt PM ₁₀)
Emissions (Water)			
Heavy Metals (HM)	12.853	ton Hg/20	Ref: CML (As 17+Cd 21,3 + Cr 271 + Cu 1690 + Pb 2260 + Hg 14,3 + Ni 551 t + Zn 11200 t)
Eutrophication (EP)	900	kt PO ₄	Ref: EEA2 (Baltic 861 N/5,4 P + North Sea 761 N/14,4 P + Danube/Black Sea 270 N/ 14,2 P)
*=caution: low accuracy for production phase			
EEA1, European Environmental Agency, National emissions reported to the Convention on Long-range Trans boundary Air Pollution (LRTAP Convention), EU-27 (national territory), 2007. (extract Feb. 2011)			
EEA2, Source apportionment of nitrogen and phosphorus inputs into the aquatic environment, 2005. [Compare: CML value for EU-15, 1995 is 1 263 kt PO ₄ eq. based on 1 370 kt N and 224 kt P; no data for aquatic emissions BOD, COD, DOC, TOC reported]			
EEA3: EEA, Annual European Community greenhouse gas inventory 1990–2007 and inventory report 2009, Submission to the UNFCCC Secretariat, 2009. Total without LULUCF (Land-Use, Land-Use Change & Forestry)			
EC1, European Commission (DG ENV), Ambient air pollution by AS, CD and NI compounds, Position Paper, 2001. [data sources stem from ca. 1990, EU-15 recalculated by VHK to 2007, EU-27 using multiplier 1,3 for EU-expansion and 55% emission reduction (e.g. Cd) 1990–2007; data are roughly in line with CML]			
Eurostat, Energy Balance Sheets 2007–2008, European Commission, edition 2010.			
VHK, Energy analysis of energy sector to final end use electricity and fuels (excl. transport & feedstock), based on Eurostat, elsewhere in this report			
CML, Centrum voor Milieukunde Leiden, Characterisation and Normalisation factors (CML-IA xls file Nov. 2010; extract Feb. 2011); data for EU-15, 1995. Assumed that EU expansion to EU-17 and emission decrease 1995–2007 will balance.			
[1] from intermediate source: AEA, ENTR Lot 3 Sound and Imaging Equipment, preparatory Ecodesign study, Nov. 2010			

The table below gives the impact of the base cases for the life cycle indicators as percentage of the EU-totals. Where the value exceeds that of 0,5% the table cell colour is deep orange. If the value is between 0,1% and 0,5% the cell is yellow.

Table 73: Impacts per base case, expressed as % of EU total

Main life cycle indicators % of EU totals	1A Fixed OIS/OIV compressor	1B Var OIS/OIV compressor	1C Piston compressor	2. Low pressure compressor	3. Oilfree/ non-lubricated air compressor	4. Turbo (air/nitro)
Materials						
Plastics	0,001%	0,000%	0,001%	0,003%	0,002%	0,000%
Ferrous metals	0,011%	0,003%	0,003%	0,005%	0,003%	0,001%
Non-ferrous metals	0,018%	0,005%	0,005%	0,008%	0,004%	0,000%
Other resources & waste						
Total Energy (GER)	0,578%	0,107%	0,018%	0,501%	0,417%	0,257%
of which, electricity	1,732%	0,320%	0,053%	1,503%	1,251%	0,772%
Water (process)*	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
Waste, non-haz./ landfill*	0,009%	0,002%	0,001%	0,007%	0,006%	0,003%
Waste, hazardous/ incinerated*	0,008%	0,001%	0,000%	0,007%	0,006%	0,003%
Emissions (Air)						
Greenhouse Gases in GWP100	0,370%	0,068%	0,012%	0,321%	0,267%	0,164%
Acidifying agents (AP)	0,370%	0,069%	0,012%	0,321%	0,267%	0,164%
Volatile Org. Compounds (VOC)	0,109%	0,020%	0,003%	0,094%	0,079%	0,049%
Persistent Org. Pollutants (POP)	0,069%	0,015%	0,009%	0,049%	0,039%	0,022%
Heavy Metals (HM)	0,079%	0,015%	0,003%	0,069%	0,057%	0,034%
PAHs	0,084%	0,016%	0,004%	0,076%	0,060%	0,033%
Particulate Matter (PM, dust)	0,068%	0,014%	0,012%	0,057%	0,042%	0,022%
Emissions (Water)						
Heavy Metals (HM)	0,016%	0,003%	0,001%	0,014%	0,011%	0,007%
Eutrophication (EP)	0,010%	0,002%	0,000%	0,009%	0,007%	0,004%
	5. Rotary lobe / air	6. Piston	7. Turbo (other gasses)	8.Screw/oil-free	9. Screw/ oil-injected	10. Rotary lobe / other gas
Materials						
Plastics	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
Ferrous metals	0,000%	0,000%	0,001%	0,000%	0,000%	0,000%
Non-ferrous metals	0,000%	0,001%	0,000%	0,000%	0,000%	0,000%
Other resources & waste						
Total Energy (GER)	0,003%	0,083%	0,290%	0,006%	0,010%	0,002%
of which, electricity	0,009%	0,250%	0,871%	0,019%	0,031%	0,005%
Water (process)*	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%
Waste, non-haz./ landfill*	0,000%	0,001%	0,004%	0,000%	0,000%	0,000%

Waste, hazardous/ incinerated*	0,000%	0,001%	0,004%	0,000%	0,000%	0,000%
Emissions (Air)						
Greenhouse Gases in GWP100	0,002%	0,053%	0,185%	0,004%	0,007%	0,001%
Acidifying agents (AP)	0,002%	0,053%	0,185%	0,004%	0,007%	0,001%
Volatile Org. Compounds (VOC)	0,001%	0,016%	0,055%	0,001%	0,002%	0,000%
Persistent Org. Pollutants (POP)	0,000%	0,007%	0,025%	0,001%	0,001%	0,000%
Heavy Metals (HM)	0,000%	0,011%	0,038%	0,001%	0,001%	0,000%
PAHs	0,000%	0,012%	0,037%	0,001%	0,001%	0,000%
Particulate Matter (PM, dust)	0,000%	0,008%	0,025%	0,001%	0,001%	0,000%
Emissions (Water)						
Heavy Metals (HM)	0,000%	0,002%	0,008%	0,000%	0,000%	0,000%
Eutrophication (EP)	0,000%	0,001%	0,005%	0,000%	0,000%	0,000%

The overall combined impacts of all base cases together is presented in the table below.

Table 74: Total of 10 Base cases

Main life cycle indicators % of EU totals	
Materials	Totals (all 10 base cases)
Plastics	0,007%
Ferrous metals	0,026%
Non-ferrous metals	0,042%
Other resources & waste	
Total Energy (GER)	2,274%
of which, electricity	6,815%
Water (process)	0,000%
Waste, non-haz./ landfill	0,032%
Waste, hazardous/ incinerated	0,031%
Emissions (Air)	
Greenhouse Gases in GWP100	1,456%
Acidifying agents (AP)	1,454%
Volatile Org. Compounds (VOC)	0,428%
Persistent Org. Pollutants (POP)	0,237%
Heavy Metals (HM)	0,310%
PAHs	0,326%
Particulate Matter (PM, dust)	0,251%
Emissions (Water)	
Heavy Metals (HM)	0,062%
Eutrophication (EP)	0,038%

The result gives an impression whether and on which impacts the product score can be called 'significant'.

The table above shows that the main relevant impact categories are linked to impacts typical for energy consumption (resource use, incl. electricity, greenhouse gases and acidifying gases) and to impacts typical to production/distribution (volatile organic compounds, PAHs and PM).

The most relevant base cases are (in order of significance):

For base cases with air as medium:

1. Standard air compressor
2. Low pressure compressor
3. Oilfree/ non-lubricated air compressor
4. process gases / Turbo (air/inert gases)

For base cases with potentially hazardous gases ('other gases') as medium:

6. process gases / Piston (other gases)
7. process gases / Turbo (other gasses)

Appendix I - Overview of Chinese Air Compressor Efficiency Grades

Table 75: Energy efficiency grades for oil lubricated direct drive portable reciprocating piston air compressors

No. of Compression Stages	Drive Motor Input Power Rating kW	Energy Efficiency Grade	Rated Discharge Pressure					
			MPa					
			0.25	0.4	0.5	0.7	0.8	1.0
			Input Specific Power					
			kW/(m ³ /min)					
Single-stage	0.25	1	8.8	10.5	11.5	13.2	14.0	15.5
		2	9.3	11.0	12.1	13.9	14.7	16.3
		3	11.6	13.8	15.1	17.4	18.4	20.4
		T	10.5	12.5	13.7	15.8	16.7	18.5
	0.37	1	8.8	10.5	11.5	13.2	14.0	15.5
		2	9.3	11.0	12.1	13.9	14.7	16.3
		3	11.6	13.8	15.1	17.4	18.4	20.4
		T	10.5	12.5	13.7	15.8	16.7	18.5
	0.55	1	8.6	10.1	10.9	12.6	13.4	14.9
		2	9.0	10.6	11.5	13.3	14.1	15.7
		3	11.2	13.3	14.4	16.6	17.6	19.6
		T	10.2	12.1	13.1	15.1	16.0	17.8
	0.75	1	8.3	9.8	10.7	12.3	13.0	14.3
		2	8.7	10.3	11.3	12.9	13.7	15.0
		3	10.9	12.9	14.1	16.2	17.2	18.8
		T	9.9	11.7	12.8	14.7	15.6	17.1
	1.1	1	7.9	9.4	10.3	11.8	12.4	13.9
		2	8.3	9.9	10.8	12.4	13.1	14.6
		3	10.5	12.4	13.5	15.5	16.4	18.3
		T	9.5	11.3	12.3	14.1	14.9	16.6
	1.5	1	7.9	9.2	10.0	11.5	12.2	13.6
		2	8.3	9.7	10.5	12.1	12.8	14.3
		3	10.4	12.1	13.2	15.2	16.1	17.9
		T	9.4	11.0	12.0	13.8	14.6	16.3
	1.8	1	7.9	9.2	10.0	11.5	12.2	13.6
		2	8.3	9.7	10.5	12.1	12.8	14.3
		3	10.3	12.1	13.2	15.2	16.1	17.9
		T	9.4	11.0	12.0	13.8	14.6	16.3
	2.2	1	7.5	9.1	9.9	11.3	11.9	13.2
		2	7.9	9.6	10.4	11.9	12.5	13.9
		3	9.9	12.0	13.1	14.9	15.7	17.4

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

	2.6	T	9.0	10.9	11.9	13.5	14.3	15.8
		1	7.5	9.1	9.9	11.3	11.9	13.2
		2	7.9	9.6	10.4	11.9	12.5	13.9
		3	9.9	12.0	13.1	14.9	15.7	17.4
	3.0	T	9.0	10.9	11.9	13.5	14.3	15.8
		1	7.4	8.7	9.6	11.1	11.8	12.9
		2	7.8	9.2	10.1	11.7	12.4	13.6
		3	9.8	11.6	12.7	14.6	15.4	17.1
		T	8.9	10.5	11.5	13.3	14.0	15.5
Two-stage	0.55	1	-					13.2
		2						13.9
		3						17.4
		T						15.8
	0.75	1						13.0
		2						13.7
		3						17.2
		T						15.6
	1.1	1						12.9
		2						13.6
		3						17.1
		T						15.5
	1.5	1						12.7
		2						13.4
		3						16.8
		T						15.3
	2.2	1						12.6
		2						13.3
		3						16.7
		T						15.2
	3.0	1						12.5
		2						13.2
		3						16.5
		T						15.0

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

Table 76: Energy efficiency grades for oil-free direct drive portable reciprocating piston air compressors

No. of Compression Stages	Drive Motor Input Power Rating kW	Energy Efficiency Grade	Rated Discharge Pressure					
			MPa					
			0.25	0.4	0.5	0.7	0.8	1.0
			Input Specific Power					
			kW/(m ³ /min)					
Single-stage	0.25	1	10.7	12.7	13.3	14.7	15.6	16.2
		2	11.3	13.4	14.0	15.5	16.4	17.1
		3	14.1	16.7	17.6	19.5	20.5	21.3
		T	12.8	15.2	16.0	17.7	18.6	19.4
	0.37	1	10.3	12.0	12.6	14.1	14.9	16.2
		2	10.8	12.6	13.3	14.8	15.7	17.1
		3	13.5	15.8	16.6	18.5	19.6	21.3
		T	12.3	14.4	15.1	16.8	17.8	19.4
	0.55	1	9.8	11.3	12.0	13.4	14.3	15.8
		2	10.3	11.9	12.6	14.1	15.0	16.6
		3	13.0	14.9	15.7	17.6	18.7	20.7
		T	11.8	13.5	14.3	16.0	17.0	18.8
	0.75	1	9.2	10.7	11.5	12.8	13.5	15.1
		2	9.7	11.3	12.1	13.5	14.2	15.9
		3	12.1	14.1	15.1	16.8	17.8	19.9
		T	11.0	12.8	13.7	15.3	16.2	18.1
	1.1	1	8.9	10.5	11.1	12.4	13.1	14.7
		2	9.4	11.1	11.7	13.0	13.8	15.5
		3	11.8	13.9	14.6	16.3	17.3	19.4
		T	10.7	12.6	13.3	14.8	15.7	17.6
	1.5	1	8.8	10.3	10.7	12.2	12.7	14.3
		2	9.3	10.8	11.3	12.8	13.4	15.0
		3	11.6	13.5	14.1	16.0	16.8	18.8
		T	10.5	12.3	12.8	14.5	15.3	17.1
	1.8	1	8.8	10.3	10.7	12.2	12.7	14.3
		2	9.3	10.8	11.3	12.8	13.4	15.0
		3	11.6	13.5	14.1	16.0	16.8	18.8
		T	10.5	12.3	12.8	14.5	15.3	17.1
	2.2	1	8.6	10.1	10.7	12.0	12.6	14.1
		2	9.0	10.6	11.3	12.6	13.3	14.8
		3	11.2	13.3	14.1	15.7	16.6	18.5
		T	10.2	12.1	12.8	14.3	15.1	16.8

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

	2.6	1	8.6	10.1	10.7	12.0	12.6	14.1
		2	9.0	10.6	11.3	12.6	13.3	14.8
		3	11.2	13.3	14.1	15.7	16.6	18.5
		T	10.2	12.1	12.8	14.3	15.1	16.8
	3.0	1	8.4	9.8	10.5	11.5	12.2	13.7
		2	8.8	10.3	11.0	12.1	12.8	14.4
		3	11.0	12.9	13.8	15.2	16.1	18.0
		T	10.0	11.7	12.5	13.8	14.6	16.4
Two-stage	0.55	1	—					13.4
		2						14.1
		3						17.6
		T						16.0
	0.75	1						13.4
		2						14.1
		3						17.6
		T						16.0
	1.1	1						13.2
		2						13.9
		3						17.4
		T						15.8
	1.5	1						13.2
		2						13.9
		3						17.4
		T						15.8
	2.2	1						12.7
		2						13.4
		3						16.8
		T						15.3
	3.0	1						12.7
		2						13.4
		3						16.8
		T						15.3

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

Table 77: Energy efficiency grades for reciprocating piston miniature air compressors

No. of Compression Stages	Drive Motor Input Power Rating kW	Energy Efficiency Grade	Rated Discharge Pressure							
			MPa							
			0.25	0.4	0.5	0.7	0.8	1.0	1.25	1.4
			Input Specific Power							
			kW/(m ³ /min)							
Single stage	0.18	1	9.1	10.8	11.8	13.6	14.4	15.9	—	
		2	9.8	11.6	12.7	14.6	15.5	17.1		
		3	11.0	13.1	14.4	16.6	17.8	19.4		
		T	10.9	13.0	14.3	16.5	17.7	19.2		
	0.25	1	8.6	10.2	11.3	12.9	13.7	15.2		
		2	9.3	11.0	12.1	13.9	14.7	16.3		
		3	10.5	12.5	13.7	15.8	17.0	18.5		
		T	10.4	12.4	13.6	15.7	16.9	18.3		
	0.37	1	8.6	10.0	10.9	12.6	13.3	14.8		
		2	9.2	10.8	11.7	13.5	14.3	15.9		
		3	10.0	11.7	12.9	14.8	15.6	17.4		
		T	9.9	11.6	12.8	14.7	15.5	17.3		
	0.55	1	7.9	9.2	10.0	11.5	12.2	13.6		
		2	8.5	9.9	10.8	12.4	13.1	14.6		
		3	9.2	10.9	12.0	13.7	14.4	16.0		
		T	9.1	10.8	11.9	13.6	14.3	15.9		
	0.75	1	7.4	8.7	9.5	10.9	11.5	12.8		
		2	8.0	9.4	10.2	11.7	12.4	13.8		
		3	8.7	10.4	11.3	12.9	13.7	15.2		
		T	8.6	10.3	11.2	12.8	13.6	15.1		
	1.1	1	6.9	8.2	8.8	10.2	10.9	12.1		
		2	7.4	8.8	9.5	11	11.7	13.0		
		3	8.3	9.7	10.6	12.2	12.9	14.4		
		T	8.2	9.6	10.5	12.1	12.8	14.3		
	1.5	1	6.7	7.9	8.6	9.8	10.3	11.5		
		2	7.2	8.5	9.2	10.5	11.1	12.4		
		3	7.8	9.4	10.3	11.7	12.5	13.8		
		T	7.7	9.3	10.2	11.6	12.4	13.7		
	2.2	1	6.1	7.3	7.8	9.0	9.6	10.6		
		2	6.6	7.8	8.4	9.7	10.3	11.4		
		3	7.2	8.6	9.4	10.8	11.4	12.7		
		T	7.1	8.5	9.3	10.7	11.3	12.6		
	3.0	1	—	7.0	7.5	8.7	9.3	10.3		
		2		7.5	8.1	9.4	10.0	11.1		

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

		3		8.3	9.1	10.5	11.2	12.4					
		T		8.2	9.0	10.4	11.1	12.3					
	4.0	1		6.6	7.3	8.4	8.8	9.9					
		2		7.1	7.8	9.0	9.5	10.6					
		3		7.9	8.7	10.0	10.6	11.8					
		T		7.8	8.6	9.9	10.5	11.7					
	5.5	1		6.5	7.1	8.3	8.7	9.6					
		2		7.0	7.6	8.9	9.4	10.3					
		3		7.7	8.5	9.8	10.5	11.5					
		T		7.6	8.4	9.7	10.4	11.4					
	7.5	1		6.4	6.9	8.0	8.5	—					
		2		6.9	7.4	8.6	9.1						
		3		7.7	8.3	9.6	10.1						
		T		7.6	8.2	9.5	10.0						
	11	1		6.2	6.7	7.7	8.2						
		2		6.7	7.2	8.3	8.8						
		3		7.5	8.2	9.3	9.8						
		T		7.4	8.1	9.2	9.7						
	15	1		6.0	6.5	7.5	8.0						
		2		6.5	7.0	8.1	8.6						
		3		7.2	8.0	9.1	9.6						
		T		7.1	7.9	9.0	9.5						
	18.5	1		—	6.3	—							
		2			6.8								
		3			7.9								
		T			7.8								

Two-stage	0.37	1	—					12.9	13.7	14.4			
		2						13.9	14.7	15.5			
		3						15.4	17.1	17.9			
		T						15.3	17.0	17.8			
	0.55	1						12.3	12.9	13.6			
		2						13.2	13.9	14.6			
		3						14.6	16.1	16.9			
		T						14.5	16.0	16.8			
	0.75	1						11.9	12.6	13.2			
		2						12.8	13.5	14.2			
		3						14.1	15.7	16.4			
		T						14.0	15.6	16.3			
	1.1	1						—		—	11.3	12.0	12.6
		2									12.2	12.9	13.5

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		3				13.5	15.0	15.7	
		T				13.4	14.9	15.6	
	1.5	1				11.0	11.7	12.3	
		2				11.8	12.6	13.2	
		3				13.2	14.6	15.3	
		T				13.1	14.5	15.2	
	2.2	1				10.2	10.9	11.4	
		2				11.0	11.7	12.3	
		3				12.3	13.6	14.3	
		T				12.2	13.5	14.2	
	3.0	1				10.1	10.7	11.3	
		2				10.9	11.5	12.1	
		3				12.1	13.5	14.1	
		T				12.0	13.4	14.0	
	4.0	1			8.4	8.8	9.6	10.0	10.7
		2			9.0	9.5	10.3	10.8	11.5
		3			9.8	10.5	11.4	12.5	13.3
		T			9.7	10.4	11.3	12.4	13.2
	5.5	1			8.3	8.7	9.5	10.0	10.5
		2			8.9	9.4	10.2	10.7	11.3
		3			9.7	10.2	11.2	12.4	13.0
		T			9.6	10.1	11.1	12.3	12.9
	7.5	1			8.1	8.6	9.3	9.8	10.2
		2			8.7	9.2	10.0	10.5	11.0
		3			9.5	10.0	11.0	12.1	12.8
		T			9.4	9.9	10.9	12.0	12.7
	11	1			7.7	8.2	8.9	9.5	10.0
		2			8.3	8.8	9.6	10.2	10.8
3		9.2	9.7		10.7	11.9	12.5		
T		9.1	9.6		10.6	11.8	12.4		
15	1		7.4	7.9	8.6	9.2	9.8		
	2		8.0	8.5	9.3	9.9	10.5		
	3		9.0	9.5	10.5	11.6	12.2		
	T		8.9	9.4	10.4	11.5	12.1		
Note: 18.5 kW 0.5 MPa single-stage air compressors are market circulation products not covered by the GB/T13928 series of standards.									

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

Table 78: Energy efficiency grades for oil-free reciprocating piston air compressors

No. of Compression Stages	Drive Motor Input Power Rating kW	Energy Efficiency Grade	Rated Discharge Pressure						
			MPa						
			0.4	0.5	0.7	0.8	1.0	1.25	1.4
			Input Specific Power						
			kW/(m ³ /min)						
Single-stage	0.18	1	13.7	14.3	14.9	15.9	—	—	
		2	14.6	15.2	15.9	16.9			
		3	16.4	17.3	19.1	20.2			
		T	16.2	17.1	18.9	20.0			
	0.25	1	12.3	12.9	14.3	14.9			
		2	13.1	13.7	15.2	15.9			
		3	14.8	15.6	17.3	18.3			
		T	14.7	15.4	17.1	18.1			
	0.37	1	11.3	11.8	13.2	13.9			
		2	12.0	12.6	14.0	14.8			
		3	13.5	14.3	15.9	16.9			
		T	13.4	14.2	15.7	16.7			
	0.55	1	10.2	10.7	12.1	12.9			
		2	10.9	11.4	12.9	13.7			
		3	12.2	13.0	14.6	15.5			
		T	12.1	12.9	14.5	15.3			
	0.75	1	9.9	10.4	11.5	12.1	13.8		
		2	10.5	11.1	12.2	12.9	14.7		
		3	11.8	12.6	13.8	14.6	16.5		
		T	11.7	12.5	13.7	14.5	16.3		
	1.1	1	9.3	9.6	10.7	11.4	12.9		
		2	9.9	10.2	11.4	12.1	13.7		
		3	11.1	11.6	13.0	13.8	15.4		
		T	11.0	11.5	12.9	13.7	15.2		
	1.5	1	8.9	9.4	10.3	11.0	12.1		
		2	9.5	10.0	11.0	11.7	12.9		
		3	10.7	11.4	12.6	13.4	14.6		
		T	10.6	11.3	12.5	13.3	14.5		
	2.2	1	8.2	8.6	9.5	10.1	11.5		
		2	8.7	9.2	10.1	10.7	12.2		
		3	9.8	10.4	11.5	12.2	13.8		
		T	9.7	10.3	11.4	12.1	13.7		
	3.0	1	7.8	8.4	9.2	9.8	—		
		2	8.3	8.9	9.8	10.4			

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		3	9.3	10.1	11.2	11.9						
		T	9.2	10.0	11.1	11.8						
	4.0	1	7.4	8.0	8.7	9.3						
		2	7.9	8.5	9.3	9.9						
		3	8.9	9.6	10.7	11.3						
		T	8.8	9.5	10.6	11.2						
		5.5	1	7.4	7.7	8.6				9.0		
	2		7.9	8.2	9.1	9.6						
	3		8.8	9.4	10.4	11.0						
	T		8.7	9.3	10.3	10.9						
	7.5	1	7.2	7.5	8.3	8.7						
		2	7.7	8.0	8.8	9.3						
		3	8.6	9.1	10.2	10.8						
		T	8.5	9.0	10.1	10.7						
	11	1	7.1	7.3	8.0	8.5						
		2	7.5	7.8	8.5	9.0						
		3	8.4	8.9	9.9	10.5						
		T	8.3	8.8	9.8	10.4						
	15	1	6.8	7.1	7.8	8.3						
		2	7.2	7.6	8.3	8.8						
		3	8.1	8.6	9.7	10.3						
		T	8.0	8.5	9.6	10.2						
	Two-stage	2.2	1	—	—	—				11.0	11.7	12.5
			2							11.7	12.4	13.3
			3							12.6	14.7	15.7
			T							12.5	14.6	15.6
		3.0	1							10.8	11.5	12.2
			2							11.5	12.2	13.0
3			12.3				14.4	15.4				
T			12.2				14.3	15.3				
4.0		1	10.3				10.9	11.7				
		2	11.0				11.6	12.4				
		3	11.7				13.7	14.7				
		T	11.6				13.6	14.6				
5.5		1	10.2				10.5	11.4				
		2	10.8				11.2	12.1				
		3	11.6				13.3	14.4				
		T	11.5				13.2	14.3				
7.5		1	10.0				10.4	11.3				
		2	10.6				11.1	12.0				

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

		3				11.3	13.2	14.2		
		T				11.2	13.1	14.1		
	11	1		7.9	8.4	9.7	9.8	10.3		
		2		8.4	8.9	10.3	10.4	11.0		
		3		9.5	10.1	11.1	12.4	13.0		
		T		9.4	10.0	11.0	12.3	12.9		
	15	1		7.6	8.1	9.5	9.5	10.0		
		2		8.1	8.6	10.1	10.1	10.6		
		3		9.3	9.9	10.8	11.9	12.6		
		T		9.2	9.8	10.7	11.8	12.5		
	18.5 22	1		7.3	7.8	9.1	9.1	9.5		
				[6.7]	[7.1]	[7.9]	[8.4]	[8.8]		
		2		7.8	8.3	9.7	9.7	10.1		
				[7.1]	[7.5]	[8.4]	[8.9]	[9.4]		
		3		8.9	9.4	10.4	11.5	12.0		
				[7.5]	[8.0]	[8.9]	[10.0]	[10.6]		
		T		8.8	9.3	10.3	11.4	11.9		
				[7.4]	[7.9]	[8.8]	[9.9]	[10.5]		
	Note: values within [] are indices for water cooled air compressors.									

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

Table 79: Energy efficiency grades for stationary reciprocating piston air compressors for general use

Drive Motor Input Power Rating kW	Energy Efficiency Grade	Rated Discharge Pressure										
		MPa										
		0.7			0.8		1.0			1.25		
		Input Specific Power										
		kW/(m ³ /min)										
		Water cooled	Water cooled	Air cooled	Water cooled	Water cooled	Water cooled	Water cooled	Air cooled	Water cooled	Water cooled	Air cooled
		Oil lubricated	Oil-free	Oil lubricated	Oil lubricated	Oil-free	Oil lubricated	Oil-free	Oil lubricated	Oil lubricated	Oil-free	Oil lubricated
18.5	1	6.20	6.36	6.69	6.62	6.79	7.42	7.56	7.84	7.84	8.00	8.28
	2	6.81	6.99	7.35	7.27	7.46	8.15	8.31	8.62	8.61	8.79	9.10
	3	7.00	7.24	7.60	7.47	7.72	8.34	8.63	9.06	9.32	9.65	10.13
	T	6.93	7.17	7.52	7.40	7.64	8.26	8.54	8.97	9.23	9.55	10.03
22	1	6.17	6.33	6.66	6.58	6.75	7.38	7.53	7.81	7.80	7.96	8.24
	2	6.78	6.96	7.32	7.23	7.42	8.11	8.28	8.58	8.57	8.75	9.05
	3	6.97	7.21	7.57	7.43	7.69	8.30	8.59	9.02	9.28	9.60	10.08
	T	6.90	7.14	7.49	7.36	7.61	8.22	8.50	8.93	9.19	9.51	9.98
30	1	5.97	6.13	6.46	6.37	6.54	7.34	7.49	7.76	7.75	7.92	8.19
	2	6.56	6.74	7.10	7.00	7.19	8.07	8.23	8.53	8.52	8.70	9.00
	3	6.93	7.17	7.53	7.39	7.65	8.25	8.54	8.97	9.23	9.55	10.03
	T	6.86	7.10	7.46	7.32	7.57	8.17	8.46	8.88	9.14	9.46	9.93
37	1	5.97	6.13	6.46	6.37	6.54	7.34	7.49	7.76	7.75	7.92	8.19
	2	6.56	6.74	7.10	7.00	7.19	8.07	8.23	8.53	8.52	8.70	9.00
	3	6.93	7.17	7.53	7.39	7.65	8.25	8.54	8.97	9.23	9.55	10.03
	T	6.86	7.10	7.46	7.32	7.57	8.17	8.46	8.88	9.14	9.46	9.93
45	1	5.66	5.93	6.27	6.04	6.32	6.68	6.95	7.43	7.16	7.54	7.92
	2	6.22	6.52	6.89	6.64	6.95	7.34	7.64	8.17	7.87	8.29	8.70
	3	6.41	6.82	7.24	6.84	7.27	7.62	8.12	8.62	8.53	9.09	9.64
	T	6.35	6.76	7.17	6.78	7.20	7.55	8.04	8.54	8.45	9.00	9.55
55*	1	5.64	5.91	6.25	6.02	6.31	6.66	6.93	7.41	7.14	7.52	7.89
	2	6.20	6.49	6.87	6.61	6.93	7.32	7.61	8.14	7.85	8.26	8.67
	3	6.38	6.80	7.21	6.81	7.25	7.60	8.09	8.59	8.51	9.06	9.60
	T	6.32	6.73	7.14	6.74	7.18	7.53	8.01	8.51	8.43	8.97	9.50
55	1	5.40	5.72	6.10	5.76	6.11	6.42	6.73	7.25	6.87	7.30	7.89
	2	5.93	6.29	6.70	6.33	6.71	7.05	7.40	7.97	7.55	8.02	8.67
	3	6.09	6.62	7.21	6.50	7.06	7.26	7.88	8.59	8.12	8.82	9.60
	T	6.03	6.55	7.14	6.44	6.99	7.17	7.80	8.50	8.04	8.73	9.50

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

63	1	5.40	5.72	6.10	5.76	6.11	6.42	6.73	7.25	6.87	7.30	7.89
	2	5.93	6.29	6.70	6.33	6.71	7.05	7.40	7.97	7.55	8.02	8.67
	3	6.09	6.62	7.21	6.50	7.06	7.26	7.88	8.59	8.12	8.82	9.60
	T	6.03	6.55	7.14	6.44	6.99	7.17	7.80	8.50	8.04	8.73	9.50
75	1	5.40	5.71	6.09	5.76	6.10	6.41	6.72	7.24	6.86	7.29	7.88
	2	5.93	6.28	6.69	6.33	6.70	7.04	7.39	7.96	7.54	8.01	8.66
	3	6.08	6.61	7.20	6.49	7.05	7.25	7.87	8.58	8.11	8.81	9.59
	T	6.02	6.54	7.13	6.43	6.80	7.18	7.79	8.49	8.03	8.72	9.50
90	1	5.31	5.61	—	5.67	5.98	6.34	6.66	—	6.80	7.22	—
	2	5.84	6.16		6.23	6.57	6.97	7.32		7.47	7.93	
	3	6.02	6.55		6.42	6.99	7.17	7.79		8.02	8.72	
	T	5.96	6.49		6.36	6.92	7.10	7.71		7.94	8.63	
110	1	5.27	5.51		5.61	5.87	6.27	6.55		6.69	7.12	
	2	5.79	6.05		6.17	6.45	6.89	7.20		7.35	7.82	
	3	6.00	6.43		6.40	6.86	7.14	7.66		7.99	8.57	
	T	5.94	6.37		6.34	6.79	7.07	7.58		7.91	8.48	
132	1	5.25	5.48		5.60	5.84	6.24	6.52		6.66	7.09	
	2	5.77	6.02		6.15	6.42	6.86	7.17		7.32	7.79	
	3	6.00	6.40		6.40	6.83	7.11	7.62		7.96	8.53	
	T	5.94	6.34		6.34	6.76	7.04	7.54		7.88	8.45	
160	1	5.25	5.44		5.60	5.81	6.21	6.49		6.62	7.04	
	2	5.77	5.98		6.15	6.38	6.82	7.13		7.28	7.74	
	3	6.00	6.37		6.40	6.79	7.07	7.58		7.91	8.48	
	T	5.94	6.31		6.34	6.72	7.00	7.51		7.83	8.40	
200	1	5.25	5.42		5.60	5.79	6.19	6.38		6.60	6.93	
	2	5.77	5.96		6.15	6.36	6.80	7.01		7.25	7.61	
	3	5.99	6.37		6.39	6.79	7.07	7.53		7.91	8.43	
	T	5.93	6.31		6.33	6.72	7.00	7.46		7.83	8.35	
250	1	5.25	5.41		5.60	5.77	6.19	6.38		6.60	6.93	
	2	5.77	5.94		6.15	6.34	6.80	7.01		7.25	7.61	
	3	5.99	6.33		6.39	6.75	7.07	7.45		7.91	8.33	
	T	5.93	6.27		6.33	6.68	7.00	6.37		7.83	8.25	
315	1	5.23	5.40		5.59	5.75	6.16	6.32		6.58	6.86	
	2	5.75	5.93		6.14	6.32	6.77	6.95		7.23	7.54	
	3	5.95	6.26		6.35	6.68	7.07	7.45		7.91	8.33	
	T	5.89	6.20		6.29	6.61	7.00	7.38		7.83	8.25	
355	1	5.22	5.39		5.57	5.74	6.16	6.32		6.58	6.86	
	2	5.74	5.92		6.12	6.31	6.77	6.95		7.23	7.54	
	3	5.94	6.24		6.34	6.66	7.07	7.45		7.91	8.33	
	T	5.88	6.18		6.28	6.59	7.00	7.38		7.83	8.25	

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400	1	5.21	5.37		5.56	5.73	6.16	6.32		6.58	6.86	
	2	5.73	5.90		6.11	6.30	6.77	6.95		7.23	7.54	
	3	5.93	6.23		6.33	6.65	7.07	7.45		7.91	8.33	
	T	5.87	6.17		6.27	6.58	7.00	7.38		7.83	8.25	
450	1	5.20	5.36		5.55	5.71	—					
	2	5.71	5.89		6.10	6.28						
	3	5.89	6.16		6.28	6.57						
	T	5.83	6.10		6.22	6.50						
500	1	5.20	5.35		5.55	5.71						
	2	5.71	5.88		6.10	6.27						
	3	5.88	6.15		6.27	6.56						
	T	5.82	6.09		6.21	6.49						
560	1	5.19	5.34		5.53	5.70						
	2	5.70	5.87		6.08	6.26						
	3	5.87	6.14		6.26	6.55						
	T	5.81	6.08		6.20	6.48						
Note: for 55 kW compressors, values marked with an asterisk (*) denote single-acting air compressors, whereas unmarked values denote dual-acting air compressors.												

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

Table 80: Energy efficiency grades for oil injected screw air compressors for general use and oil injected single screw air compressors for general use

Drive Motor Input Power Rating kW	Energy Efficiency Grade	Rated Discharge Pressure							
		MPa							
		0.7		0.8		1.0		1.25	
		Input Specific Power							
		kW/(m ³ /min)							
		Water cooled	Air cooled	Water cooled	Air cooled	Water cooled	Air cooled	Water cooled	Air cooled
2.2	1	—	8.2	—	8.7	—	9.8	—	11.0
	2		9.2		9.8		11.0		12.4
	3		10.4		11.1		12.4		14.0
	T		10.3		11.0		12.3		13.9
3.0	1		8.2		8.7		9.8		11.0
	2		9.2		9.8		11.0		12.4
	3		10.4		11.1		12.4		14.0
	T		10.3		11.0		12.3		13.9
4.0	1		8.2		8.7		9.8		11.0
	2		9.2		9.8		11.0		12.4
	3		10.4		11.1		12.4		14.0
	T		10.3		11.0		12.3		13.9
5.5	1		8.2		8.7		9.8		11.0
	2		9.2		9.8		11.0		12.4
	3		10.4		11.1		12.4		14.0
	T		10.3		11.0		12.3		13.9
7.5	1	6.9	7.5	7.3	7.9	8.6	8.7	9.5	9.9
	2	7.7	8.4	8.2	8.9	9.7	9.9	10.8	11.2
	3	9.1	9.6	9.6	10.2	10.8	11.3	12.2	12.8
	T	9.0	9.5	9.5	10.1	10.7	11.2	12.1	12.7
11	1	6.9	7.5	7.3	7.9	8.6	8.7	9.5	9.9
	2	7.7	8.4	8.2	8.9	9.7	9.9	10.8	11.2
	3	9.1	9.6	9.6	10.2	10.8	11.3	12.2	12.8
	T	9.0	9.5	9.5	10.1	10.7	11.2	12.1	12.7
15	1	6.5	6.9	6.9	7.4	8.2	8.3	9.3	9.5
	2	7.3	7.9	7.7	8.4	9.2	9.4	10.4	10.7
	3	8.4	9.0	8.9	9.5	10.3	10.8	11.6	12.2
	T	8.3	8.9	8.8	9.4	10.2	10.7	11.5	12.1
18.5	1	6.5	6.9	6.9	7.4	8.2	8.3	9.3	9.5
	2	7.3	7.9	7.7	8.4	9.2	9.4	10.4	10.7
	3	8.4	9.0	8.9	9.5	10.3	10.8	11.6	12.2

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

	T	8.3	8.9	8.8	9.4	10.2	10.7	11.5	12.1
22	1	6.2	6.8	6.6	7.2	7.8	8.1	8.7	9.1
	2	7.0	7.6	7.4	8.1	8.8	9.1	9.8	10.2
	3	8.0	8.4	8.5	8.9	9.9	10.3	11.0	11.6
	T	7.9	8.3	8.4	8.8	9.8	10.2	10.9	11.5
30	1	6.2	6.8	6.6	7.2	7.8	8.1	8.7	9.1
	2	7.0	7.6	7.4	8.1	8.8	9.1	9.8	10.2
	3	8.0	8.4	8.5	8.9	9.9	10.3	11.0	11.6
	T	7.9	8.3	8.4	8.8	9.8	10.2	10.9	11.5
37	1	6.2	6.8	6.6	7.2	7.8	8.1	8.7	9.1
	2	7.0	7.6	7.4	8.1	8.8	9.1	9.8	10.2
	3	8.0	8.4	8.5	8.9	9.9	10.3	11.0	11.6
	T	7.9	8.3	8.4	8.8	9.8	10.2	10.9	11.5
45	1	6.2	6.8	6.6	7.2	7.8	8.1	8.7	9.1
	2	7.0	7.6	7.4	8.1	8.8	9.1	9.8	10.2
	3	8.0	8.4	8.5	8.9	9.9	10.3	11.0	11.6
	T	7.9	8.3	8.4	8.8	9.8	10.2	10.9	11.5
55	1	5.8	6.1	6.1	6.5	7.5	7.7	8.4	8.6
	2	6.5	6.9	6.9	7.3	8.4	8.7	9.4	9.7
	3	7.6	7.9	8.1	8.4	9.4	9.9	10.5	11.1
	T	7.5	7.8	8.0	8.3	9.3	9.8	10.4	11.0
63	1	5.8	6.1	6.1	6.5	7.5	7.7	8.4	8.6
	2	6.5	6.9	6.9	7.3	8.4	8.7	9.4	9.7
	3	7.6	7.9	8.1	8.4	9.4	9.9	10.5	11.1
	T	7.5	7.8	8.0	8.3	9.3	9.8	10.4	11.0
75	1	5.8	6.1	6.1	6.5	7.5	7.7	8.4	8.6
	2	6.5	6.9	6.9	7.3	8.4	8.7	9.4	9.7
	3	7.6	7.9	8.1	8.4	9.4	9.9	10.5	11.1
	T	7.5	7.8	8.0	8.3	9.3	9.8	10.4	11.0
90	1	5.8	6.1	6.1	6.5	7.5	7.7	8.4	8.6
	2	6.5	6.9	6.9	7.3	8.4	8.7	9.4	9.7
	3	7.6	7.9	8.1	8.4	9.4	9.9	10.5	11.1
	T	7.5	7.8	8.0	8.3	9.3	9.8	10.4	11.0
110	1	5.6	6.0	6.0	6.3	7.2	7.4	8.1	8.4
	2	6.3	6.7	6.7	7.1	8.1	8.3	9.1	9.4
	3	7.2	7.6	7.6	8.1	9.1	9.6	10.1	10.7
	T	7.1	7.5	7.5	8.0	9.0	9.5	10.0	10.6
132	1	5.6	6.0	6.0	6.3	7.2	7.4	8.1	8.4
	2	6.3	6.7	6.7	7.1	8.1	8.3	9.1	9.4
	3	7.2	7.6	7.6	8.1	9.1	9.6	10.1	10.7

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

	T	7.1	7.5	7.5	8.0	9.0	9.5	10.0	10.6
160	1	5.6	6.0	6.0	6.3	7.2	7.4	8.1	8.4
	2	6.3	6.7	6.7	7.1	8.1	8.3	9.1	9.4
	3	7.2	7.6	7.6	8.1	9.1	9.6	10.1	10.7
	T	7.1	7.5	7.5	8.0	9.0	9.5	10.0	10.6
200	1	5.3	5.5	5.7	5.9	7.0	7.2	7.8	8.2
	2	6.0	6.2	6.4	6.6	7.9	8.1	8.8	9.2
	3	6.8	7.2	7.5	7.9	8.9	9.4	9.8	10.5
	T	6.7	7.1	7.4	7.8	8.8	9.3	9.7	10.4
250	1	5.3	5.5	5.7	5.9	7.0	7.2	7.8	8.2
	2	6.0	6.2	6.4	6.6	7.9	8.1	8.8	9.2
	3	6.8	7.2	7.5	7.9	8.9	9.4	9.8	10.5
	T	6.7	7.1	7.4	7.8	8.8	9.3	9.7	10.4
315	1	5.3	5.5	5.7	5.9	7.0	7.2	7.8	8.2
	2	6.0	6.2	6.4	6.6	7.9	8.1	8.8	9.2
	3	6.8	7.2	7.5	7.9	8.9	9.4	9.8	10.5
	T	6.7	7.1	7.4	7.8	8.8	9.3	9.7	10.4
355	1	5.2	—	5.4	—	6.7	—	7.4	—
	2	5.8		6.1		7.5		8.3	
	3	6.4		7.1		8.5		9.4	
	T	6.3		7.0		8.4		9.3	
400	1	5.2		5.4		6.7		7.4	
	2	5.8		6.1		7.5		8.3	
	3	6.4		7.1		8.5		9.4	
	T	6.3		7.0		8.4		9.3	
450	1	5.2		5.4		6.7		7.4	
	2	5.8		6.1		7.5		8.3	
	3	6.4		7.1		8.5		9.4	
	T	6.3		7.0		8.4		9.3	
500	1	5.2		5.4		6.7		7.4	
	2	5.8		6.1		7.5		8.3	
	3	6.4		7.1		8.5		9.4	
	T	6.3		7.0		8.4		9.3	
560	1	5.2		5.4		6.7		7.4	
	2	5.8		6.1		7.5		8.3	
	3	6.4		7.1		8.5		9.4	
	T	6.3		7.0		8.4		9.3	
630	1	5.2		5.4		6.7		7.4	
	2	5.8		6.1		7.5		8.3	
	3	6.4		7.1		8.5		9.4	

Appendix I – Overview of Chinese Air Compressor Efficiency Grades

	T	6.3		7.0		8.4		9.3	
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Appendix I – Overview of Chinese Air Compressor Efficiency Grades

Table 81: Energy efficiency grades for oil flooded sliding vane air compressors for general use

Drive Motor Input Power Rating kW	Energy Efficiency Grade	Rated Discharge Pressure										
		MPa										
		0.4		0.5	0.7		1.0	0.4		0.5	0.7	
		Input Specific Power										
		kW/(m ³ /min)										
		Rated speed ≤1500 rpm						Rated speed > 1500 rpm				
		Water cooled	Air cooled	Air cooled	Water cooled	Air cooled	Air cooled	Water cooled	Air cooled	Air cooled	Water cooled	Air cooled
1.5	1	—	—	—	8.7	8.9	10.6	—	—	—	8.8	9.1
	2				9.6	9.8	11.6				9.7	10.0
	3				11.2	11.7	13.8				11.5	12.8
	T				11.1	11.6	13.7				11.4	12.7
2.2	1				8.5	8.6	10.3				8.6	8.8
	2				9.3	9.5	11.3				9.4	9.7
	3				10.5	10.8	12.8				10.8	11.1
	T				10.4	10.7	12.7				10.7	11.0
3.0	1				8.3	8.6	10.1				8.4	8.6
	2				9.1	9.4	11.1				9.2	9.5
	3				10.5	10.8	12.8				10.8	11.1
	T				10.4	10.7	12.7				10.7	11.0
4.0	1				7.9	8.2	9.6				8.1	8.3
	2				8.7	9.0	10.6				8.9	9.1
	3				10.0	10.3	12.2				10.3	10.5
	T				9.9	10.2	12.1				10.2	10.4
5.5	1	6.6	6.7	7.1	7.8	7.9	9.4	6.9	7.1	7.5	7.9	8.1
	2	7.2	7.4	7.8	8.6	8.7	10.3	7.6	7.8	8.2	8.7	8.9
	3	8.4	8.6	9.0	9.7	10.0	11.7	8.8	9.0	9.4	10.0	10.2
	T	8.3	8.5	8.9	9.6	9.9	11.6	8.7	8.9	9.3	9.9	10.1
7.5	1	6.6	6.7	7.0	7.7	7.9	9.3	6.8	7.0	7.4	7.9	8.0
	2	7.2	7.4	7.7	8.5	8.7	10.2	7.5	7.7	8.1	8.7	8.8
	3	8.3	8.6	8.9	9.6	9.9	11.6	8.7	8.9	9.3	9.9	10.2
	T	8.2	8.5	8.8	9.5	9.8	11.5	8.6	8.8	9.2	9.8	10.1
11	1	6.2	6.5	6.7	7.4	7.6	—	6.5	6.6	6.9	7.5	7.6
	2	6.8	7.1	7.4	8.1	8.3		7.1	7.3	7.6	8.2	8.4
	3	7.8	8.2	8.5	9.1	9.5		8.2	8.4	8.8	9.5	9.8
	T	7.7	8.1	8.4	9.0	9.4		8.1	8.3	8.7	9.4	9.7
15	1	6.1	6.4	6.6	7.3	7.5		6.4	6.6	6.9	7.4	7.6
	2	6.7	7.0	7.3	8.0	8.2		7.0	7.2	7.6	8.1	8.3

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	3	7.7	8.1	8.4	9.0	9.4		8.1	8.3	8.7	9.4	9.6
	T	7.6	8.0	8.3	8.9	9.3		8.0	8.2	8.6	9.3	9.5
18.5	1	6.0	6.3	6.6	7.2	7.5		6.3	6.6	6.8	7.3	7.6
	2	6.6	6.9	7.3	7.9	8.2		6.9	7.2	7.5	8.0	8.3
	3	7.5	7.8	8.2	8.8	9.1		7.8	8.1	8.4	9.1	9.4
	T	7.4	7.7	8.1	8.7	9.0		7.7	8.0	8.3	9.0	9.3
22	1	5.8	6.0	6.4	6.9	7.1		6.1	6.2	6.5	7.0	7.2
	2	6.4	6.6	7.0	7.6	7.8		6.7	6.8	7.1	7.7	7.9
	3	7.2	7.5	7.8	8.5	8.7		7.6	7.7	8.0	8.8	9.1
	T	7.1	7.4	7.7	8.4	8.6		7.5	7.6	7.9	8.7	9.0
30	1	5.7	6.0	6.3	6.8	7.0		6.1	6.1	6.5	6.9	7.1
	2	6.3	6.6	6.9	7.5	7.7		6.7	6.7	7.1	7.6	7.8
	3	7.2	7.4	7.7	8.4	8.7		7.5	7.7	8.0	8.8	9.0
	T	7.1	7.3	7.6	8.3	8.6		7.4	7.6	7.9	8.7	8.9
37	1	5.7	5.9	6.2	6.8	7.0		6.0	6.1	6.4	6.9	7.1
	2	6.3	6.5	6.8	7.5	7.7		6.6	6.7	7.0	7.6	7.8
	3	7.2	7.4	7.7	8.4	8.7		7.5	7.7	8.0	8.8	9.0
	T	7.1	7.3	7.6	8.3	8.6		7.4	7.6	7.9	8.7	8.9
45	1	5.6	5.8	6.2	6.7	6.9		6.0	6.0	6.4	6.8	7.0
	2	6.2	6.4	6.8	7.4	7.6		6.6	6.6	7.0	7.5	7.7
	3	7.1	7.4	7.7	8.4	8.6		7.5	7.6	7.9	8.7	9.0
	T	7.0	7.3	7.6	8.3	8.5		7.4	7.5	7.8	8.6	8.9
55	1	5.6	5.6	—	6.6	6.8		5.7	5.8	—	6.7	6.9
	2	6.1	6.2		7.3	7.5		6.3	6.4		7.4	7.6
	3	7.0	7.1		8.1	8.3		7.2	7.3		8.5	8.7
	T	6.9	7.0		8.0	8.2		7.1	7.2		8.4	8.6
63	1	5.6	5.6		6.6	6.7		5.7	5.8		6.6	6.8
	2	6.1	6.2		7.2	7.4		6.3	6.4		7.3	7.5
	3	7.0	7.1		8.1	8.3		7.2	7.3		8.5	8.7
	T	6.9	7.0		8.0	8.2		7.1	7.2		8.4	8.6
75	1	5.6	5.6		6.5	6.6		5.7	5.8		6.6	6.8
	2	6.1	6.2		7.1	7.3		6.3	6.4		7.2	7.5
	3	7.0	7.1		8.1	8.3		7.2	7.3		8.5	8.7
	T	6.9	7.0		8.0	8.2		7.1	7.2		8.4	8.6
90	1	5.5	5.6		6.4	6.6		5.6	5.7		6.5	6.6
	2	6.0	6.1		7.0	7.2		6.2	6.3		7.1	7.3
	3	6.8	6.9		7.9	8.1		7.0	7.1		8.3	8.5
	T	6.7	6.8		7.8	8.0		6.9	7.0		8.2	8.4
110	1	5.5	5.6		6.4	6.6		5.6	5.7		6.5	6.6
	2	6.0	6.1		7.0	7.2		6.2	6.3		7.1	7.3

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	3	6.8	6.9		7.9	8.1		7.0	7.1		8.3	8.5
	T	6.7	6.8		7.8	8.0		6.9	7.0		8.2	8.4
132	1	5.3	5.4		6.3	6.6		5.4	5.6		6.4	6.6
	2	5.8	5.9		6.9	7.2		5.9	6.1		7.0	7.3
	3	6.6	6.8		7.6	8.0		6.8	7.0		8.0	8.3
	T	6.5	6.7		7.5	7.9		6.7	6.9		7.9	8.2
160	1	5.3	5.4		6.3	6.5		5.4	5.6		6.4	6.6
	2	5.8	5.9		6.9	7.1		5.9	6.1		7.0	7.2
	3	6.6	6.7		7.6	7.9		6.7	7.0		7.9	8.3
	T	6.5	6.6		7.5	7.8		6.6	6.9		7.8	8.2