Diplomarbeit

Greenhouse Gas Inventory

&

Greenhouse Gas Mitigation Potential

erstellt für

austriamicrosystems AG

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Kurzfassung

Greenhouse Gas Inventory & Greenhouse Gas Mitigation Potential

austriamicrosystems AG ist ein Halbleiterhersteller der analoge Hochleistungsschaltkreise herstellt. Die Firma besitzt schon seit Jahren ein hohes Engagement im Umweltschutz und hat sich nun auch entschlossen, die von ihr verursachten Treibhausgasemissionen in einem Projekt zu erheben. Im Zuge dieser Arbeit wurden alle CO_2-Emissionen erhoben, die durch den Produktionsprozess, durch die Mitarbeiter bei der Anreise zum Arbeitsplatz, durch Geschäftsreisen oder durch den Transport von Produkten verursacht werden. Die Emissionen des Produktionsprozesses setzen sich aus dem Umsatz an thermischer Energie (fossile Brennstoffe Erdgas, Erdöl), dem Verbrauch an elektrischer Energie und dem Einsatz von Spezialgasen in der Waferherstellung zusammen. Als Basisjahr für die Treibhausgasbilanz wurde das Jahr 2007 festgesetzt. Insgesamt hat austriamicrosystems in diesem Zeitraum 35,633 Tonnen CO_2-Äquivalent emittiert. Der Großteil der Emissionen (87%) entsteht durch den Produktionsprozess an den beiden Standorten in Österreich und auf den Philippinen. 6% entfallen auf die Anreise zum Arbeitsplatz, 5% auf Geschäftsreisen und 2% auf den Transport der Produkte. Als zweiter Teil der Arbeit wurden Maßnahmen erarbeitet die kurz- und mittelfristig die CO_2-Emissionen des Unternehmens verringern sollen. Die für das Budgetjahr 2009 geplanten Verbesserungen werden ca. 1,000 t CO_2 pro Jahr einsparen. Zusätzlich wurde auch eine Grobabschätzung von Möglichkeiten vorgenommen, um austriamicrosystems CO_2-neutral werden zu lassen. Dafür wurden der Bau eines firmeneigenen Kraftwerks, die Beteiligung an Offset-Projekten sowie das Aufforsten von Waldflächen in Betracht gezogen.

Abstract

Greenhouse Gas Inventory & Greenhouse Gas Mitigation Potential

austriamicrosystems AG is a semiconductor manufacturer that produces high performance analog integrated circuits. For years austriamicrosystems has shown high environmental awareness; it has now decided to determine its greenhouse gas emissions in order to further improve its ecological responsibility. In this project CO_2-emissions from the production process, employee commuting, business travel and product transport were evaluated. Production emissions result from thermal energy conversion, electric energy consumption and special gases used in wafer manufacturing. The base year for the greenhouse gas balance was chosen to be 2007. During that year austriamicrosystems emitted a total of 35.633 tons of CO_2-equivalent. The majority of emissions (87%) were caused by the production process in Austria and the test center in the Philippines. Additionally, 6% resulted from employee commuting, 5% from business travel and 2% from product transportation. The project also developed short and long-term measures to reduce the company's overall CO_2-emissions. Measures budgeted for 2009 will save approximately 1,000 tons of CO_2 per year. A rough evaluation of possible measures to convert austriamicrosystems into a carbon-neutral enterprise was made after investigating the construction of wholly-owned power plants, contributions to offset-projects and reforestation possibilities.

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APPENDIX I

1 Introduction

1.1 Problem definition

austriamicrosystems AG is a semiconductor manufacturer that produces high performance analog integrated circuits including standardized and customized products. Its headquarters and only production site is situated in Unterpremstaetten, Austria. The new 200 mm wafer fabrication with a production capacity of approximately 8,000 wafer starts per month (WSPM) is located there.

As a state-of-the-art enterprise, austriamicrosystems possesses a high environmental awareness. This is evidenced in repeated ISO 14001 certifications and numerous environmental awards. Rising natural gas and electricity prices, as well as recent global events and catastrophes that are undoubtedly linked to climate change, have drawn the company's interests towards the topic of "greenhouse gas balancing".

In its corporate environmental policy published in July 2007, austriamicrosystems clearly states that it "recognizes that human activities are contributing to global climate change" and that it "will pursue activities to lessen [the] company's impact on CO_2-production".

1.2 Goal

One of the company's goals is to optimize its carbon balance sheet by minimizing the impact of machinery and company employees on the environment. In order to fulfill this aim, austriamicrosystems initiated the greenhouse gas (GHG) project. The initial goal of this project was to determine austriamicrosystems' thorough GHG inventory of primary and secondary emission sources.

The GHG project involved identifying, analyzing and evaluating the company's GHG related activities. It required calculating the resulting emissions from primary and secondary energy sources, business travel, everyday employee commuting and product shipment. The purpose was to create an overall balance sheet in order to determine the main contributors, to evaluate the mitigation potential of different influences, and to develop a list of possible short term and long term measures which would allow the company to then optimize its balance sheet by systematically reducing its CO_2-emissions within the next few years.

The GHG project team included Dr. Karl Mueller, Gerit Goetz, DI. Karl Wild, DI Peter Dingsleder, Bak. Roman Wallner, Nikolas Trofaier, MSc., Professor Dr. Werner Kepplinger, and assistant professors Dr. Rupert Baumgartner and Dr. Franz Aschenbrenner of the Mining University of Leoben.

The data acquisition process and the calculation procedure were partly based on the guidelines stated in ISO 14064, the Greenhouse Gas Protocol of the World Resources Institute and the guidelines of the Intergovernmental Panel on Climate Change (IPCC).

These references provide information on internationally applied GHG accounting methodologies and are excellent references for voluntary or mandatory reporting activities.

ISO 14064 describes principles and requirements for designing, developing, managing and reporting company level greenhouse gas inventories. It was prepared by the Technical Committee “Environmental Management” of the International Organization for Standardization and is meant to benefit organizations, governments, project proponents and stakeholders by providing clarity and consistency for quantifying, monitoring, reporting and validating or verifying greenhouse gas inventories or projects. [1]

The Greenhouse Gas Protocol Initiative is a partnership of businesses, non-governmental organizations (NGO), governments and others convened by the World Resource Institute, which is a US-based environmental non-governmental organization. The initiative itself comprises two separate but linked standards: the GHG Protocol Corporate Accounting and Reporting Standard and the GHG Protocol Project Quantification Standard. The former document provides a step-by-step guide to quantifying and reporting GHG emissions; the latter is a guide for quantifying reductions from GHG mitigation projects. [2]

Both the ISO 14064 and the Greenhouse Gas Protocol are partly based on papers and data that IPCC collected and published. The IPCC was established “…to provide the decision-makers and others interested in climate change with an objective source of information about climate change” [3]. It does not conduct any research itself and only assesses on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide. [3]

austriamicrosystems’ GHG project was the company’s first approach towards quantifying its GHG inventory and had to take the prevailing conditions and the company’s special requirements and interests into account. Thus, this report is a company unique paper that made use of the described guidelines and standards whenever possible. The information presented in this report will be as accurate, transparent, complete and extensive as possible in order to facilitate the understanding of austriamicrosystems’ GHG related activities and guide further actions and future decisions related to optimization of its carbon balance sheet.

2 Company and Data structure

The administration, design, engineering, mask shop and wafer fabrication required for austriamicrosystems AG's production of high performance analog integrated circuits, are situated on a 24.400 m^2 area in Unterpremstaetten. Figure 1 shows the layout of the site.

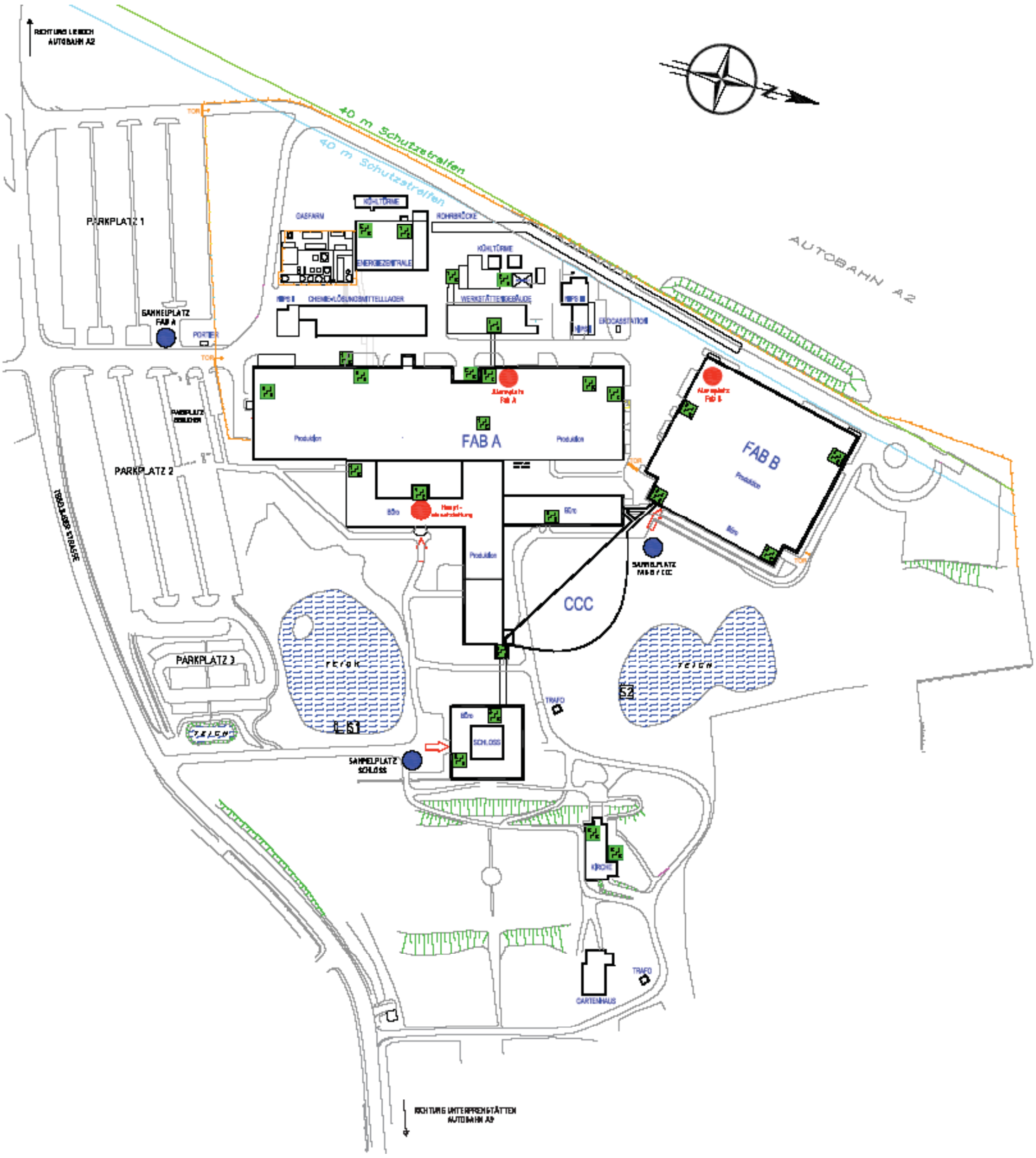

Figure 1: Site plan austriamicrosystems Unterpremstaetten

The entire chip fabrication process takes place in the FAB B building in the northern part of the area. The FAB A building (the former wafer fabrication site) now houses some of the test and assembly equipment, the mask-shop, all laboratories, part of the facility equipment and most of the offices. To the west of FAB A are the energy center for FAB B, the cooling towers, the gas farm, the uninterrupted power supply units (UPS) and a chemical storage depot.

The Castle houses most of the management offices. A glass-covered walkway connects the Castle to FAB A. Between the Castle and FAB B lies the newest building on the property, the CCC (Cafeteria & Conference Center). The new canteen, an event hall and 14 conference rooms are located there.

2.1 Organizational boundary

The first important step of the project was to define the organizational boundaries of the company. In addition to the Austrian headquarters, austriamicrosystems also runs a test center in Calamba in the Philippines, a test development center in Plymouth in the UK, a test development and design center in Rapperswil in Switzerland, two design centers in Hyderabad and Bangalore in India and two design centers in Pisa and Pavia in Italy.

As the sites with significant energy consuming equipment are Unterpremstaetten and Calamba, the project team decided only to account for these two locations.

The GHG protocol distinguishes between two approaches to consolidate GHG emissions: the equity share approach and the control approach. [2] Using the equity share approach, the company has to account for GHG emissions from operations according to its share of equity in the operation. When the control approach is used, the company has to account for 100 % of the GHG emissions from operations that it controls. If a company wholly owns all its operations, its organizational boundary will be the same for both approaches. [2] It is not necessary for austriamicrosystems to follow either of these approaches at the moment as the company wholly owns both operations taken into consideration. However, compliance has to be kept in mind for future reporting projects when other operations also need to be accounted for.

Another aspect for future GHG projects is to distinguish between GHG accounting and GHG reporting. GHG accounting concerns the recognition and consolidation of GHG emissions and linking the data to specific operations, sites, geographic locations, business processes and owners. GHG reporting, on the other hand, concerns the presentation of data in formats tailored to the needs of different reporting uses and users. This would affect how austriamicrosystems might prepare future reporting for official government reporting requirements, mandatory or voluntary emission trading programs, public reporting or just internal improvements.

As this paper is mainly for internal use, it was not specifically adjusted to any GHG accounting or reporting purpose.

2.2 Operational boundaries

After having determined the organizational boundaries, the operational boundaries had to be set. Direct and indirect GHG emissions can generally be distinguished. Direct emissions are emissions from sources that are owned or controlled by a company. Indirect emissions are a consequence of the activities of the company, but occur at sources owned or controlled by another company. [2]

In order to help delineate direct and indirect emission sources and to improve transparency, the GHG Protocol defines three different scopes for GHG accounting and reporting [2].

- **Scope 1** comprises all direct GHG emissions such as emissions from combustion in owned or controlled boilers, furnaces or vehicles or from chemical production in process equipment.
- **Scope 2** accounts for GHG emissions from the generation of electricity or steam, which is purchased from another company and then consumed within the organizational boundary.
- **Scope 3** emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by it. This can be transport-related activities, electricity-related activities not included in scope 2, leased assets or outsourced activities, use of sold products and services and waste disposal.

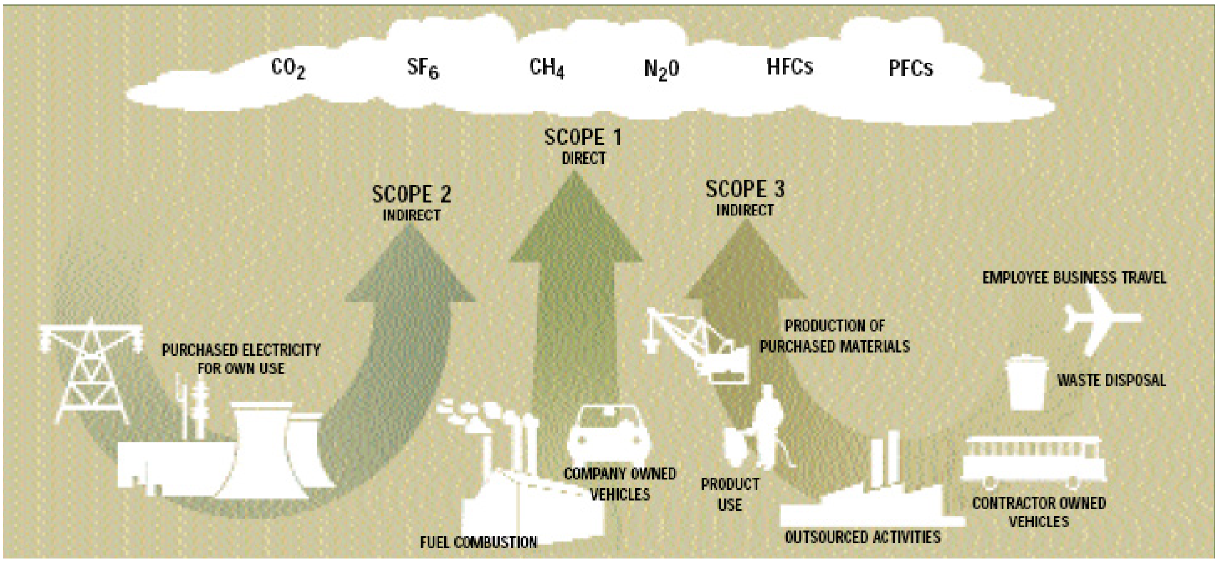

Figure 2: Overview of scopes and emissions [2]

The following list allocates all GHG emission sources of austriamicrosystems within the previously defined organizational boundaries to the three scopes:

- **Scope 1:** combustion of natural gas and fuel oil in steam, hot water boilers and abatement systems, combustion of diesel fuel in engines for the uninterrupted power supply (UPS) systems, combustion of diesel fuel in the pool cars
- **Scope 2:** purchased electricity used for all electrical equipment
- **Scope 3:** employee business travel, employee commuting to and from work, transportation of products and semi-finished goods

It is important to stress that the inclusion of Scope 3 emissions is optional. However, inclusion allows austriamicrosystems to expand its GHG inventory boundary along its value chain and to identify more relevant GHG emissions. [2] A broader view of GHG emissions involving austriamicrosystems can offer additional opportunities for significant emission reductions.

As already described in the introduction, one of the most important goals of this study was to allocate the resulting GHG emissions to its sources as precisely as possible. Based on the allocation weak points were detected and as consequence measures, possible improvements and reduction potential could be determined. In order to find possible weak points, the GHG emissions had to be allocated to individual technical equipment as precisely as possible.

The following flow chart, shown in Figure 3, was developed in cooperation with the facility staff of austriamicrosystems to depict greenhouse gas emission allocations. The chart defines the operational boundaries, which are basically identical to the respective plant boundaries of FAB A, FAB and the Philippines. These three levels were broken down to the machine-unit level wherever possible. A fourth parallel level was also defined: Transport Processes. This is not an operational area itself but the resulting GHG emissions could be allocated to one of the other areas. As these emissions can be considered to be equally distributed over the whole company this section was also placed on the second level.

The so called sub-units or sectors for FAB A, FAB B and the Philippines were chosen based on their technical and functional coherence in order to facilitate accountability of input streams. This structure also alleviated finding and assessing technological improvements.

The sub-units were further divided into individual machines or machine groups, which represents the highest reasonable and feasible level of detail. Machines and machine groups were labeled with their abbreviations from the facility control system and specification sheets. This means, for example, that the hot water boiler HK1 of the BOILER sector in FAB A summarizes smaller machines linked to it, such as the burner and the circulation pumps.

The chart also defines all input streams, which then result in GHG output streams. The ISO 14064 requires that an organization uses tons of CO_2 as the unit for emissions. All greenhouse gases have to be converted to their CO_2-equivalents by using the greenhouse gas global warming potentials (GWP) published by the IPCC. [1]

Thus, all output streams in the flow chart are expressed in tons CO_2.

Figure 3: Flow Chart

FLOW CHART WILL BE PLOTTED!

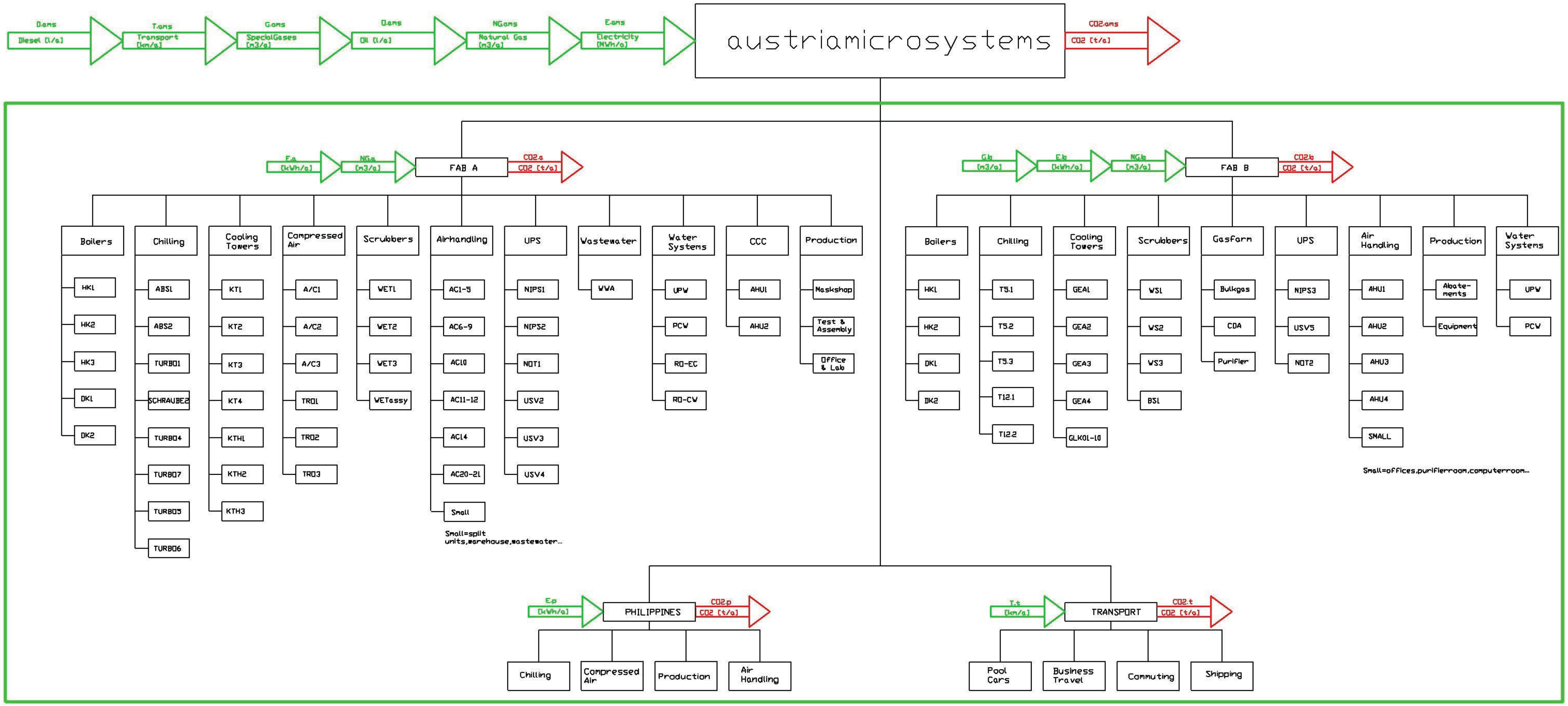

Figure 3

FLOW CHART
ENERGY - CO2

austriamicrosystems

2.3 Emission sources

Internal archives, specification sheets, and facility personnel provided the data and information relevant to the emission sources for the operational areas under study: FAB A, FAB B, the Philippines, and Transport Processes.

2.3.1 FAB A:

Fab A comprises a building complex built in 1982, which originally housed the former wafer fabrication plant. Upon completion of the new fabrication hall, FAB B, all of the wafer production was moved there and test machines, the mask shop and an assembly section remained in FAB A. The laboratories, the facility installations, and most of the engineering and administration offices are also located in the building complex of FAB A.

Boilers: Five boiler units are installed in the northern part of FAB A. Three hot water boilers (HK1, HK2, HK3) are used to supply hot water to the heating system, the sanitary installation and the two absorption chillers of FAB A. Two 2,000-kW steam boilers (DK1, DK2) provide steam for compartment air humidification. All five units run on natural gas. In addition, the steam boilers have fuel oil backup burners.

Chilling: In order to maintain specified climatic conditions in the clean rooms, storage facilities, offices and other building areas, five turbo chillers (Turbo1, Turbo4-7), two absorption chillers (ABS1, ABS2) and one screw chiller (Schraube2) operate on the ground floor of FAB A. Turbo1 possesses 1,400 kW of chilling power and Turbo4-7 and Schraube2 each has 870 kW. The absorption chillers ABS1 and ABS2 have a chilling power of 1,100 and 1,200 kW, respectively. The machines are used for dehumidification and to produce two different ranges of cold water, 0 to 5° and 5 to 10° Celsius, respectively. All machines except for Turbo1 and Schraube2 are original inventory.

Cooling Towers: Seven cooling tower units recool the accumulated heat from the chillers. Three cooling towers are air cooled with a cooling capacity 3,000 kW each (KT2T, KT3T, KT4T). To improve cooling power, KT2T and KT4T can also be sprinkled with water. The other four towers use water-cooling technology with a capacity of 3,800 kW for KT1, KT3 and KT4 and 1,900 kW for KT3A.

Compressed Air: Each of the three air compressors (A/C1, A/C2, A/C3) produces 2,756 m^3 of compressed air per hour, which is dried in three drier units (TRO1, TRO2, TRO2).

Scrubbers: Two scrubbers (WET3, WETassy) treat acidic and alkaline process off gas.

Air Handling: This section comprises seven air-handling unit (AHU) groups for make-up air and indoor air circulation: AC1-5, AC6-9, AC10, AC11-12, AC14, AC20-21 and SMALL

Uninterrupted Power Supply (UPS): In order to secure an uninterrupted supply of electrical power, which is absolutely crucial to the production process, austriamicrosystems possesses a total of seven UPS units. These units continuously operate in standby mode and can balance voltage drops of the grid and bridge electrical power outages. Five units are assigned to the FAB A operational area due their installation location. Units NIPS1 and NIPS2 are two 500 kVA UPS units with diesel engines and flywheels. Units USV2, USV3, USV4 are 250 kVA units with flywheels only.

Wastewater: The wastewater plant physically and chemically treats polluted water from the production processes and the abatement systems. This subarea includes all electrical consumers in the wastewater plant such as pumps and aeration devices. The treated water is sent to the public water treatment plant in Wildon for post treatment of nitrogen compounds.

Water Systems: The water systems consist of the equipment related to the input water streams. Process water is pumped from a company-owned well approximately 3 km away from the property. Three immersion pumps pump the water through a pipeline to austriamicrosystems. A system of reverse osmosis, ion-exchangers, ultra-filtration, membrane-degasification and UV-disinfection treats the water for the chip fabrication process (UPW[1], PCW[2]). A number of reverse osmosis units (RO-EC, RO-CW) treat cooling water for the cooling towers and the chillers.

CCC: The CCC is the newest building on the property of austriamicrosystems. It was completed in spring 2007 and is home to the new canteen, conference rooms and an event hall. Electrical consumption such as ventilation, kitchen equipment, lighting and air conditioning, is allocated to the individual areas within the CCC: Event, Canteen, Wardrobe and Conference.

Production: The three production areas are Mask Shop with the mask manufacturing equipment, Test and Assembly with the testers and some assembly equipment, and Office and Laboratories. Mask Shop and Test and Assembly are two of the biggest electrical energy consumers of FAB A, with 210 kW and 430 kW installed power, respectively.

2.3.2 FAB B:

The new chip plant was brought into service in 2000 and has been continuously operating since then. The first 8 hours of scheduled downtime were in spring 2008 for necessary maintenance work. The following subareas are assigned to FAB B even though several interconnections between the two plants exist.

[1] Ultra Pure Water

[2] Process Water

Boilers: FAB B possesses two steam boilers and two hot water boilers. The two hot water boilers (HK1, HK2) are mounted in the energy center whereas the two steam boilers (DK1, DK2) are placed directly in the FAB B building. The hot water from HK1 and HK2 is transferred to FAB B via a pipeline bridge. All the boilers use natural gas as the main fuel source except for HK1 which uses oil as backup fuel. HK1 has a thermal power of 2,900 kW and was over dimensioned, thus it is almost never used. HK2 has a thermal power of 1,860 kW and produces the entire hot water for FAB B. Both steam boilers have a thermal power of 862 kW.

Chilling: Five turbo chillers are installed in the energy center (T5.1, T5.2, T5.3, T12.1, T12.2). T5.1, T5.2 and T5.3 have a chilling capacity of 2,000 kW whereas T12.1 and T12.2 possess 2,400 kW each. The pipeline bridge transfers the cooled water to FAB B at two different temperature levels of 5° and 12° Celsius.

Cooling Towers: FAB B actually uses a two-fold system to cool the cooling water. If the outside temperature is below 10° C, the heat is redirected to a free-cooling system by a heat switch. This system uses Glycol as heat transfer medium, which is circulated through air ventilators (GLK01-10). When the outside temperature is too high for the free-cooling system, the turbo chillers are used instead. They use four water towers to re-cool the accumulated heat (GEA1, GEA2, GEA3, GEA4).

Scrubbers: The exhaust from the FAB B production equipment is treated in three scrubbers and one bio scrubber (BS1) before it is blown to the stacks. Two of the scrubbers use acidic dissolutions (WS1, WS2) and one uses caustic dissolutions (WS3).

Gas Farm: The gas farm produces technical gases (N_2, O_2, H_2, CDA[3]) for the production equipment in FAB B. The farm is run by Linde Nippon Sanso but is still part of austriamicrosystems. To facilitate the allocation of energy consumption, the farm was split into its three main functional areas: Bulk Gas, CDA and Purifier. Bulkgas comprises two machine lines that produce 1000 m^3 and 600 m^3 of nitrogen gas per day. Both lines consist of a compressor, pumps, chillers and a mole sieve. These machines together with the compressor and the purifier plant are some of the biggest electrical consumers at the austriamicrosystems site.

Air handling: The air-handling units are responsible for make-up air, air circulation and air management in the individual sections of the building. Based on their respective size and the purpose they serve, the units are categorized into 11 groups (AHU1, AHU2, AHU3, AHU4, KL05, KL08, KL09, KL21, KL22, KL23, FFU[4]). Most units are installed on the top floor right under the roof and above the production clean room.

[3] Compressed Dry Air

[4] Fan Filter Units

UPS: Another two UPS units are assigned to FAB B, which work on the same principles as their counterparts in FAB A. Unit NIPS3 consists of a 1,000 kVA synchronous generator powered by a diesel engine and connected to a flywheel. Unit USV 5 is a 500 kVA flywheel generator.

Air handling: The air-handling units are responsible for make-up air, air circulation and air management in the individual sections of the building. Based on their respective size and the purpose they serve, the units are categorized in 11 groups (AHU1, AHU2, AHU3, AHU4, KL05, KL08, KL09, KL21, KL22, KL23, FFU[5]). Most units are installed on the top floor right under the roof and above the production clean room.

Water Systems: Like FAB A, FAB B has a water processing plant of its own that produces ultra pure water (UPW) and process water (PCW).

Production: Production encompasses Equipment and Abatements. Equipment includes large production machinery as well as smaller energy consumers such as the vacuum pumps and the office areas. PFCs[6] are necessary for some of the process steps in chip fabrication. External companies deliver these gases in gas bottles to austriamicrosystems. After usage the bottles are incinerated in the abatement systems. The abatement systems are small combustion chambers, that use natural gas for incineration.

2.3.3 Philippines:

austriamicrosystems' test center in Calamba in the Philippines has 1,800 m^2 of production area and 360 m^2 of office area. The energy consumption there is solely electrical. A local power plant supplies electricity via two 1 MVA transformers which transform the grid voltage of 13,5 kV to 400 V.

The four main areas at the test center are chilling, compressed air, production and air handling. Their total energy consumption and installed capacity are rather small compared to the equipment in Unterpremstaetten.

2.3.4 Transport processes

Transport processes consist primarily of Scope 3 emission sources and a few Scope 1 sources. Including these sources provides austriamicrosystems with a broader understanding of its GHG emissions from activities not directly related to the actual production process. The sectors relating to transport processes at austriamicrosystems are:

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[5] Fan Filter Units

[6] PerFluorCarbons

- Combustion of fuel in pool cars
- Employee business travel
- Employee commuting
- Transportation of products and semi-finished goods

Combustion of fuel in pool cars: There are five company owned cars (minivans) in the car pool at Unterpremstaetten. Their plate numbers are: GU711EU, GU613ED, GU224DF, GU223DF and GU556DZ. These cars are only used for company-related rides. There are also several company owned cars that management personnel use as private cars; these have not been included in this study since the majority of their emissions are not linked to austriamicrosystems' activities. The test center on the Philippines has a diesel-powered car. Its kilometer reading is included.

Employee business travel: There is insufficient data to consider travel by car or railway. Air travel, however, is well documented and constitutes by far the largest portion of business travel.

Employee commuting: An important indicator of the environmental awareness of a company is how its employees get to work everyday. austriamicrosystems broached this topic several times in the past years and various efforts have been made to influence the commuting habits of employees. The company-operated commuter bus is just one example. As the majority of employees still use private cars to get to work every day, the resulting GHG emissions were estimated.

Transportation of products and semi-finished goods: austriamicrosystems has all of its product shipping done by forwarding agencies. This study estimated the GHG emissions resulting from shipping completed products to the first recipient. While delivery processes from the last supplier were not included for reasons discussed in section 3.4, internal transport processes between two austriamicrosystems sites were investigated.

2.4 Base year

The first step of the data gathering process was to select which 365-day period to measure. This period, called the base year, provided a performance year with which future data could be compared. ISO 14064 and the GHG Protocol prescribe a very specific definition of the base year: "Companies shall choose and report a base year for which verifiable emissions data are available and specify their reasons for choosing that particular year". [2]

The GHG protocol requires using the base year as a starting point for setting and tracking progress towards a GHG target. [2] It further requires companies to develop a base year emissions recalculation policy. This policy is necessary for modifying previous base year values so that meaningful emission comparisons can be made as companies change and evolve.

Possible situations necessitating base year emission recalculations are [2]:

- Structural changes that significantly impact the base year emissions take place in the company (i.e. acquisitions, divestments and mergers).
- Decisions are made to change the calculation methodology or there are improvements in the accuracy of emission data or factors.
- Significant errors in inventory or other calculations are discovered.

Base year emissions have to be recalculated when a pre-defined significance threshold is met. The California Climate Action Registry, for example, suggests a threshold of 10% of base year emissions. [4]

No base year recalculation is necessary if a facility is acquired which did not exist in the base year or when the company is subject to organic growth or decline. This means that an increase or a decrease in production output, a change in product mix, or the closure or opening of operating units owned or controlled by the company does not trigger a recalculation. [2]

The austriamicrosystems GHG project team agreed on 2007 as the base year for this first GHG inventory. The reasons for this decision were:

- Substantial changes to austriamicrosystems' production setup were made up through 2007 in order to set the company up for future manufacturing needs.
- The CCC opened in spring 2007.
- As some of the control and communication systems only hold data sets for a limited time span, data was most accessible for 2007.
- 2007 was the kick-off year for the austriamicrosystems GHG project.

austriamicrosystems will follow the GHG Protocol requirements for recalculating base year emissions and will use the 10 % threshold to initiate recalculation. Thus, any non-organic change at austriamicrosystems that would impact the base year emission levels by 10% or more will trigger recalculation.

3 Fundamentals

As described austriamicrosystems possesses numerous energy consumers. At the lowest level of detail there is an almost countless number of small consumers such as light bulbs, coffee machines or cell phone chargers. Their rated power is very low (a few W). Thus it is quite complicated and also inefficient to affect and reduce their individual or total power performance. It is much more effective to influence the performance of the comparatively few high power machines with a rated power (thermal or electrical) of over 1000 kW. Most of these are refrigerator units and boilers.

In order to offer a better understanding of the thermodynamic and mechanical principles of these machines, the fundamental theoretical concepts of refrigeration and combustion are outlined in this chapter.

3.1 Refrigeration

The biggest individual electric power consumers at the austriamicrosystems plant in Unterpremstaetten are the chiller units. They are used to generate and maintain convenient working conditions in the offices as well as on the production floors. They also cool and dehumidify inside air and re-cool production equipment. In order to get a better understanding of their purpose and method of operation, this chapter provides an introduction into refrigeration.

Refrigeration describes the process of heat transfer from a lower temperature level to a higher temperature level. Machines that produce refrigeration are called refrigerators. The cycles that describe their mode of operation are called refrigeration cycles. The most frequently used refrigeration cycle is the vapor-compression cycle. In this cycle the refrigerant is vaporized and condensed alternately. In the vapor phase it is compressed. Another well-known refrigeration cycle is the gas refrigeration cycle. This cycle uses a constant gaseous refrigerant. Some other refrigeration cycles are cascade refrigeration, absorption refrigeration and thermoelectric refrigeration. These cycles, however, shall not be covered in this section. [5]

3.1.1 Refrigerators and heat pumps

Figure 4 shows a schematic of the principles of a refrigerator (left) and a heat pump (right). Both machines basically work on the same principle. They transfer heat from a low level to a high(er) level. The only difference lies in their objectives. The purpose of a refrigerator is to maintain a refrigerated space at a low temperature by removing heat from it. Discharging this heat to a higher-temperature area is necessary for the process but is not its purpose. The objective of a heat pump, however, is to maintain a heated space at a high temperature. A refrigerator and a heat pump are more or less the same machine. However, one makes use of the cold side and the other of the warm side. [5]

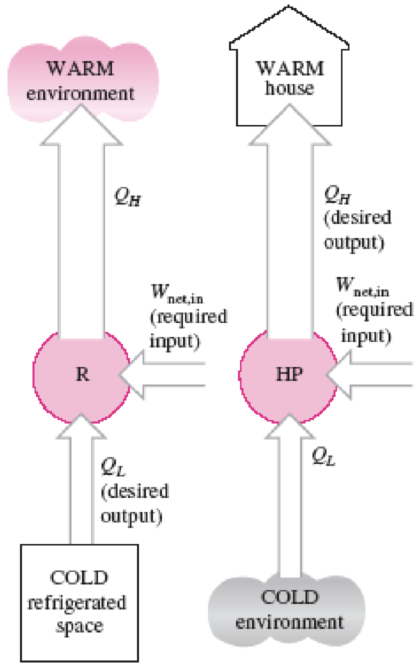

Figure 4: Schematic of Refrigerator (R) and Heat Pump (HP) [5]

In Figure 4 Q_L stands for the magnitude of the removed heat from the refrigerated space at temperature T_L. Q_H stands for the magnitude of the heat discharged to the warm space at temperature T_H. In order to achieve this temperature lift, a work input is required represented by $W_{net,in}$.

The performance of refrigerators and heat pumps is expressed as the coefficient of performance (COP) and is defined as [5]:

$$COP_R = \frac{Desired\ output}{Required\ input} = \frac{Cooling\ effect}{Work\ input} = \frac{Q_L}{W_{net,in}} \quad (1)$$

$$COP_{HP} = \frac{Desired\ output}{Required\ input} = \frac{Heating\ effect}{Work\ input} = \frac{Q_H}{W_{net,in}} \quad (2)$$

3.1.2 Reversed Carnot Cycle

Most refrigerators or heat pumps operate on the reversed Carnot cycle. The classic Carnot cycle is used as a standard against which actual power cycles can be compared because it describes the maximum thermal efficiency for given temperature limits. It is totally reversible and consists of two reversible isothermal and two isentropic processes. On the T-s diagram it rotates to the right or clockwise.

If this cycle is reversed, the directions of any heat and work interactions are also reversed. The result is a cycle that operates in the counterclockwise direction. This is the cycle refrigerators are based on. Figure 5 shows a reversed Carnot cycle. [5]

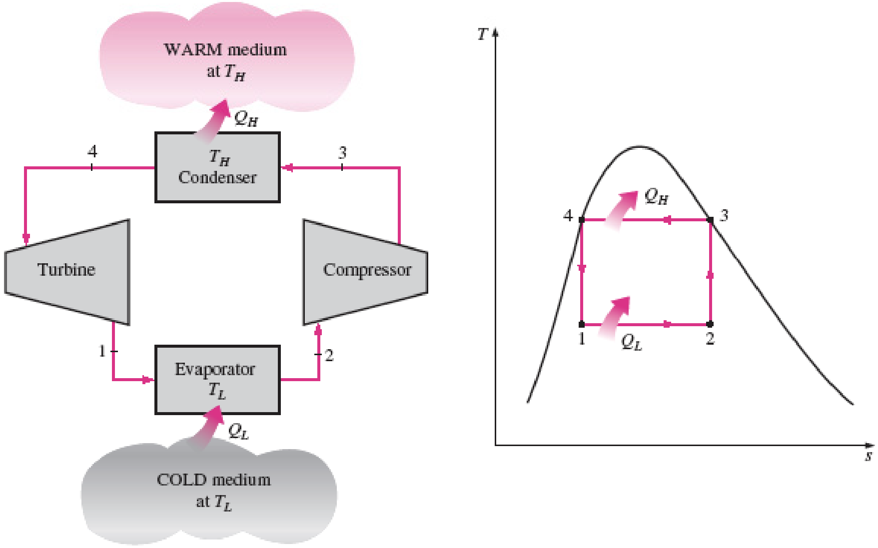

Figure 5: Schematic and T-s diagram of reversed Carnot cycle [5]

In the evaporator (1-2) the refrigerant absorbs heat isothermally from a low-temperature source at T_L in the amount of Q_L. It is then compressed isentropically in a compressor to state 3. The temperature rises to T_H. In the condenser (3-4) the refrigerant rejects heat isothermally to a high-temperature sink at T_H in the amount of Q_H. It expands isentropically to state 1 in a turbine. This makes the temperature drop to T_L. In the condenser the refrigerant changes from a saturated vapor state to a saturated liquid state. Usually the coefficients of performance of Carnot refrigerators are expressed in terms of temperatures. A coefficient is calculated for the refrigerator by:

$$COP_{R,Carnot} = \frac{1}{\frac{T_H}{T_L} - 1} \quad (3)$$

The COP increases when the difference between the two temperatures decreases, or when T_L rises or T_H falls.

In actual refrigeration applications, however, the reversed Carnot cycle cannot be used. This is mainly due to the impracticalities a liquid-vapor mixture causes in the compressor and the turbine. Thus, it only serves as a standard against which actual refrigeration cycles are compared because it represents the most efficient refrigeration cycle operating between two specified temperature levels. [5]

3.1.3 Ideal vapor-compression refrigeration cycle

Vaporizing the refrigerant completely before it is compressed can eliminate many problems of the reversed Carnot cycle. Additionally, if the turbine is replaced with a throttling device, such as an expansion valve or capillary tube, the resulting cycle is called the ideal vapor-compression refrigeration cycle. Figure 6 shows a schematic of the process. The ideal vapor-compression refrigeration cycle is the most widely used cycle for refrigerators, air-conditioning systems, and heat pumps.

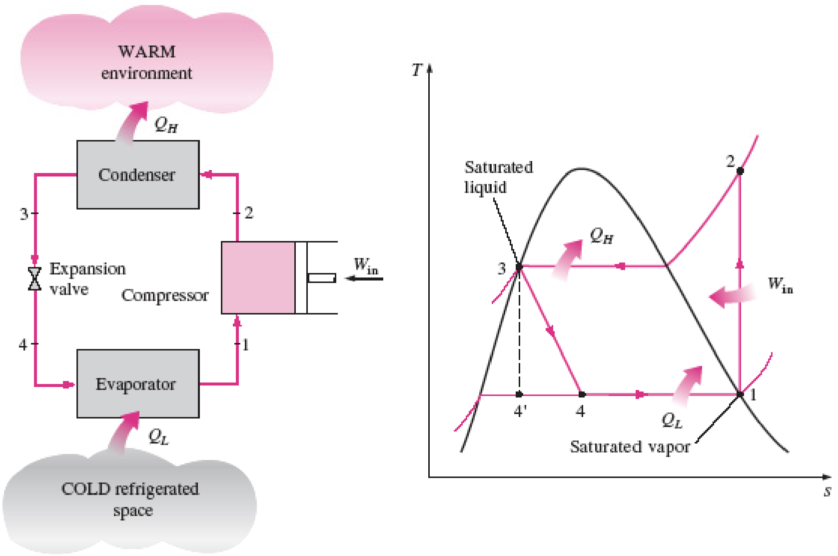

Figure 6: Ideal vapor-compression refrigeration cycle [5]

The four steps of the process are:

1-2 Isentropic compression in a compressor

2-3 Constant-pressure heat rejection in a condenser

3-4 Throttling in an expansion device

4-1 Constant-pressure heat absorption in an evaporator

The refrigerant enters the compressor at state 1 as saturated vapor and is compressed isentropically to the condenser pressure. During the isentropic compression process the temperature of the refrigerant increases to above the temperature of the surrounding medium. It then enters the condenser as superheated vapor and leaves as saturated liquid (2-3). At state 3 the temperature of the refrigerant is still above the temperature of the surroundings. By throttling the saturated liquid refrigerant through an expansion valve to the evaporator pressure, its temperature drops below the temperature of the refrigerated space. The refrigerant then enters the evaporator where it absorbs heat from the refrigerated space. It completely evaporates and leaves as saturated vapor. The cycle is completed when the refrigerant reenters the compressor.

The area under the process curve on a T-s diagram represents the heat transfer for internally reversible processes. The area under the process curve 4-1 represents the heat absorbed by the refrigerant in the evaporator, and the area under the process curve 2-3 represents the heat rejected in the condenser. [5]

3.1.4 Actual vapor-compression refrigeration cycle

The actual vapor-compression refrigeration cycle differs from the ideal cycle in many ways. This is mainly due to the irreversibilities that occur in the individual components. The most common irreversibilities are pressure drops due to fluid friction and heat transfer to or from the surroundings.

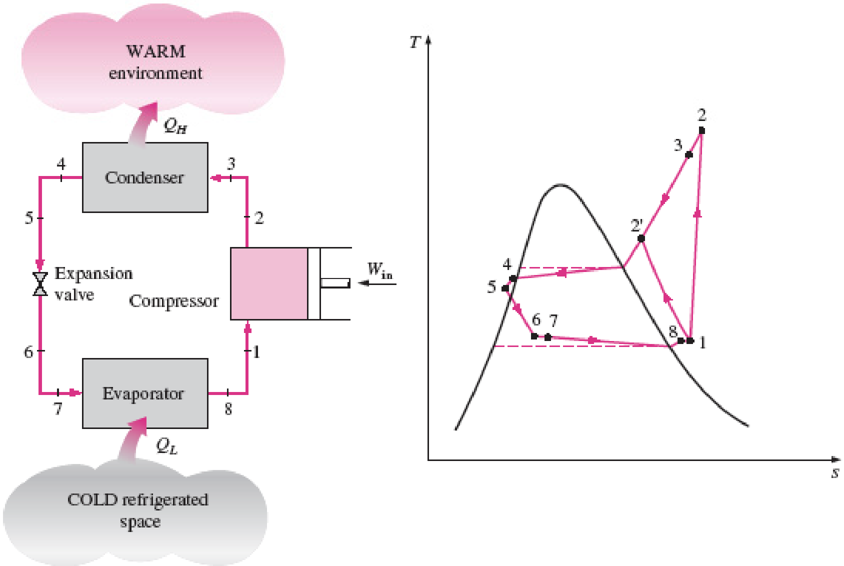

Figure 7: Actual vapor-compression refrigeration cycle [5]

Figure 7 shows the schematic of an actual cycle. In the ideal cycle, the refrigerant leaves the evaporator and enters the compressor as saturated vapor. In practice, however, it is not possible to control the state of the refrigerant precisely. Instead, it is easier to design the system so that the refrigerant is superheated when it enters the compressor. This ensures that the refrigerant is completely vaporized at the compressor inlet. Moreover, the pressure drop due to fluid friction and heat transfer from the surroundings to the refrigerant can be very significant because connecting tubes between the evaporator and the compressor are usually very long. The superheating also increases in the power input to the compressor.

The actual compression process itself – in contrast to the ideal one – is not reversible and not adiabatic, thus not isentropic. Frictional effects can increase the entropy and heat transfer can increase or decrease the entropy, depending on the direction. So in the actual compression process, the entropy of the refrigerant may increase or decrease depending on which effects dominate. [5]

The compression process is the step of the refrigeration cycle where work is brought into the system from outside. This is done by mechanical power input to the shaft that drives the compressor. The mechanical power is usually produced by an electric motor. So the compressor itself is the technical component of a refrigerator where electric energy consumption happens. Therefore compressors shall be discussed in more detail in the following section. [5]

3.1.5 Compressors

Basically there are two types of compressors:

- Positive displacement compressors.
- Dynamic compressors.

Positive-displacement compressors increase the pressure of refrigerant vapor by reducing the volume of the compression chamber through work applied to the compressor's mechanism. The individual principles are: reciprocating, rotary (rolling piston, rotary vane, screw) and scroll.[7]

Dynamic compressors, on the other hand increase the pressure of refrigerant vapor by a continuous transfer of angular momentum from the rotating member to the vapor followed by the conversion of this momentum into a pressure rise. Centrifugal compressors work with this principle. [6]

Compressor performance

Two measures of compressor performance are the coefficient of performance (COP) and the measure of power required per unit of refrigerating capacity. The hermetic COP (COP_h) includes the combined operating efficiencies of the motor and the compressor. According to the COP-definition from above, the hermetic COP is defined as:

$$COP_h = \frac{Refrigerating\ capacity}{Input\ power\ to\ motor} \quad \left[\frac{W}{W}\right] \qquad (4)$$

The COP (COP_o) for an open compressor does not include the motor efficiency:

$$COP_o = \frac{Refrigerating\ capacity}{Input\ power\ to\ shaft} \quad \left[\frac{W}{W}\right] \qquad (5)$$

The power input per unit of refrigerating capacity is a measure of performance, which is mainly used to compare different compressors at the same operating conditions. [6]

$$\frac{W_{in}}{W_{out}} = \frac{Power\ input\ to\ shaft}{Compressor\ capacity} \quad \left[\frac{W}{W}\right] \qquad (6)$$

[7] Another type of positive-displacement compressors is trochoidal compressors. These shall not be covered in this section due to their relative small capacity.

The compressor capacity at any given operating condition is a function of the mass of gas compressed per unit time. In an ideal situation the mass flow equals the product of the compressor displacement per unit time and the gas density:

$$\dot{m} = \rho * V_d \quad \left[\frac{kg}{s}\right] \quad (7)$$

$$P_i = Ideal\ power\ input = \dot{m} * Q_{work\ of\ compression} \quad (8)$$

From the pressure enthalpy diagram of a vapor-compression refrigeration cycle – as shown in Figure 8 – the refrigeration effect and the work of compression can be read as enthalpy differences.

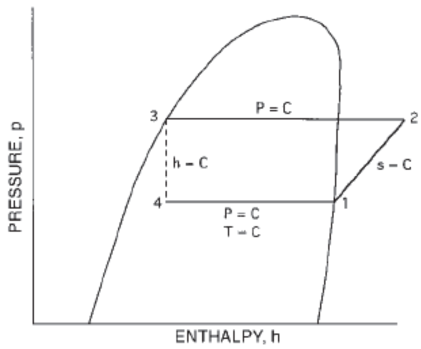

Figure 8: P-h diagram of single stage vapor compression refrigeration cycle [7]

$$Q_{refirgeration\ effect} = (h_1 - h_4) \quad \left[\frac{kJ}{kg}\right] \quad (9)$$

$$Q_{work\ of\ compression} = (h_2 - h_1) \quad \left[\frac{kJ}{kg}\right] \quad (10)$$

The ideal capacity and the ideal power input can then be calculated with the mass flow of gas:

$$Ideal\ capacity = \dot{m} * Q_{refirgeration\ effect} \quad (11)$$

$$P_i = Ideal\ power\ input = \dot{m} * Q_{work\ of\ compression} \quad (12)$$

An actual compressor, however, has various losses, which result in a decrease in capacity and an increase in power input. Some causes for decreased compressor performance are: pressure drops within the compressor, heat gain to refrigerant, valve efficiencies, internal gas leakage, oil circulation, re-expansion, deviation from isentropic compression, over- and under-compression. [6]

Since these deviations from an ideal performance are hard to measure, they are grouped together in categories and determined by the following efficiencies:

- Volumetric efficiency (e_0)
- Compression efficiency (e_2)
- Mechanical efficiency (e_3)
- Isentropic efficiency (e_4)

With these the actual shaft power ($P_{a,s}$) can be calculated:

$$P_{a,s} = \frac{P_i * e_0}{e_2 * e_3} = \frac{P_i * e_0}{e_4} \qquad (13)$$

Once the actual shaft power is known, a suitable motor can be chosen to drive the compressor[8]. [6]

Compressor types

a) Reciprocating compressors:

The majority of reciprocating compressors are single acting. They use pistons that are driven directly through a pin and connecting rod from the crank shaft. Figure 9 shows a full-hermetic piston compressor with a single piston. [6]

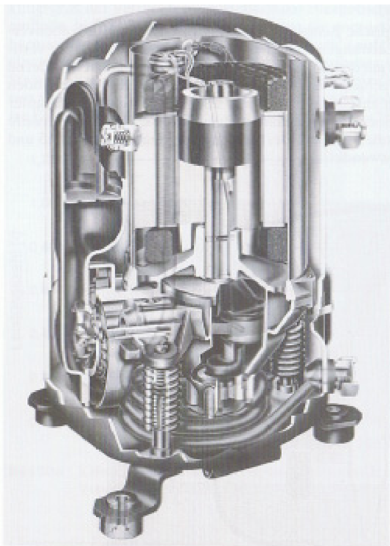

Figure 9: Full-hermetic piston compressor [8]

[8] In a hermetic compressor the motor and the compressor are contained in the same housing.

b) Rolling piston compressors

Rolling piston compressors are also called fixed cane compressors. They use a rolling piston that is mounted on an eccentric of a shaft with a single vane or blade positioned in the non-rotating housing. The blade reciprocates in a slot in the in the cylinder block. This motion is caused by the eccentrically moving piston. Figure 10 sows the concept of these compressors. The maximum power of rolling piston compressors is 2 kW and their main field of application is kitchen refrigerators and air conditioning units. [6]

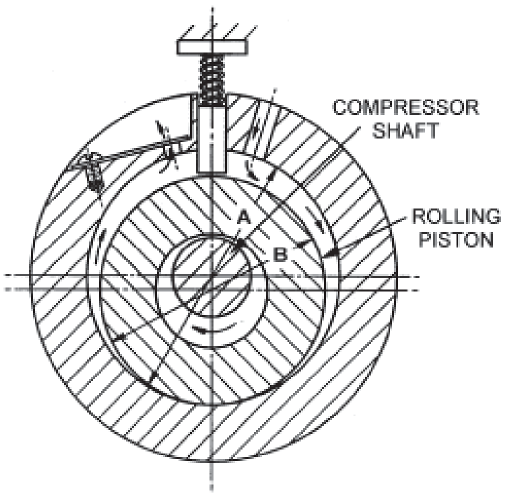

Figure 10: Rolling piston compressor [6]

Rotary piston compressors possess a high volumetric efficiency because of the small clearance volume and correspondingly low reexpansion in their design. Since the gas flow is continuous and no suction valves are necessary, the compressors are relatively quiet. [6]

c) Rotary vane compressor

A rotary vane compressor uses a rotating wheel that is eccentrically mounted in a cylinder block. Cut into the wheel are a certain number of slots in which vanes reciprocate. The vanes form air pockets that shrink when the wheel rotates, thereby creating the compression. Figure 11 shows a cross-sectional view of an eight-bladed compressor.

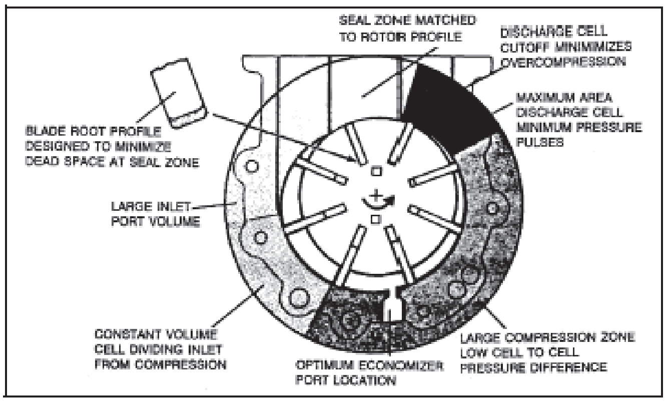

Figure 11: Rotary vane compressor with 8 blades [6]

Rotary vane compressors possess a low mass-to-displacement ratio, which makes them especially suitable for mobile applications. This is also due to their compact size. Rotary vane compressors are built up to a size of 40 kW refrigeration capacity. [6]

d) Screw compressors

There are two different types of screw compressors: single screw and twin screw.

The operation of a screw compressor can be divided into three distinct phases: suction, compression and discharge. These phases are slightly different for the two types. For a single screw compressor, which has two gate rotors in addition to the screw, the process works as follows:

Suction: During rotation of the main rotor, a groove forms that is then open to the suction chamber. It gradually fills with suction gas. The tooth of the gate rotor in mesh with the groove acts as an aspirating piston.

Compression: As the main rotor continues to turn, the groove meets a tooth on the gate rotor and is covered simultaneously by the cylindrical casing of the main rotor. In that phase the gas is trapped in the space formed by the three sides of the groove, the casing, and the gate rotor tooth. The groove volume decreases with the rotation and compression occurs.

Discharge: The gas discharges into the delivery line until the groove volume has been reduced to zero. [6]

The whole process is shown in Figure 12.

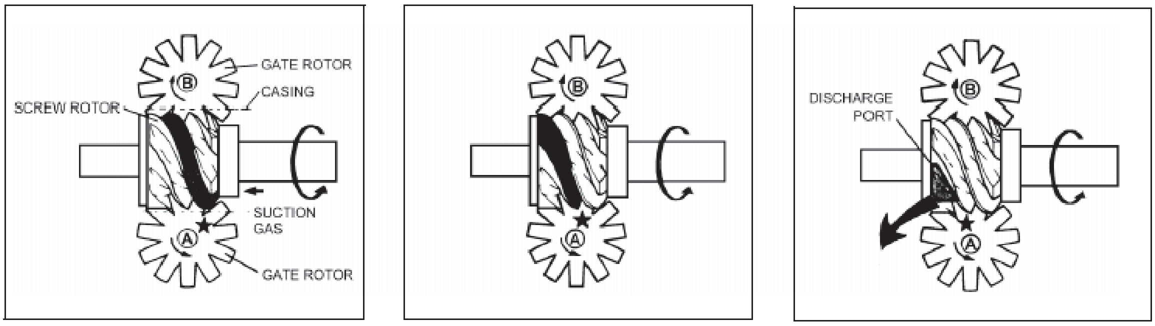

Figure 12: Compression process in single-screw compressor [6]

For a twin-screw compressor the compression principle is basically the same with the only difference being that a second screw replaces the gate rotors. Figure 13 shows a semi-hermetic twin-screw compressor.

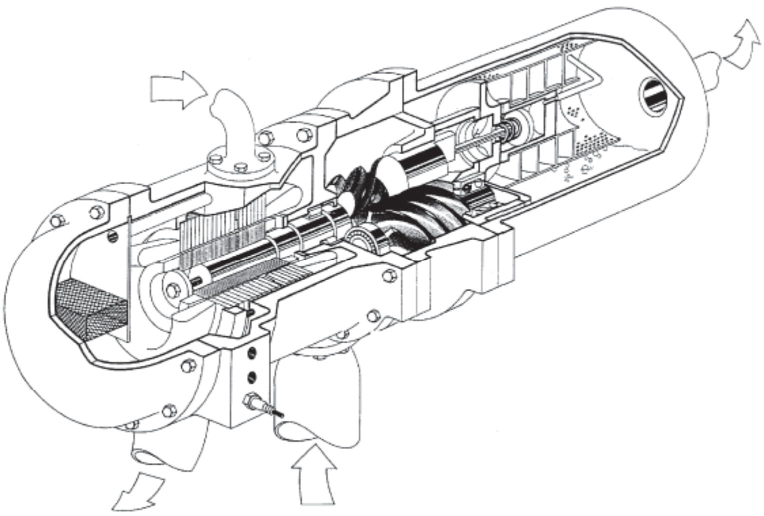

Figure 13: Twin-screw compressor [6]

The capacity of screw compressors ranges up to 4.6 MW. [6]

e) Scroll compressors

Scroll compressors are orbital motion, positive-displacement machines. They use two interfitting, spiral-shaped scrolls for compression. The two scrolls of the compressor are fitted to form pockets between their respective base plate and various lines of contact between their vane walls. One of the scrolls is fixed, while the other moves in an orbital path in relation to the first. The flanks of the scrolls remain in contact, but the contact locations move progressively inward. Figure 14 shows the phases of the compression process. [6]

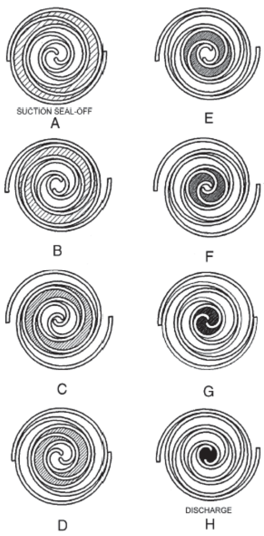

Figure 14: Scroll compression process [6]

The compression is accomplished by sealing suction gas in pockets at the outer periphery of the scrolls. The size of these pockets is then continuously reduced as the scroll's relative motion moves them inwards towards the discharge point. The main fields of application for scroll compressors are residential and commercial air-conditioning, refrigeration, and heat pump applications. Capacities range from 3 to 50 kW. [6]

f) Centrifugal compressors

Centrifugal compressors are also called turbo compressors. They continuously exchange angular momentum between a rotating mechanical element and a steadily flowing fluid. Due to their continuous flows, turbo machines have greater volumetric capacities than positive displacement compressors. That and their ability to produce a high pressureratio makes them well suited for large scale air-conditioning and refrigeration applications. The rotating element is called an impeller. The suction flow enters the impeller in axial direction and is discharged radially at a higher velocity. Figure 15 shows the front view of an impeller and the resulting velocities.

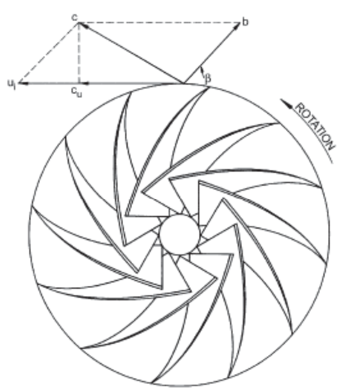

Figure 15: Impeller front view with exit velocity diagram [6]

The change in diameter through the impeller increases the velocity of the gas. This dynamic pressure is then converted to static pressure by a radial diffuser, which can be vaned or vaneless.

There are single-stage turbo compressor with only one impeller (as shown in Figure 16) or multistage turbo compressors with two or more impellers. In multistage compressors, the gas discharged from the first stage is directed to the inlet of the second stage. When the gas reaches the last stage, it is discharged into a collector chamber.

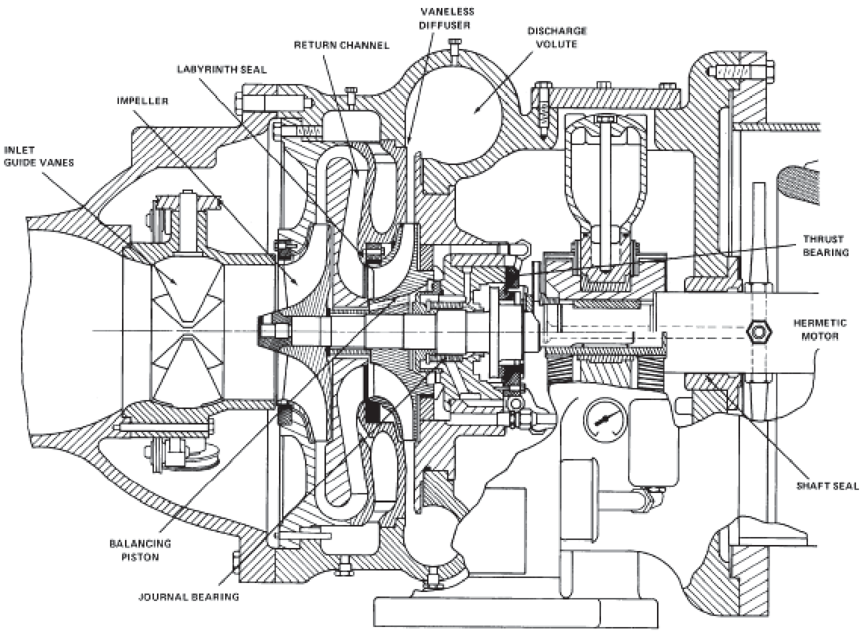

Figure 16: Single stage turbo compressor [6]

Turbo compressors are used in various applications where their capacity can range up to 7.4 MW. [6]

3.2 Combustion

3.2.1 Basics

This section will describe how greenhouse gas emissions result from the conversion of chemically stored energy in fossil fuels into thermal energy. Any material that releases thermal energy when burned is called a fuel. Fossil fuels are fuels that have been generated by geochemical processes in the earth's crust. Most fuels consist mainly of hydrogen and carbon. Therefore, they are called hydrocarbon fuels. Their general formula is C_nH_m. Hydrocarbon fuels exist in all aggregate states. Some examples are coal (solid), gasoline (liquid), and natural gas (gaseous). Since the fossil fuels that austriamicrosystems AG uses to supply its thermal energy needs are diesel, fuel oil and natural gas, only liquid and gaseous fuels will be covered in this section. [5]

Liquid hydrocarbon fuels are usually a mixture of various hydrocarbons and are distilled from crude oil. In a distillation column the most volatile hydrocarbons vaporize first, forming what is known as gasoline. The less volatile fuels obtained during distillation are kerosene, diesel fuel, and fuel oil. The composition of a particular fuel depends on the source of the crude oil as well as on the refinery itself. Although liquid hydrocarbon fuels are a mixture of different hydrocarbons, they are usually considered to be a single hydrocarbon (the predominant one) for convenience. Gasoline, for example, is treated as octane, C_8H_{18}, and diesel fuel as dodecane, $C_{12}H_{26}$.

In the same way the gaseous hydrocarbon fuel natural gas, is usually treated as methane CH_4. Natural gas, however also contains smaller amounts of other gases such as ethane, propane, hydrogen, helium, carbon dioxide, nitrogen, hydrogen sulfate, and water vapor. It is produced from gas wells or oil wells that are rich in natural gas. [5]

3.2.2 Combustion process

Chemical reactions during which fuel is oxidized and energy is released are called combustion. The most common oxidizer used in combustion processes is air, more specifically, the oxygen content in air. In some specialized applications pure oxygen is also used. Dry ambient air is composed of 20.9 % oxygen, 78.1 % nitrogen, 0.9 % argon, and small amounts of carbon dioxide, helium, neon, and hydrogen. In the analysis of combustion processes, the argon in the air is treated as nitrogen, and the gases that exist in trace amounts are disregarded. So dry air can be approximated as 21 % oxygen and 79 % nitrogen by mole numbers. Consequently, each mole of oxygen entering a combustion chamber is accompanied by 0.79/0.21 = 3.76 moles of nitrogen. In total 4.76 moles of air enter the chamber. [5]

During the combustion process itself, nitrogen behaves as an inert gas and does not react with other elements except for forming a small amount of nitric oxides at very high temperatures. The presence of nitrogen, however, greatly affects the outcome of a combustion process. It enters the combustion chamber in large quantities and at low temperatures. The gas then exits at higher temperatures, having absorbed a large amount of the chemical energy released during combustion.

Air that enters a combustion chamber is normally never completely dry. It contains some water vapor. The moisture in the air and the H_2O that forms during combustion are also treated as an inert gas, like nitrogen. At high temperatures, however, some water vapor can also dissociate into H_2 and O_2 as well as into H^+, O^{2-}, and OH^-. When the combustion gases are cooled below the dew-point temperature of the water vapor, some moisture condenses. It is important to be able to predict the dew-point temperature since water droplets can combine with the sulfur dioxide that may be present in the combustion gases. They can so form sulfuric acid, which is highly corrosive (See Appendix I).

In order to start combustion, fuel must be brought above its ignition temperature. The minimum ignition temperatures in atmospheric air are approximately 260°C for gasoline, 400°C for carbon, 580°C for hydrogen, 610°C for carbon monoxide, and 630°C for methane. In addition, the concentration of fuel in the air has to be in a certain range to start combustion. Natural gas, for example does not burn in air in concentrations less than 5 percent or greater than about 15%.

The mass balance principle states that the total mass of each element is conserved during a chemical reaction. This means that the total mass of each element on the right-hand side of the reaction equation must be equal to the total mass of that element on the left-hand side, or that the total mass of products is equal to the total mass of reactants.

To quantify the amounts of fuel (m_{fuel}) and air (m_{air}) in a combustion process, the air–fuel ratio AF is used. It is usually expressed on a mass basis and is defined as the ratio of the mass of air to the mass of fuel for a combustion process.

$$AF = \frac{m_{air}}{m_{fuel}} \quad (14)$$

The mass *m* of a substance is related to the number of moles *N* through the relation,

$$m = N * M \quad (15)$$

where *M* is the molar mass.

A combustion process is called complete if all the combustible components are oxidized to their highest oxidation level. This means that carbon is oxidized to CO_2, hydrogen to H_2O, and sulfur to SO_2. On the other hand, the combustion process is incomplete if the combustion products contain any unburned fuel or components such as C, H_2, CO, or OH^-. [5]

Table 1 lists some of the reactions that occur during combustion.

Table 1: Combustion reactions [7]

Constituent	Molecular Formula	Combustion Reaction
Carbon (to CO)	C	$C + 0.5\ O_2 \rightarrow CO$
Carbon (to CO_2)	C	$C + O_2 \rightarrow CO_2$
Carbon Monoxide	CO	$CO + 0.5\ O_2 \rightarrow CO_2$
Hydrogen	H_2	$H_2 + 0.5\ O_2 \rightarrow H_2O$
Methane	CH_4	$CH_4 + 2\ O_2 \rightarrow CO_2 + H_2O$
Sulfur	S	$S + O_2 \rightarrow SO_2$

See Appendix I for a complete list

Incomplete combustion can be due to many reasons. It occurs when insufficient oxygen is available or when more oxygen is present in the combustion chamber than is needed. Another reason for incomplete combustion is dissociation, which is observed at high temperatures. The minimum amount of air needed for the complete combustion of a fuel is called the stoichiometric or theoretical air. Thus, when a fuel is completely burned with theoretical air, no uncombined oxygen is present in the off-gases. A combustion process with less than the theoretical air is bound to be incomplete. [5]

Stoichiometric combustion is seldom realized in practice due to imperfect mixing and finite reaction rates. For economy and safety, most combustion equipment should operate with some excess air. The amount of air in excess of the stoichiometric amount is called excess air. This ensures that fuel is not wasted and that combustion is complete despite variations in fuel properties and in the supply rates of fuel and air. [7]

Excess air can also be used to control the temperature in the combustion chamber. It is usually expressed in terms of the stoichiometric air as percent excess air or percent theoretical air. [7]

$$Excess\ air[\%] = \frac{Air\ supplied - Theoretical\ air}{Theoretical\ air} \quad (16)$$

On the other hand, an amount of air less than the stoichiometric amount, called deficiency of air, is expressed as percent deficiency of air. This means, for example, that 90% theoretical air is equivalent to 10% deficiency of air. The amount of air used in combustion processes is also expressed in terms of the equivalence ratio, which is the ratio of the actual fuel–air ratio to the stoichiometric fuel–air ratio. Calculating the amount of excess air is important to estimate combustion system performance. However, in order to be able to specifically size system components, to calculate efficiencies and to predict the actual amount of emitted CO_2, more detailed calculations would be necessary. [5]

3.2.3 Combustion calculations

3.2.3.1 Liquid fuels

The calculations formulas below are based on the ultimate analysis of the fuel. The ultimate analysis provides the mass percentage of the elements in the fuel. However, it does not give any information on the chemical species the elements are bound in. The moisture of the fuel and the percentage of noncombustible components are given by the water content w and the ash content a. The mass balance after the ultimate analysis is [9],

$$c + h + s + o + n + w + a = 1 \qquad (17)$$

The mass percentages are related to the fuel mass m_f.

Carbon: $c = \frac{m_c}{m_f}$ Hydrogen: $h = \frac{m_{H_2}}{m_f}$ Sulfur: $s = \frac{m_S}{m_f}$

Oxygen: $o = \frac{m_{O_2}}{m_f}$ Nitrogen: $n = \frac{m_{N_2}}{m_f}$ Water: $w = \frac{m_{H_2O}}{m_f}$

Ash: $a = \frac{m_{ash}}{m_f}$ (18)

To facilitate calculations with chemical reactions, moles (kmol) are used and the mass percentage is converted into a mole percentage:

$$n_c = \frac{m_c}{M_c} = \frac{c * m_f}{M_c}. \qquad (19)$$

So the amount of carbon in 1 kg of fuel can be calculated from

$$\frac{n_c}{m_f} = \frac{c}{M_c} = \frac{c}{12} \left[\frac{kmol}{kg}\right] \qquad (20)$$

with M_c=12 kg/kmol. The same conversions are done for hydrogen n_h, sulfur n_s and oxygen n_o with the molar masses[9] M_h = 2 kg/kmol, M_s = 32 kg/kmol and M_o = 32 kg/kmol:

$$\frac{n_h}{m_f} = \frac{h}{M_h} = \frac{h}{2}\left[\frac{kmol}{kg}\right] \qquad \frac{n_s}{m_f} = \frac{s}{M_s} = \frac{s}{32}\left[\frac{kmol}{kg}\right] \qquad \frac{n_o}{m_f} = \frac{o}{M_o} = \frac{o}{32}\left[\frac{kmol}{kg}\right] \qquad (21)$$

With this the oxygen demand for a combustion reaction can be calculated. [10]

[9] Rounded values

Oxygen demand:

For the complete combustion of 1 kmol C, 1 kmol O_2 is needed according to Table 1. Accordingly for 1 kmol H_2 0.5 kmol O_2 are necessary and for 1 kmol S 1 kmol O_2. The oxygen content in a fuel can be subtracted from the necessary oxygen demand, which results in the so-called minimum oxygen demand.

$$\{O_{\min}\} = \frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32} \quad \left[\frac{kmol\ O_2}{kg\ fuel}\right] \qquad (22)$$

Air demand:

As discussed before 1 kmol of dry air contains roughly 0.21 kmol of oxygen. The minimum amount of dry air for complete combustion of an amount of fuel can be calculated with:

$$l_{\min} = \frac{O_{\min}}{0.21} \quad \left[\frac{kmol\ air}{kmol\ O_2}\right] \qquad (23)$$

The humidity of the air w_l is expressed in kmol water per kmol dry air, which equals the partial pressure of water vapor p_w divided by the partial pressure of dry air p_l:

$$w_l = \frac{p_w}{p_l} = \frac{p_w}{p - p_w} \qquad w_l = \frac{\varphi_l * p_s}{p - \varphi_l * p_s} \quad \left[\frac{kmol\ H_2O}{kmol\ air}\right] \qquad (24)$$

In the expression, φ_l is the relative humidity of air and p_s is the saturated vapor pressure of the water vapor. Thus the minimum humid air demand is related to the amount of fuel by:

$$l_{\min,h} = (1 + w_l) * l_{\min} \qquad (25)$$

Excess air:

Under actual combustion conditions more air is supplied to the process than stoichiometrically necessary. The ratio between theoretical to actual air demand is simply called air ratio λ:

$$\lambda = \frac{l}{l_{\min}} \qquad (26)$$

So the actual amount of combustion air that has to be supplied is:

$$l = \lambda * l_{\min} \qquad (27)$$

Excess air should be as low as possible. Typical λ values used for oil and gas burners range between 1.05 to 2.0. [10]

Quantity of flue gas produced:

The gaseous reaction products of a combustion process are called flue gas or off gas or exhaust gas. A complete combustion can produce the following species: CO_2, SO_2, H_2O, N_2 and O_2.

The total quantity of humid flue gas related to the amount of fuel is:

$$V_{n,fuel} = n_{fuel} * V_{mn} \quad (28)$$

The chemical reaction of fuel results in the formation of CO_2, SO_2 and H_2O. Since 1 kmol of C is converted into 1 kmol of CO_2 the amount of carbon (c/12) in 1 kg fuel reacts to c/12 of CO_2 (in kmol CO_2/kg fuel). The same happens to sulfur and hydrogen.

In addition, water and nitrogen from the fuel and the combustion air as well as excess oxygen end up in the flue gas. The amount of nitrogen in the fuel is n/28 (in kmol N_2/kg fuel) and the amount of water is w/18 (in kmol H_2O/kg fuel). The nitrogen content from the combustion air is $0.79*\lambda*l_{min}$, the air humidity is $w_l*\lambda*l_{min}$ and the excess oxygen is $0.21*(l-l_{min})$, which equals $0.21*(\lambda-1)*l_{min}$. [10]

So complete combustion leads to the following individual species in the flue gas [10]:

$$v_{CO_2} = \frac{c}{12} \quad \left[\frac{kmol\ CO_2}{kg\ fuel}\right] \quad (29)$$

$$v_{SO_2} = \frac{s}{32} \quad \left[\frac{kmol\ SO_2}{kg\ fuel}\right] \quad (30)$$

$$v_{H_2O} = \frac{h}{2} + \frac{w}{18} + w_l * \lambda * l_{min} \quad \left[\frac{kmol\ H_2O}{kg\ fuel}\right] \quad (31)$$

$$v_{N_2} = \frac{n}{28} + 0.79 * \lambda * l_{min} \quad \left[\frac{kmol\ N_2}{kg\ fuel}\right] \quad (32)$$

$$v_{O_2} = 0.21 * (\lambda - 1) * l_{min} \quad \left[\frac{kmol\ O_2}{kg\ fuel}\right] \quad (33)$$

Theoretical CO_2:

Finally, using the equations from above, the theoretical amount of CO_2 can be calculated. CO_2 however is always balanced and treated on a mass basis. Thus, it has to be converted.

$$m_{CO_2} = v_{CO_2} * M_{CO_2} \quad \left[\frac{kg\ CO_2}{kg\ fuel}\right] \qquad (34)$$

M_{CO2}, the molar mass of carbon dioxide, is 44 kg/kmol. From this the total mass of CO_2 resulting from the combustion of a certain amount of fuel can be calculated. The volume of CO_2 produced can be estimated with the following equation:

$$V_{n,CO_2} = v_{CO_2} * V_{mn} \quad \left[\frac{m_3\ CO_2}{kg\ fuel}\right] \qquad (35)$$

with V_{mn} = 22.4 m^3/kmol as the norm volume for an ideal gas. The exact amount of CO_2 resulting from a combustion reaction, however, can only be determined by a flue gas analysis. [10]

3.2.3.2 Gaseous fuels

Gaseous fuels are not analyzed in an ultimate analysis but rather in a gas analysis. A gas analysis describes the volume fraction of the individual species in fuel gas and not the mass fraction. Since all fuel figures are expressed in kmol, the volume fraction does not need to be converted. [9]

The most common fuel gas is natural gas. It is also used by austriamicrosystems AG in its steam and hot water boilers. Natural gas is usually assumed to be mostly methane (CH_4).

The chemical reaction equation for complete combustion from Table 1 is,

$$CH_4 + 2\ O_2 \leftrightarrow CO_2 + 2\ H_2O. \qquad (36)$$

The general form of the combustion equation for any hydrocarbon is,

$$C_nH_m + \left(n + \frac{m}{4}\right)O_2 \leftrightarrow nCO_2 + \frac{m}{2}H_2O \qquad (37)$$

The oxygen demand can be read directly from the combustion equations. For example, to fully oxidize 1 kmol of CH_4 2 kmol of O_2 are necessary. If the fuel gas contains 25 % CH_4 the necessary amount of oxygen is 0.5 kmol.

The total **minimum amount of oxygen** is given by:

$$O_{\min} = \left(0.5 * (CO + H_2) + 2CH_4 + \sum\left(n + \frac{m}{4}\right) C_n H_m\right) \quad \left[\frac{kmol\ O_2}{kmol\ fuel}\right] \qquad (38)$$

The minimum air demand as well as the minimum humid air demand and the excess air can be calculated in the same way as for liquid fuels:

Minimum air demand: $l_{\min} = \dfrac{O_{\min}}{0.21} \quad \left[\dfrac{kmol\ air}{kmol\ O_2}\right]$ (23)

Air humidity: $w_l = \dfrac{p_w}{p_l} = \dfrac{p_w}{p - p_w} \qquad w_l = \dfrac{\varphi_l * p_s}{p - \varphi_l * p_s} \quad \left[\dfrac{kmol\ H_2O}{kmol\ air}\right]$ (24)

Minimum air demand, humid: $l_{\min,h} = (1 + w_l) * l_{\min}$ (25)

Excess air: $\lambda = \dfrac{l}{l_{\min}} \qquad l = \lambda * l_{\min}$ (26)

The **fuel gas humidity** is also related to the dry fuel gas and can be calculated according to the air humidity.

$$w_g = \frac{p_w}{p_g} = \frac{\varphi_g * p_s}{p - \varphi_g * p_s} \qquad (39)$$

The partial pressure of the dry fuel gas is given by p_g. The amount of the individual components in the flue gas can be estimated with the following equations:

$$v_{CO_2} = \left(CO + CH_4 + \sum nC_nH_m + CO_2\right) \quad \left[\frac{kmol\ CO_2}{kmol\ fuel}\right] \qquad (40)$$

$$v_{H_2O} = \left(H_2 + 2CH_4 + \sum \frac{m}{2} C_nH_m + w_l + w_g\right) \quad \left[\frac{kmol\ H_2O}{kmol\ fuel}\right] \qquad (41)$$

$$v_{N_2} = (N_2 + 0.79 * \lambda * l_{\min}) \quad \left[\frac{kmol\ N_2}{kmol\ fuel}\right] \qquad (42)$$

$$v_{O_2} = 0.21 * (\lambda - 1) * l_{\min} \quad \left[\frac{kmol\ O_2}{kmol\ fuel}\right] \qquad (43)$$

With these the total quantity of humid flue gas is

$$v_f = v_{CO_2} + v_{H_2O} + v_{N_2} + v_{O_2} \text{.[10]} \qquad (44)$$

Theoretical CO_2

The mole fraction of CO_2 in the flue gas is used to calculate the generated mass of carbon dioxide from the combustion of a certain amount of fuel (kg CO_2/kmol fuel). This can also be expressed in m^3 CO_2/m^3 fuel or in kg CO_2/m^3 fuel. The last option is actually the most suitable one for emission calculation as most gaseous fuels are balanced in m^3/h or per year. [10]

$$m_{CO_2} = v_{CO_2} * M_{CO_2} \quad \left[\frac{kg\ CO_2}{kmol\ fuel}\right] \qquad (45)$$

$$m_{CO_2} = \frac{v_{CO_2} * M_{CO_2}}{V_{nm}} \quad \left[\frac{kg\ CO_2}{kmol\ fuel}\right] \qquad (46)$$

4 Data acquisition

The first step of the actual quantification process was to select a quantification methodology. ISO 14064 and the GHG Protocol distinguish among the three below mentioned data collection approaches. [1]

a) Calculation based on

   i. GHG activity data multiplied by GHG emission or removal factors

   ii. The use of models

   iii. Facility-specific correlations

   iv. The mass balance approach

b) Measurement

   i. Continuous

   ii. Intermittent (instantaneous)

c) A combination of measurement and calculation

The most suitable approach for the austriamicrosystems GHG-project was to combine calculations based on GHG activity and emission factors with instantaneous measurements.

First, all readily available data was collected using a top-down approach based on the flow chart. Acquiring data for the operational areas was fairly straightforward. However, gathering information for the next levels posed a serious challenge to the data collecting process. Most of the time, the required and desired level of detail was not available. In these cases, instantaneous measurements, assumptions based on operational experience, literature references and extrapolations had to be substituted for hard facts. The following chapter describes the data acquisition process for the different functional units and their specific machinery. It also summarizes the emission factors used for the calculations.

4.1 FAB A:

The annual electric and natural gas utility bills provided the electricity and natural gas consumption of FAB A and FAB B. These statements included separate consumption values for the energy center housing the two hot water boilers and five turbo chillers for FAB B. In order to properly allocate the values to FAB A and the other sub-areas and units, the statement numbers had to be broken down and appropriately reallocated.

Fuel oil and diesel consumption for the backup burners and the UPS units is very low. Thus, this consumption was not allocated to FAB A units but instead balanced for austriamicrosystems en bloc. Cos(φ)[10]-values were checked for some of the machines in FAB A and then assumed to be the same for all FAB A machinery.

Boilers: Three of the five units in this subarea (HK1, HK2, DK1) have flow meters for natural gas consumption. The other natural gas streams had to be calculated. The fuel oil consumption – as mentioned above - was not allocated. In order to determine the electricity consumption of the boilers, instantaneous current was measured in the switchboard. Operating hours are logged in the control system and the installed capacities were taken from existing operating data.

Chilling: The chillers only consume electric energy. Again the control system provided the operating hours. For some units an instantaneous current measurement was made. For the rest the nominal current was taken from existing operating data.

Cooling Towers: The nominal current and the instantaneous current of the units were determined. However, there was no reasonable data available on the operating hours for pumps and ventilators. The control system only logs on/off-events and the time span between those events for each machine. This means, for example, that for one pump thousands of data points were logged. To analyze all data sets would go beyond the scope of this study. Therefore, the operating hours had to be estimated with the facility staff based on operation experience.

Compressed Air: For the compressor and driers, operating hours were available in the control system. Instantaneous current was measured and compared with the nominal current.

Scrubbers: Again operating hours were available in the control system and instantaneous current was measured and compared with the nominal current.

Air Handling: For the air-handling units, the instantaneous current was measured and compared with the nominal current. Since there was no operating hour data available it had to be estimated from operation experience, which was done fairly easily as the machines work continuously throughout the year.

UPS: The UPS units are also continuously operating throughout the year. Even though they run in standby mode, they are consuming a certain amount of electricity. Based on the specification sheets of the machine manufacturers, this amount is approximately 5% of the installed capacity.

Wastewater: The wastewater equipment current was measured in the switchboard and the operating hours were assumed to be 8760 per year.

[10] Power factor

Water Systems: The energy consumption of the pumps in the water supply was estimated by checking the nominal power directly on the machines. The operating hours had been logged into the control system.

CCC: The instantaneous current of the various electrical installations in the CCC was measured in the respective switchboards. They operate continuously throughout the year.

Production: For all three sections in production the instantaneous power was determined by power measurement in the switchboards. The machines run continuously.

4.2 FAB B:

As FAB B is the only production facility, there are more input streams to consider compared to FAB A. In addition to the electricity, there is natural gas for the boilers and the abatement systems, as well as special chemicals for the production equipment. Data acquisition involved the same procedures and approaches used for FAB A. It is important to mention that many electrical machines in FAB B are controlled by frequency converters (FC). Thus, their energy consumption can vary in the given range of the nominal power. For detailed calculation, average control values for the frequency converters had to be estimated based on the experience of the facility personnel.

Boilers: The boilers in FAB B unfortunately are not equipped with flow meters. Thus, it was not possible to retrieve the natural gas consumption directly. However, the natural gas consumption for the energy center could be determined using the annual utility bill. The only two natural gas consuming units in the energy center are the two hot water boilers of FAB B. The utility bill also provided the m^3 of natural gas per year needed for the abatement systems. The operating hours were taken from the control system and the nominal electrical power was read from the specification plate.

Chilling: The chillers have different power ranges, which were given in their specification sheets. The operating hours were logged in the control system but the control values for the frequency converter had to be estimated.

Cooling Towers: Exactly the same situation as for Chilling existed for the pumps and fans of the cooling towers and the free cooling system. The power ranges were taken from the specification sheets and the operating hours from the control system.

Scrubbers: For the scrubbers the instantaneous power was read from the control panel of the frequency converters. The operating hours for 2007 were also still stored in the control system.

Gas Farm: The large compressors at the gas farm have control panels that show the instantaneous power. For the other machines the nominal power was read either from the specification plates or from the specification sheets. The operating hours of all larger units and some of the smaller ones are logged in the control system. Others have fixed operating cycles (i.e. 3 x 4 hours per day, or 6 hours every 48 hours) or run continuously throughout the year.

UPS: Just like the UPS units in FAB A, those in FAB B are also running throughout the year. Their consumed electric energy for standby operation can be estimated to be 5% of the installed capacity.

Air handling: The operating hours of the 11 air-handling units are logged in the control system. Their instantaneous power was read from the control panels of the frequency converters.

Water Systems: The nominal power of the water system machinery was taken from the specification sheets. The plant has to work for 8760 hours per year.

Production: All machines of both units, Equipment and Abatements, operate uninterruptedly. Their instantaneous power was measured in the respective switchboards.

4.3 Philippines:

As the test facility in Calamba in the Philippines is only equipped with electricity consuming equipment, the energy consumption of its four subareas were measured in kilowatt-hour meters. The facility team of the Philippines operational area provided the required figures.

4.4 Transport processes

Combustion of fuel in pool cars: The mileage of the five pool cars registered at the plant in Unterpremstaetten was retrieved from the data storage of the Finance and Accounting Department. The mileage of the pool car in Calamba is recorded at the site and sent once a year to the headquarters.

Employee business travel: The Finance and Accounting Department provided the CO_2/km/person calculation for business air travel in 2007.

Employee commuting: The easiest way to estimate the total amount of commuting kilometers was to set up a questionnaire and determine the amount of kilometers covered by various means of transport.

The intranet system at austriamicrosystems offered the option to create questionnaires to which employees could reply anonymously. The answers were stored automatically and could be exported to Excel for further calculation. An e-mail containing a link to the commuting questionnaire was sent to everyone working in Unterpremstaetten.

The questionnaire asked:

- Distance to austriamicrosystems (km):
- How many weeks per year do you use the car (max. 47 weeks/year):
- How many weeks per year do you use the bus (max. 47 weeks/year):
- How many weeks per year do you use the train (max. 47 weeks/year):
- How many weeks per year do you walk or use the bike (max. 47 weeks/year):

Within two weeks after the first e-mail was sent, 367 persons had replied to the survey. The e-mail was resent with the same link to remind employees to respond.

Within another two weeks, a total of 504 persons had replied. A third reminder was not sent. Rather, the resulting distribution was extrapolated to cover 850 employees - the average number of employees at austriamicrosystems Unterpremstaetten in 2007.

Transportation of products and semi-finished goods:

External transportation agents ship austriamicrosystems' products around the world. Most of the shipping is done by plane except for very close customers in Austria and neighboring countries, which are reachable by small delivery trucks.

The shipping list for 2007 was retrieved from the SAP-system and shows 17,731 individual shipments for 2007. The shipping list provided the destination countries using the ISO 3166 two-letter country code. However, it did not give the precise addresses of the recipients since the packages were handed over to a forwarding agent. In order to facilitate distance estimation, one city was randomly selected for each country listed in the SAP data and the distances were calculated accordingly.

More precise information on each shipment might be available from the transportation agents. This would go beyond the scope of this study and thus was not pursued.

The internal data for inbound shipments from suppliers was useless since there was no information either on the location of the senders or on the mode of transportation.

4.5 Emission factors

The local utility companies provided emission factors for electric energy and natural gas. The emission factors for transportation and technical gases were taken from the IPCC-data sets. Table 2 lists all the emission factors used in this report.

Table 2: Emission factors used for the GHG inventory

Emission Sources	Value	Unit
Electric Energy	0.322	kg CO_2/kWh [11]
Natural Gas	2.25	kg CO_2/m^3 [3], [13]
Air Cargo	0.5	kg CO_2/(t freight*km) [3]
Road Cargo	0.15	kg CO_2/(t freight*km) [3]
Car (diesel)	14,85	kg CO_2/(100 km*person) [12]
Car (gas)	20,15	kg CO_2/(100 km*person) [12]
Car (average)	17.5	kg CO_2/(100 km*person) [12]
Bus	2.08	kg CO_2/(100 km*person) [12]
Train	0.075	kg CO_2/(100 km*person) [12]
Airplane	12.97	kg CO_2/(100 km*person) [12]
Diesel	2.63	kg CO_2/l [13]
Fuel Oil	2.9	kg CO_2/l [13]

5 Data evaluation and Greenhouse gas inventory

This chapter describes how the data sets acquired for each operational area were combined to determine the GHG inventory of austriamicrosystems. The calculations are described by going through each operational area's applicable emission sources.

5.1 FAB A:

The sources of GHG emissions in FAB A are the electricity consumed by the various sub-areas and the natural gas used for the boilers.

5.1.1 Electricity:

All the machines in FAB A consume electricity. With the acquired electricity usage data, the energy consumption for individual machine units was calculated in kilowatt-hours per year. All machines are connected to the internal 400 V grid, thus all calculations were done with this voltage value. (see the first rows for the sub-areas).

Table 3 lists all the measured and assumed figures used in the calculation process. Whenever current measurements were taken or the nominal currents were given, the electricity consumption was calculated with following formula:

$$E = \frac{\sqrt{3} * I * U * \cos(\varphi) * L * T}{1000} \quad [kWh/a] \qquad (47)$$

I stands for the electrical current [A], U stands for the voltage [V], cos(φ) is the power factor given by the machine, L is the load factor [%] and T is the operating hours per annum.

The load factor was used to adjust nominal data or instantaneous measurements in order to reach a realistic annual performance. The load factor was estimated in cooperation with experienced facility staff.

Whenever instantaneous power measurements were made or nominal powers were given, the electricity consumption was calculated with the following formula:

$$E = P * T * L \quad [kWh/a] \qquad (48)$$

P stands for the power [kW], T for the operating hours per annum and L for the Load factor [%].

The various unit consumptions were summed to give the total consumption for each sub-area (see the first rows for the sub-areas).

Table 3: Electrical Data Evaluation

Units		P (kW)	I (A)	T(h/a)	L (%)	cos(φ)	E [kWh/a]
Boilers							**60,496**
	HK1		8.5	3,244	0.8	0.89	13,602
	HK2		8.5	16	0.8	0.89	67
	HK3		8.5	8,475	0.8	0.89	35,535
	DK1		5.5	987	0.8	0.89	2,678
	DK2		5.5	3,175	0.8	0.89	8,614
Chilling							**1,848,263**
	ABS1		160	2,948	0.8	0.89	232,674
	ABS2		160	3,863	0.8	0.89	304,891
	Turbo1		401	4,883	0.8	0.89	965,899
	Schraube2			19	0.8	0.89	0
	Turbo4		350	543	0.8	0.89	93,749
	Turbo5		350	349	0.8	0.89	60,255
	Turbo6		350	75	0.8	0.89	12,949
	Turbo7		310	1,163	0.8	0.89	177,845
Cooling Towers							**1,154,482**
	KT2T		130	3,285	0.7	0.89	184,326
	KT3T		130	3,285	0.7	0.89	184,326
	KT4T		130	3,285	0.7	0.89	184,326
	KT3A		58	3,285	0.7	0.89	82,238
	KT1		116	2,920	0.7	0.89	146,201
	KT3		180	2,920	0.7	0.89	226,863
	KT4		116	2,920	0.7	0.89	146,201
Compressed Air							**2,416,109**
	A/C1		193	2,051	0.99	0.89	241,640
	A/C2		183	8,726	1	0.89	984,639
	A/C3		201	7,035	0.9	0.89	784,717
	Tro1		25	8,760	1	0.89	135,038
	Tro2		25	8,760	1	0.89	135,038
	Tro3		25	8,760	1	0.89	135,038

Scrubbers							**415,916**
	Wet3		56	8,760	1	0.89	302,484
	Wetassy		21	8,760	1	0.89	113,432
Airhandling							**4,263,407**
	AC1-5		260	8,760	0.9	0.89	1,263,952
	AC6-9		217	8,760	0.9	0.89	1,054,914
	AC10		52	8,760	0.9	0.89	252,790
	AC11-12		93	8,760	0.9	0.89	452,106
	AC14		104	8,760	0.9	0.89	505,581
	AC20-21		116	8,760	0.9	0.89	563,917
	Small		35	8,760	0.9	0.89	170,147
UPS							**766,500**
	NIPS1	25.0		8,760			219,000
	NIPS2	25.0		8,760			219,000
	USV2	12.5		8,760			109,500
	USV3	12.5		8,760			109,500
	USV4	12.5		8,760			109,500
Wastewater							**324,090**
	WWA		60	8,760	1	0.89	324,090
Water Systems							**689,402**
	Supply	30		8,760	0.35		91,980
	UPW		84	8,760	1	0.89	320,877
	PCW	5.8		8,760			50,808
	RO-EC	24.2		1,563			37,825
	RO-CW	31.5		3,425			187,913

CCC							**309,731**
	Event		26.5	8,760	1	0.82	131,882
	Canteen		15.6	8,760	1	0.82	77,636
	Wardrobe		5.6	8,760	1	0.86	29,229
	Conference		13.6	8,760	1	0.86	70,984
Production							**5,606,400**
	Maskshop	210		8,760			1,839,600
	Test and Assembly	430		8,760			3,766,800
	Office and Laboratory	90		8,760	0.4		315,360

Figure 17 and Figure 18 show the absolute and relative electric energy consumption for each of the sub areas of FAB A. FAB A consumes a total of 17,854,796 kWh of electric energy per year. By far the biggest energy consumer is the equipment installed in Production with 32% of the total energy consumption or 5.6 million kWh/a. Next in usage are Airhandling with 24% and 4 million kWh/a, Compressed Air with 14% and 2.4 kWh/a, and Chilling with 10% and 1.8 million kWh/a. These statements included separate consumption values for the energy center housing the two hot water boilers and five turbo chillers for FAB B.

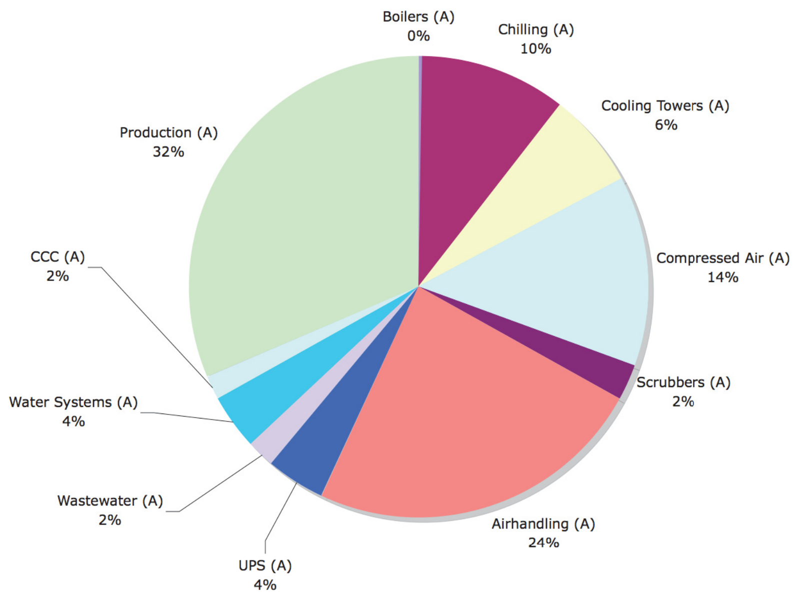

Figure 17: Electric energy consumption FAB A (relative)[11],[12]

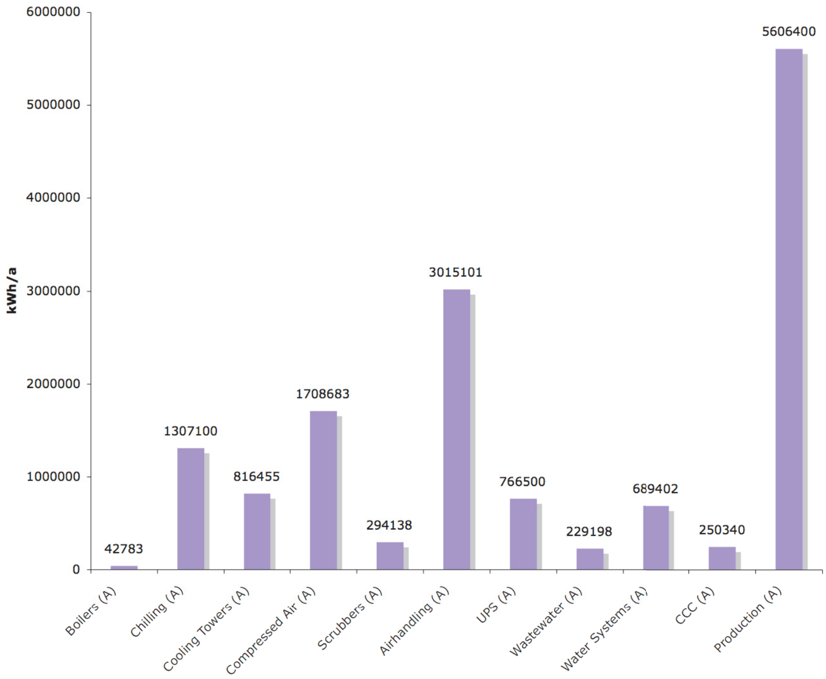

Figure 18: Electric energy consumption FAB A (absolute)

[11] Energy balance estimation: Production x 0.35 = Chilling + Exhaust

[12] If a portion is displayed as 0%, then it consumed less than 1 % of the total.

5.1.2 Natural Gas:

As stated in section 4.1, the annual utility bills provided the total natural gas consumption for FAB A. Fortunately, flow meter of HK1, HK2 and DK1 readings were stored in the control center. Combining the information from both sources allowed calculation of the natural gas consumption of HK3 and DK2 combined. Since HK3 has the same thermal power as HK1 and HK2 and since DK2 the same as DK1, their individual gas consumption could be estimated by using the respective operating hours. Table 4 shows the results.

Table 4: Natural gas consumption of FAB A

Units		Time T (h/a)	Natural gas [m^3/a]
Boilers			**1,745,186**
	HK1	3,244	402,419
	HK2	16	1,379
	HK3	8,475	1,051,330
	DK1	987	68,786
	DK2	3,175	221,272

5.1.3 CO_2-Emissions FAB A:

The electrical consumption (kWh/a) and natural gas consumption (m^3/a) values were then multiplied with the emission factor values given in Table 1 of section 3.5. The resulting CO_2-emission, expressed in tons per annum, was calculated for each of the subareas and then summed up to give the total CO_2-emission of FAB A. The results are shown in Table 5. The percentage contribution of the individual subareas is shown in Figure 19.

Table 5: CO_2-emissions of FAB A

Units	Electricity [kWh/a]	Natural Gas [m^3/a]	CO_2 electric [t/a]	CO_2 thermal [t/a]	CO_2 total [t/a]
Boilers (A)	60496	1,745,186	14	3,250	**3,940**
Chilling (A)	1,848,263		421		**421**
Cooling Towers (A)	1,154,482		263		**263**
Compressed Air (A)	2,416,109		550		**550**
Scrubbers (A)	415,916		95		**95**
Airhandling (A)	4,263,407		971		**971**
UPS (A)	766,500		247		**247**
Wastewater (A)	324,090		74		**74**
Water Systems (A)	689,402		222		**222**
CCC (A)	309,731		81		**81**
Production (A)	5,606,400		1,805		**1,805**
TOTAL	**17,854,796**	**1,745,186**	**4,742**	**3,927**	**8,668**

The two biggest emission sources in FAB A are the Boilers with 37% and Production with 20%. It is important to note that while the Boilers subarea is the largest single emitter of GHG, electric energy is the largest combined GHG source involving the other subareas of FAB A and also involving a negligible part of the Boiler subarea.

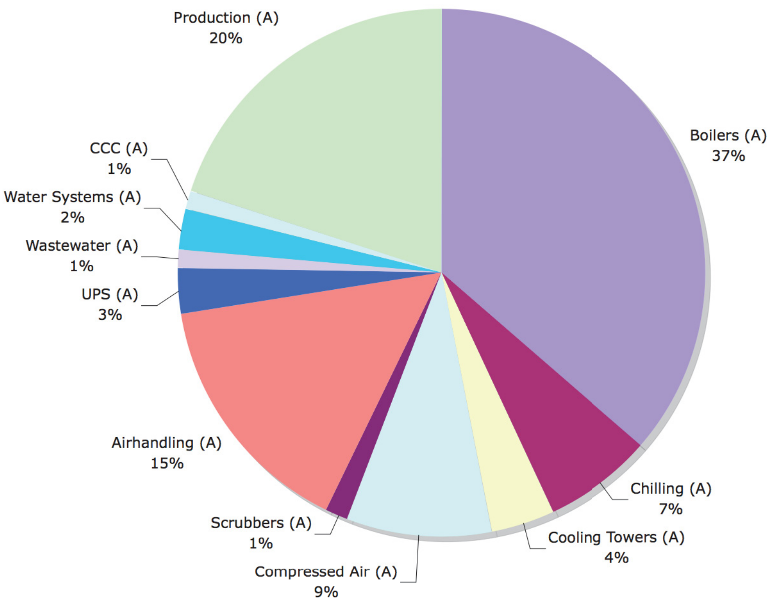

Figure 19: CO_2-emissions of FAB A

5.2 FAB B:

In addition to electricity and natural gas, there are also technical gases causing GHG emissions in FAB B.

5.2.1 Electricity:

All subareas allocated to FAB B consume electric energy in one way or another. Either the machinery uses electricity directly or auxiliary devices such as pumps and ventilators consume it. An important difference from the electric data evaluation of FAB A is that the equipment in FAB B is more modern and generally operates in a constant mode in terms of energy consumption. Many machines are equipped with frequency converters that modulate the rotational speed of motors for pumps and fans. These converters adjust the power consumption to the load, so one should keep in mind that the instantaneous power could vary greatly.

In order to determine the electricity consumption of individual machines (with or without frequency converters), two different calculation approaches had to be made. Formula 48 was used to calculate the electric energy consumption for both approaches. However, for those units for which the nominal power had been determined, the load factor L had to be used to estimate the actual consumption. If the frequency converter set values had been recorded, an average value was calculated and used for L. If these recordings were not available, the load factor had to be estimated based on operational experience. For units with a fairly constant performance the instantaneous power was determined and the load factor was set to 1. Table 6 shows the data used for the calculation and lists the results.

Table 6: Electric energy consumption of FAB B

Units		P (kW)	T (h/a)	L (%)	E [kWh/a]
Boilers					**105,856**
	HK1		0		
	HK2	18.5	6,173	0.8	91,360
	DK1	2.2	3,985	0.8	7,014
	DK2	2.2	4,251	0.8	7,482
Chilling					**3,134,704**
	T5.1	451	1,095	0.75	370,384
	T5.2	451	2,081	0.75	703,898
	T5.3	451	2,595	0.75	877,759
	T12.1	397	2,589	0.75	770,875
	T12.2	397	1,383	0.75	411,788
Cooling Towers					**667,969**
	GEA1	20	4,546		90,920
	GEA2	20	2,266		45,320
	GEA3	20	4,104		82,080
	GEA4	20	4,938		98,760
	GLK01-10	147	2,387		350,889
Scrubbers					**298,006**
	WS1	9.2	8,752	1	80,518
	WS2	9.2	8,752	1	80,518
	WS3	9.2	8,752	1	80,518
	BS1	8.6	8,752	0.75	56,450
Gas Farm					**6,898,696**
	Bulkgas				5,031,940
	CDA				1,401,600
	Purifier				465,156
UPS					**657,000**
	NIPS3	50.0	8,760		438,000
	USV5	25.0	8,760		219,000
Airhandling					**2,172,883**

	AHU1	28	3,872	1	108,416
	AHU2	28	6,251	1	175,028
	AHU3	28	7,236	1	202,608
	AHU4	28	8,427	1	235,956
	KL05	15	8,760	0.75	98,550
	KL08	39	8,760	0.75	256,230
	KL09	19	8,760	1	166,440
	KL21	9	8,760	1	78,840
	KL22	9	8,760	1	78,840
	KL23	1.5	8,760	0.75	9,855
	FFU	116	8,760	0.75	762,120
Production					**18,601,860**
	Abatements	3.5	8,760		30,660
	Frontend	2,120	8,760		18,571,200
Water Systems					**1,267,747**
	UPW	150.2	8,760	0.6	789,451
	PCW	91	8,760	0.6	478,296

Figure 20 and Figure 21 show the relative and absolute values for the sub units. By far the biggest electricity consumer is the production equipment with 56% of the entire energy consumption. The “Gasfarm” amounts to 20% and “Chilling” to 9%. In total FAB B consumes 33,804,720 kWh of electric energy per year.

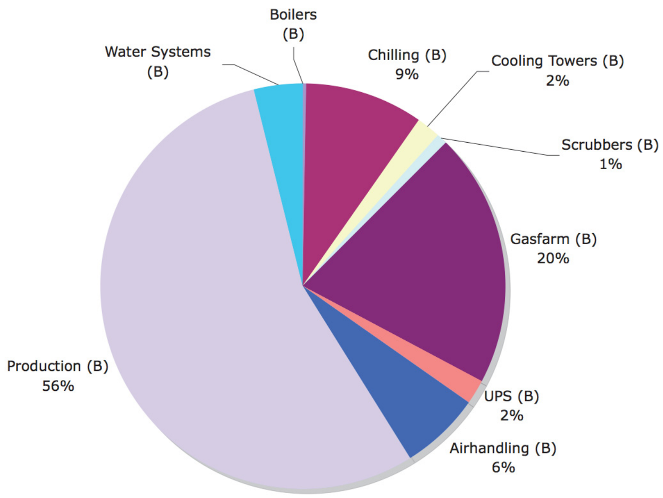

Figure 20: Electric energy consumption of FAB B (relative)[13]

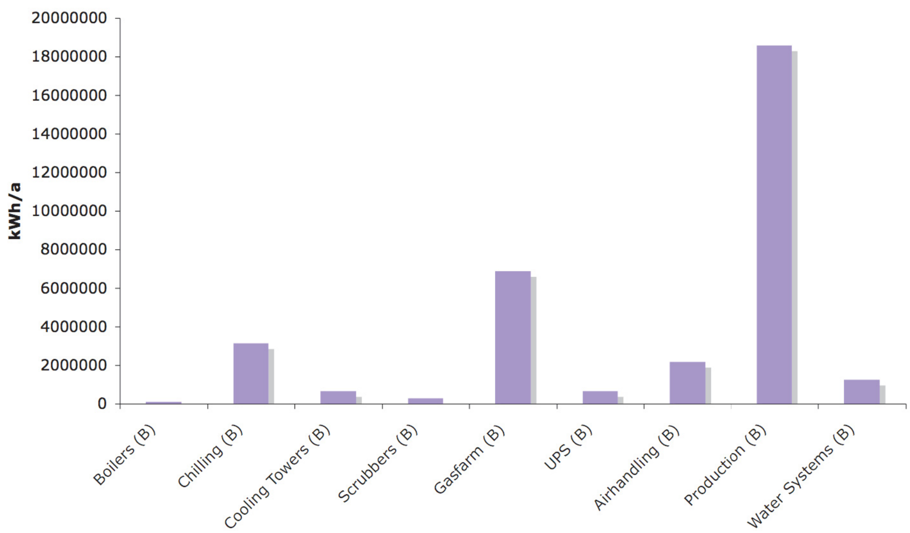

Figure 21: Electric energy consumption of FAB B (absolute)

5.2.2 Natural Gas:

There are two subareas in FAB B that use natural gas: the boilers and the production abatement systems. As already described in section 3.2, the annual utility bill provided overall natural gas consumption sums for the energy center and for the FAB B building. As explained in 2.3.2, HK1 in the energy center is almost never in use. Thus the entire natural gas use was applied to HK2. As for FAB B, the allocations to DK1 and DK2 were based on the operating hour. The gas consumption of the abatement system was reported. Table 7 shows the natural gas usage results.

[13] If a portion is displayed as 0%, then it consumed less than 1 % of the total.

Table 7: Natural gas consumption of FAB B

Units		Time T [h/a]	Natural gas [m^3/a]
Boilers			**790,480**
	HK1	0	
	HK2	6,173	387,210
	DK1	3,985	195,141
	DK2	4,251	208,129
Production			**140,000**
	Abatements	8760	140,000

5.2.3 Special Gases:

The abatement systems achieve an 87% separation efficiency. The emitted amount of PFCs is continuously measured. With the GWP of the gases from the IPCC database [3], their annual CO_2-emission equivalents were calculated (See Appendix II). The results are shown in Table 8.

Table 8: CO_2-emissions from special gases[14]

	INPUT [kg gas/a]	Emitted [kg gas/a]	GWPs [kg CO_2/kg gas]	CO_2-equivalent [t/a]
SF6 Schwefelhexafluorid	416	52	23,900	1,253
CF4 Tetrafluormethan (R 14)	1,050	132	6,500	860
CHF3 Trifluormethan (R 23)	240	30	150	5
C2F6 Hexafluormethan (R 116)	2,860	360	9,200	3,315
C4F6 Hexafluorbutadien	30	4	10,000	38
C4F8 Octafluorcyclobutan (R 318)	40	5	8,700	44
Nf3 Stickstofftrifluorid	1,612	203	17,200	3,493
TOTAL	**6,248**	**787**		**9,007**

[14] Data from the CFC-report to the Austrian Environmental Agency 2007.

5.2.4 CO_2-Emissions FAB B

The calculated activity data (kWh/a and m^3/a) was multiplied by the emission factors given in section 3.5. The emissions from the special gases and the emissions from the subareas were summed up to give the total CO_2-emissions of FAB B.

Table 9 summarizes the activity data of the subareas, the resulting CO_2-emissions and the total emissions for FAB B.

Table 9: CO_2-emissions FAB B

Units	Electricity [kWh/a]	Natural Gas [m^3/a]	CO_2 Electric [t/a]	CO_2 Thermal [t/a]	CO_2 Special Gases [t/a]	CO_2 Total [t/a]
Boilers (B)	105,856	790,480	34	1,472		**1,813**
Chilling (B)	3,134,704		1,009			**1,009**
Cooling Towers (B)	667,969		215			**215**
Scrubbers (B)	298,006		96			**96**
Gasfarm (B)	6,898,696		2,221			**2,221**
UPS (B)	657,000		212			**212**
Airhandling (B)	2,172,883		700			**700**
Production (B)	18,601,860	140,000	5,990	261	9,007	**15,312**
Water Systems (B)	1,267,747		408			**408**
TOTAL	**33,804,720**	**930,480**	**10,885**	**1,733**	**9,007**	**21,625**

Figure 22 and Figure 23 clearly illustrate that there is one major emission source in FAB B: the chip production process. Over 2/3 of the total CO_2-emissions are caused by the production equipment. Gasfarm, Boilers and Chilling are next in size but with comparably small contributions of 10 %, 8 % and 5 %, respectively.

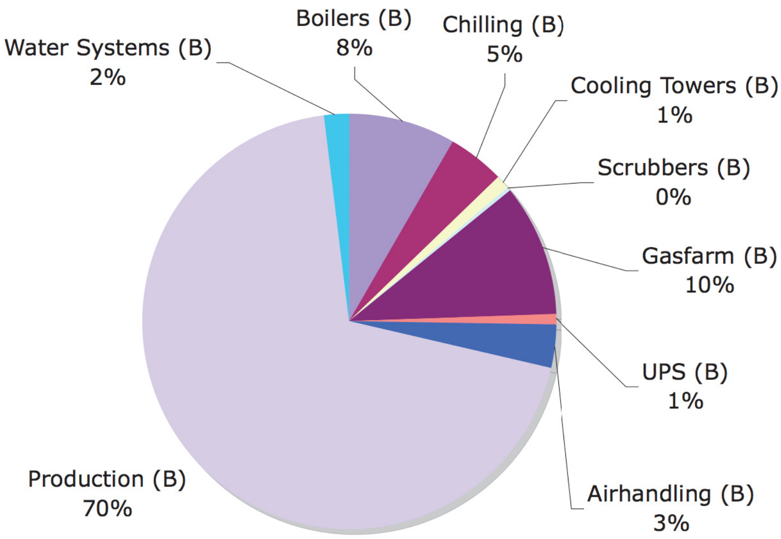

Figure 22: CO_2-emissions of FAB B (relative) [15]

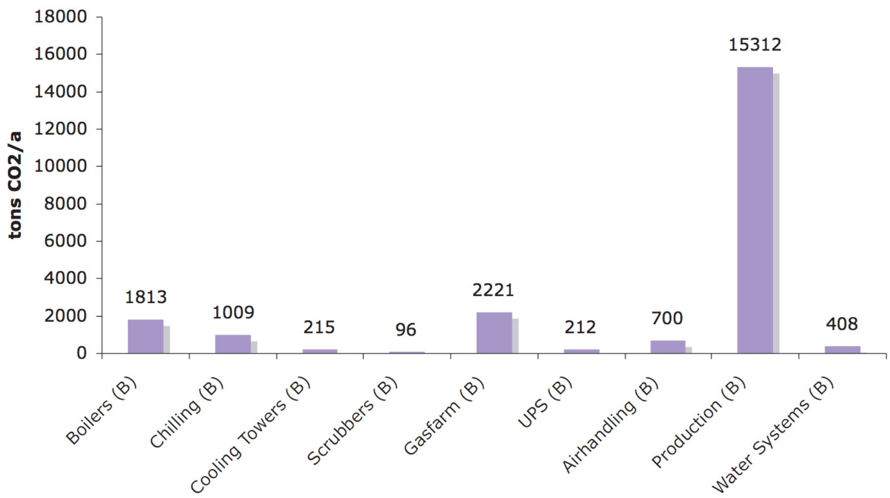

Figure 23: CO_2-emissions of FAB B (absolute)

Another important finding from Table 9 is that the PFC-emissions more than double the energy-related CO_2-emissions from the Production subarea and significantly contribute to the 21,625 tons of total GHG emissions of FAB B.

[15] The chillers do not recool the entire production heat. The missing percentage results from heat recovery and free cooling.

5.3 Philippines:

The test center in Calamba only consumes electric energy. Since the installed capacity is rather small compared to FAB A and FAB B, no measurements were made at the site for individual machine units. The local facility team submitted the required readings for the subareas.

5.3.1 Electricity

The forwarded activity data is listed in Table 10. Figure 24 shows that like in FAB A and FAB B, Production is by far the biggest energy consumer.

Table 10: Electric energy consumption of the Philippines

Units	Electricity [kWh/a]
Chilling	551,724
Compressed Air	124,138
Production	962,071
Airhandling	86,206
TOTAL	**1,724,139**

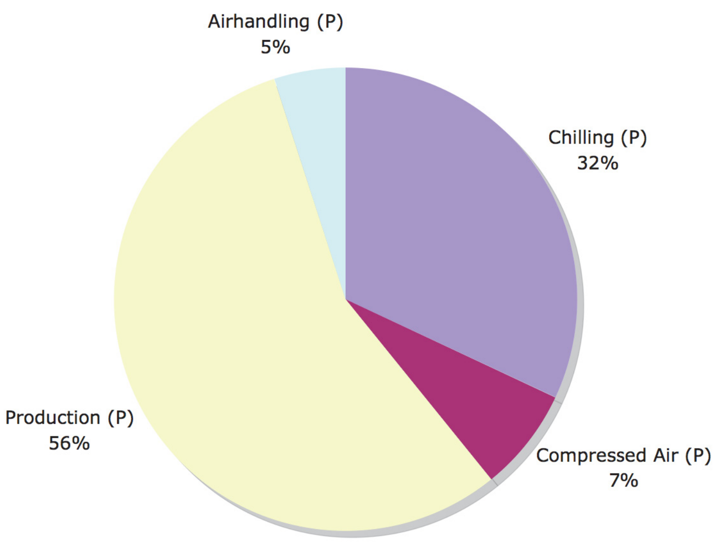

Figure 24: Electric energy consumption of the Philippines (relative)

5.3.2 CO_2-Emissions

The activity data was multiplied with the emission factor for electricity from section 3.5 to calculate the CO_2-emissions from the Philippines. As there was no specific number available for the Philippines, the emission factor for Austria was used for approximation. The resulting error, however, is rather minimal due to the comparably small amount of kilowatt-hours involved.

Table 11 shows the results of the calculations. The percentage distribution of the individual subareas contributing to the total GHG emissions, seen in Figure 25, of course exactly corresponds to the distribution for electric energy consumption shown in Figure 10.

Table 11: CO_2-emissions of the Philippines

Units	Electricity [kWh/a]	CO_2 Total [t/a]
Chilling (P)	551,724	178
Compressed Air (P)	124,138	40
Production (P)	962,071	310
Airhandling (P)	86,206	28
TOTAL	**1,724,139**	**555**

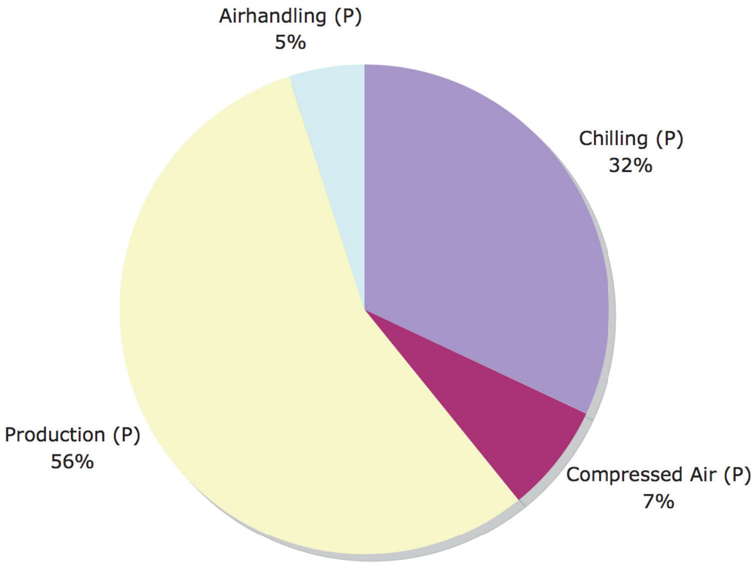

Figure 25: CO_2-emissions of the Philippines (relative)

5.4 Summary (FAB A, FAB B, Philippines)

The emissions from FAB A, FAB B and the Philippines are directly related to their production processes and installed production capacities. They depend to a certain extent on the magnitude of manufactured chips or wafer starts per month and are called production-related GHG emissions. Since these three operational areas are under direct control of austriamicrosystems, they shall be reviewed in more detail.

Figure 26 clearly shows that FAB B is the primary source of GHG emissions with over 12,000 tons per year. The amount produced by all activities in former FAB A is less than half as much. The emissions from the Philippines are only 10% of FAB A's. In fact, the entire test center is not even emitting as much CO_2 as the boilers of FAB B do.

Most equipment consumes electric energy. Therefore, the largest source of GHG emissions at austriamicrosystems is purchased electricity. As shown in Figure 27, electric consumers are responsible for 55% of the CO_2-emissions. The tons of CO_2-equivalent of the special gases are almost 1.5 times the emissions from the combustion of natural gas in boilers and abatement systems.

The high consumption of electricity at austriamicrosystems has to be kept in mind for future improvement projects. Reducing electric energy consumption can most strongly influence the achievement of GHG reduction targets. Therefore, it is the most important task at hand.

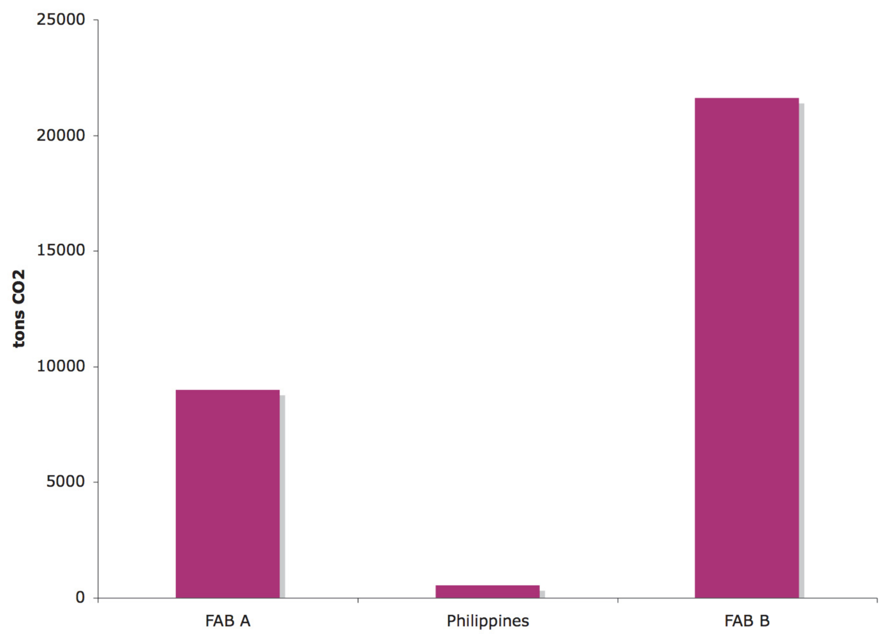

Figure 26: Absolute GHG emissions of production-related operational areas

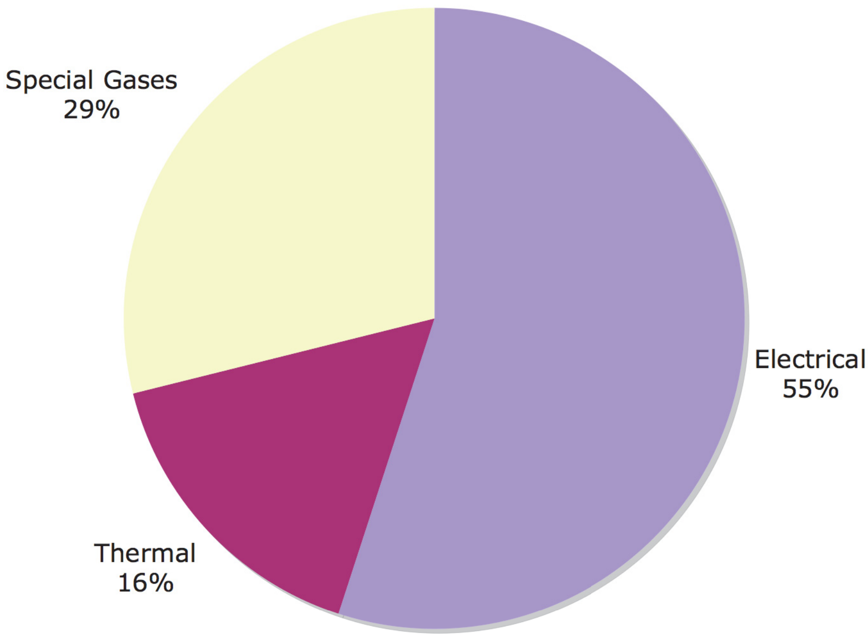

Figure 27: Percentage distribution of emission sources

Figure 28 illustrates each investigated subarea's portion of the total electric energy consumption. If a portion is displayed as 0%, then it consumed less than 1% of the total. Figure 28 also shows there are only three subareas with a two-digit percentage. At the same time only four subareas show a percentage higher than 4%. In other words, four subareas consume 67% of austriamicrosystems' electric energy requirements. At 35%, the production equipment in FAB B uses approximately 1/3 of the entire allotment. This leaves many areas for small improvements, but little room for big improvements given that there is no foreseeable way to change the electric energy consumption of the production machines.

This situation becomes even more apparent when all three emission sources are taken into account and the total GHG emissions of FAB A, FAB B and the Philippines are investigated.

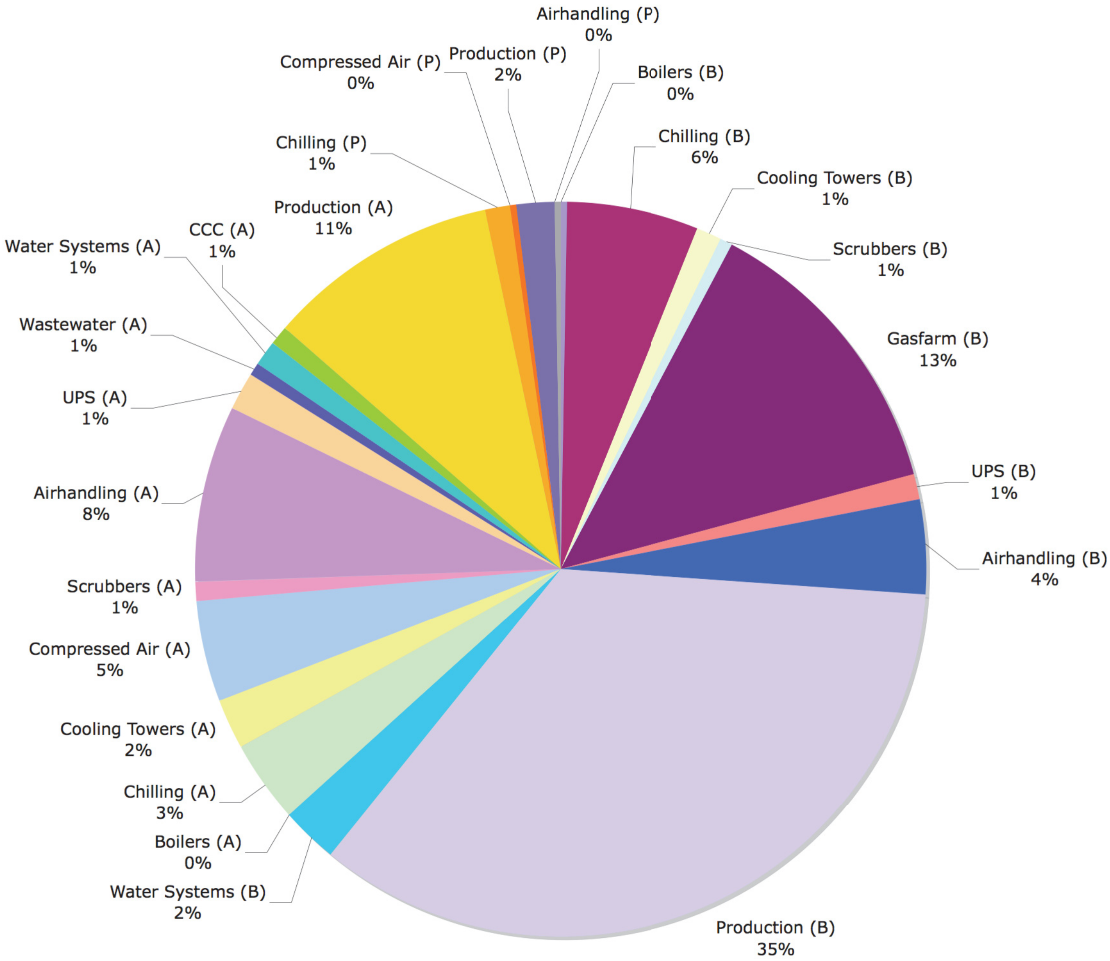

Figure 28: Electrical energy consumption of subareas

When natural gas consumption and technical gases are included, the Production subarea of FAB B amounts to even 49% of the CO_2-emissions caused by production-related processes. In Figure 29 the Production sector is split into actual production equipment and GHG emission from Special Gases. The sectors next in size, the boilers of FAB A, the gas farm, the production equipment in FAB A and the boilers of FAB B all together amount to another 32% of the total emissions. Hence only five sectors cause 81% of austriamicrosystems production-related GHG emissions.

This implies that the five main fields of action for possible reductions and improvements are well determined. However, once again it is important to stress that the larger fraction of these emissions cannot be manipulated without altering production capacity.

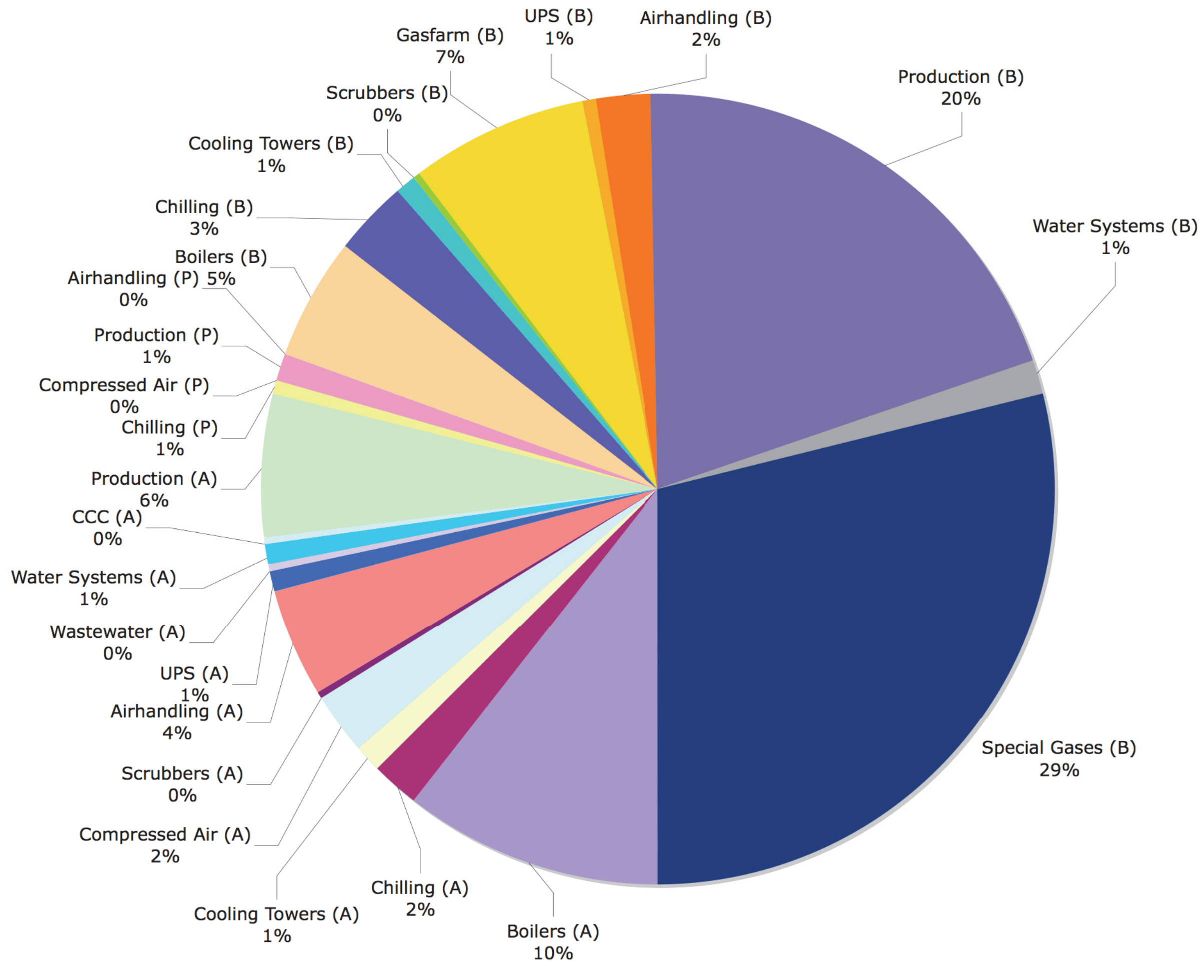

Figure 29: Sector-related CO_2-emissions[16]

[16] If a portion is displayed as 0%, then it consumed less than 1 % of the total.

5.5 Transport processes

The fourth operational area mainly comprises Scope 3 emission sources, which – as discussed in Chapter 2 – can be voluntarily included in the corporate GHG inventory. The only exception is the combustion of fuel in pool cars. This source is actually categorized as Scope 1 emission in the GHG Protocol. Nevertheless, the use of a pool car represents a transportation process and therefore shall be covered in this section. It is very easy to shift the resulting GHG emissions to Scope 1 later on if a reporting system might require them to be allocated correctly.

5.5.1 Combustion of fuel in pool cars:

The mileage-data of all five pool cars, which has been obtained from the Finance and Control department, is listed in Table 12. The pool car at Calamba is not included in this table because there was no mileage data available. Instead a total amount of diesel consumption was reported, which was added to the diesel for the production sites. All cars run on diesel fuel. So the total number of km was multiplied by the emission factor from Chapter 4.5. Hence the pool cars at the plant in Unterpremstaetten emit a total amount of 25 tons of CO_2-per year.

Table 12: Mileage of pool cars

Pool Car	Km/a
GU711EU	48,679
GU613ED	39,163
GU224DF	39,396
GU223DF	25,569
GU556DZ	4,658
TOTAL	**157,465**

5.5.2 Employee business travel:

In 2007 austriamicrosystems personnel flew eight million miles around the globe. This corresponds to 12.88 million passenger kilometers. Multiplied by the emission factor, the business traveling amounts to 1,671 tons of CO_2.

5.5.3 Employee commuting:

The employees had been interrogated on their commuting habits. The result of the survey was a spreadsheet listing the distance to austriamicrosystems and the number of weeks that each means of transport was used for the respective distance. The amount of weeks for one type of vehicle was multiplied by the distance to austriamicrosystems and by 10 rides per week. The resulting overall distances for the individual transportation modes are summarized in Table 13. Assuming the same commuting habits in 2007, the collected data was extrapolated to the number of employees in 2007. These extrapolated numbers were then multiplied by the respective emission factors.

Table 13: Kilometers and CO_2-emissions from employee commuting

	Collected [km/a]	Extrapolated [km/a]	CO_2 [t/a]
Car	5,203,605	11,057,660	1,935
Bus	418,630	889,589	19
Train	185,585	394,368	30
Bike/Walk	372,364	791,274	0
TOTAL	**6,180,184**	**13,132,891**	**1,983**

Based on these assumptions, the employees at the austriamicrosystems plant in Unterpremstaetten cause 1,983 tons of GHG emissions per year by commuting to work everyday. The plant in Unterpremstaetten has not succeeded in convincing its employees to use public transportation as Figure 31 and Figure 32 quite impressively illustrate. Of the total distance, 84% is covered by car and commuting cars also amount to 98 % of the CO_2-emissions. The information presented in Figure 31 and Figure 32 can help to review the existing company bus system as well as recommend future improvements and possible alterations in public transport organized by the company.

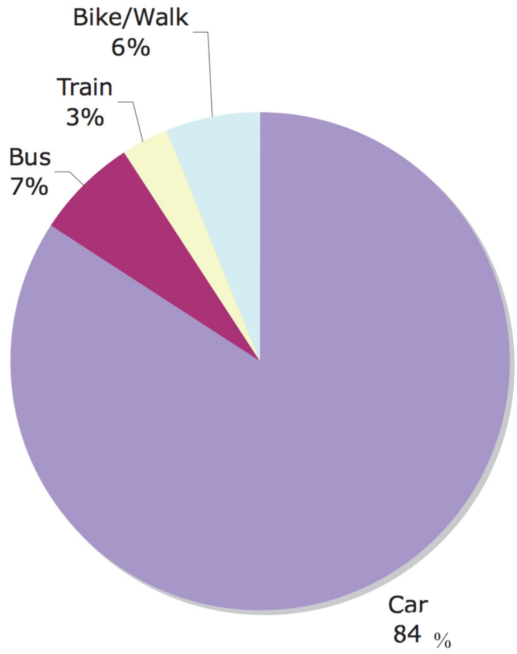

Figure 31: Kilometers of commuting (relative)

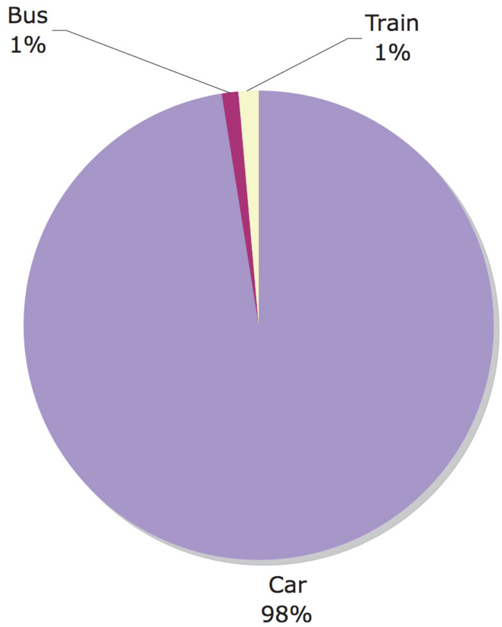

Figure 32: CO_2-emissions from means of transportation

5.5.4 Transportation of products and semi-finished goods:

For each country on the SAP shipping list, one destination was assumed. The chosen destination was either the most important interchange in that particular country or the geographically most centrally located destination. The distance to that destination was calculated using an online database for flight distances [14] for longer destinations and an online route calculator [15] for closer destinations. Table 14 lists all shipping destinations of austriamicrosystems in 2007 and their distances from Graz.

Table 14: Shipping distances

Country Code	Country	Destination	Distance from Graz [km]
AG	Antigua and Barbud	Saint Vincent	7167
AR	Argentina	Buenos Aires	11434
AS	American Samoa	Aasu	16040
AT	Austria	Vienna	190
AU	Australia	Sydney	16498
BE	Belgium	Brussels	1105
BG	Bulgaria	Sofia	960
BH	Bahrain	Al Manama	4459
BR	Brazil	Brasilia	9149
BY	Belarus	Minsk	1370
CA	Canada	Toronto	6346
CH	Switzerland	Zurich	701
CN	China	Shanghai	8849
CZ	Czech Republic	Prague	494
DE	Germany	Frankfurt	700
DK	Denmark	Copenhagen	684
EE	Estonia	Tallinn	912
EG	Egypt	Cairo	1819
ES	Spain	Madrid	1434
FI	Finland	Helsinki	1527
FR	France	Paris	1068
GB	Great Britain	London	1245
GR	Greece	Athens	1798
HK	Hong Kong	Hong Kong	9168
HR	Croatia	Zagreb	200
HU	Hungary	Budapest	400
ID	Indonesia	Jakarta	11122
IE	Ireland	Dublin	1696

IL	Israel	Tel Aviv	2955
IN	India	New Delhi	6115
IR	Iran	Teheran	3783
IT	Italy	Rome	960
JO	Jordan	Amman	3025
JP	Japan	Tokyo	9369
KR	Korea	Seoul	8586
LI	Liechtenstein	Vaduz	600
LT	Lithuania	Vilnius	1249
MK	Macedonia	Skopje	1336
MT	Malta	La Valetta	1645
MX	Mexico	Mexico City	9569
MY	Malaysia	Kuala Lumpur	9968
NL	Netherlands	Amsterdam	365
NO	Norway	Oslo	1110
NZ	New Zealand	Auckland	18177
PH	Philippines	Manila	10300
PL	Poland	Warsaw	898
PT	Portugal	Lisbon	1880
RO	Romania	Bucharest	1218
RU	Russia	Moscow	2039
SE	Sweden	Stockholm	1203
SG	Singapore	Singapore	10264
SI	Slovenia	Ljubljana	198
SK	Slovakia	Bratislava	658
TH	Thailand	Bangkok	9519
TK	Tokelau	Auckland	18177
TN	Tunisia	Tunis	1471
TR	Turkey	Antara	1600
TW	Taiwan	Taipei	9411
UA	Ukraine	Kiev	1054
US	United States	Denver	8129
VE	Venezuela	Caracas	8653
VN	Vietnam	Hanoi	8257
ZA	South Africa	Johannesburg	8650

The kilometers of all shipments were multiplied by the corresponding gross weight and by the correlating emission factor for air transport or road transport. The resulting emissions were summed up and sorted by internal and external recipient numbers.

Based on the assumptions above, product shipping produces 1,737,069 kilometer-tons and causes 790 tons of CO_2 per year.

One interesting finding of this survey illustrated in Figure 33 is that 64% of the GHG emissions are related to internal recipients. This is due to the much higher gross weight shipped to internal recipients compared to that shipped to external recipients.

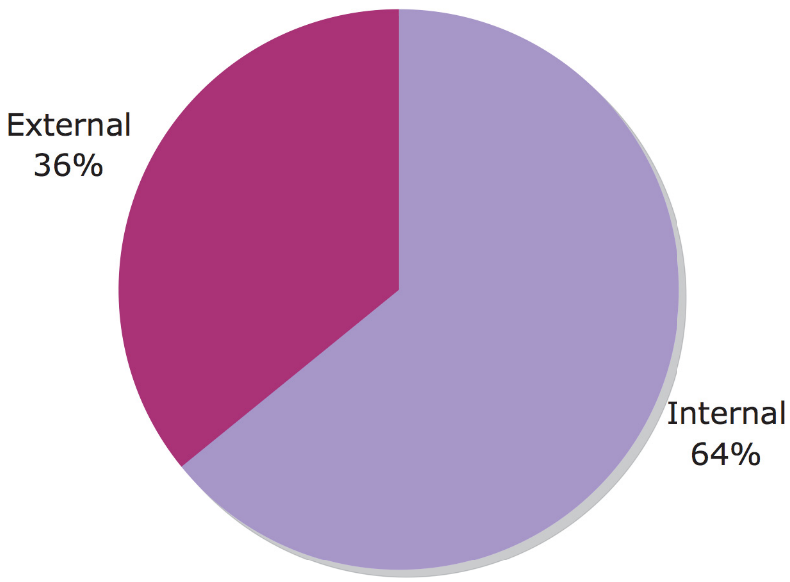

Figure 33: CO_2-emissions related to type of recipient

5.6 GHG Inventory

Finally, the GHG emissions from each of the investigated areas are merged and added. Based on the applied calculation methodology, the retrieved data and the assumptions that had to be made, the company is liable for 35,622 tons of CO_2-equivalent released into the atmosphere in 2007. The contribution of the individual areas to that sum is quite remarkable. As Figure 34 and Figure 35 show, there are two main contributors: FAB A and FAB B. In fact production-related CO_2 amounts to 91% of the total emissions. Even though many simplifications and assumptions had to be made to estimate the GHG emissions caused by transportation processes, the magnitude is definitely representative.

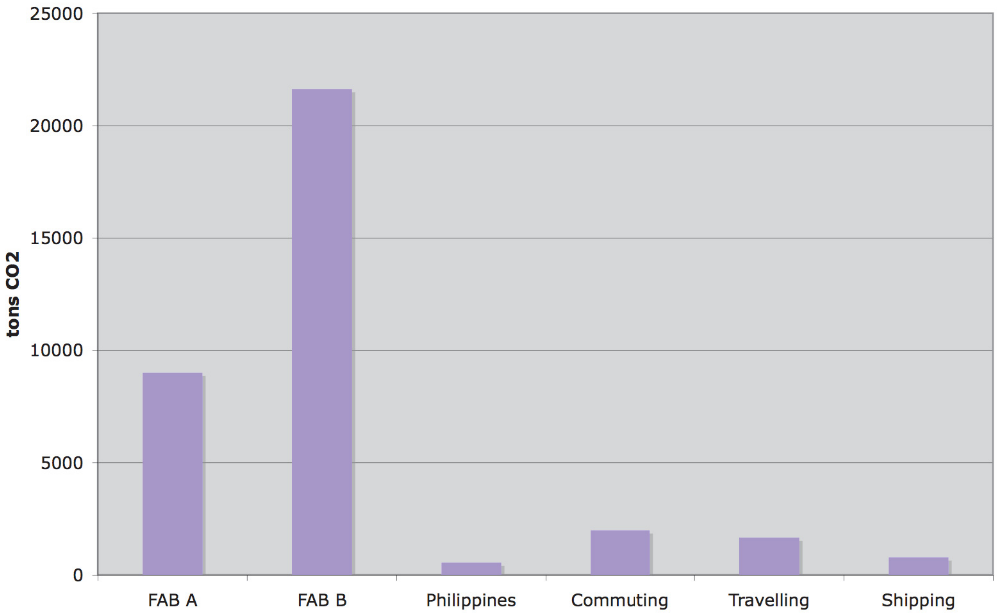

Figure 34: austriamicrosystems GHG emissions (absolute)

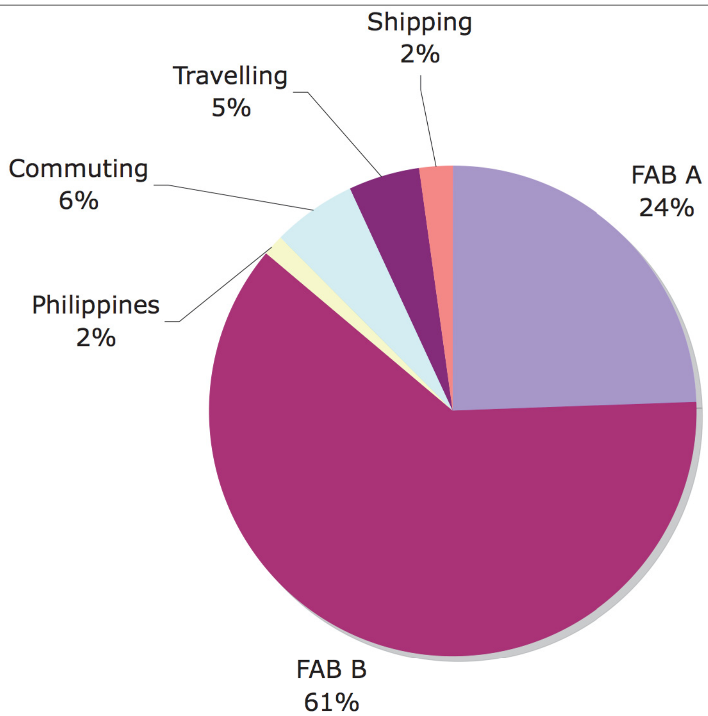

Figure 35: austriamicrosystems GHG emissions (relative)

Hence, in order to significantly reduce the total amount of GHG emissions, projects aiming to mitigate the emissions of FAB A and FAB B should have priority. Nevertheless it is important to state that the “Commuting” is causing the biggest amount of CO_2-emissions of all transport processes. This should trigger at least a littler closer investigation of this sector.

6 Measures and targets

6.1 List of measures

After reviewing the GHG emission data, the austriamicrosystems GHG project team developed a list of possible mitigation measures. The mitigation measures, most of which aim at increasing energy efficiency, were looked at in terms of their applicability, investment requirements and improvement potential. They were divided into three groups based on how quickly they could be implemented.

The first group comprised measures that could be handed in by August 29th, the deadline for 2009's budget drafts. Projects for which the technical feasibility had been determined and for which an offer could be obtained were handed in in time. The second group comprised measures with a much higher technical complexity and larger investment sums. These measures will have to be discussed more thoroughly and investigated by feasibility studies. The third group included "soft" organizational measures such defining corporate GHG policies and raising employee awareness. The following chapters describe the measures and their possible effects.

6.1.1 Measures for 2009 budget

- **Savings in compressed air systems:** The gas farm is continuously producing excess compressed air resulting from the process parameters of nitrogen production. The installation of a new pipeline between the gas farm and FAB A could reduce the compressed air production there.
- **Lighting:** The facility department has determined the installed electric power of all lighting devices at austriamicrosystems in Unterpremstaetten. In addition, the continuously illuminated areas have been determined. The results show that lights use approximately 3% to 5% of the entire electricity consumption. Three ways to reduce light usage are:
    - **Motion detectors:** The installation of motion detectors in less frequented areas would reduce the amount of constantly illuminated areas. This could be especially effective during nighttime and on weekends when few employees are present in the buildings.
    - **Timed switches:** As an alternative to motion detectors, less frequented areas could have timed switches that automatically turn off lights after a set time span.

  - **Energy saving lamps:** Most of the lighting is done by fluorescent lamps. Energy saving bulbs should replace the few light bulbs that exist.

- **Wafer storage:** The test department uses 80 nitrogen-flushed wafer storage boxes in FAB A. The formation of nitrogen consumes electric energy at the gas farm. Approximately 30 % of the wafers can be stored in a spare clean room area next to the storage area. This would shut down the equivalent amount of boxes and save 32 m^3/h of nitrogen gas.

- **Thermal check:** "Grazer Energie Agentur" will do a thermal check of all buildings on the property next winter. This survey could highlight insulation weak points in the buildings and trigger further actions such as thermal coating, window insulation, or the replacement of windows. The thermal check costs 1,480 Euros for the entire company for a general look through. For a closer inspection, the charge is 800 Euros extra.

- **Retrofitting of frequency converters:** Approximately 10 pumps (mainly FAB A air handling pumps) with an electric power between 10 and 30 kW are operating continuously but are heavily throttled to adjust the volume flow to momentary needs. Retrofitting these with frequency converters could significantly reduce the energy consumption as the converters convert static motors into adjustable speed drives (ASD). [16]

6.1.2 Measures for future investigations

Most of the mitigation measures described in this section are more complex and sweeping. So in order to determine their applicability, cost, and GHG reduction potential they should be investigated more thoroughly and supported by feasiblity studies.

- **Improve electric efficiency**: Electric energy usage is the biggest source of CO_2-emissions for austriamicrosystems. Thus it would be beneficial to investigate all electric installations at all austriamicrosystems plants more closely. Some options:

  - **Survey of electric machinery:** In order to have a thorough understanding of the current electric power consumption and in order to form a base for deciding on future equipment efficiency improvements, it would be very helpful to develop a complete list of electricity consuming units. While this survey should include all consumers, the priority is to list units with electric motors. The list should state the following information wherever possible: plate number, manufacturer, motor type, location of installation, assignment, nominal current and nominal power, power factor (cos(φ)) or efficiency factor, year of construction and year of installation, efficiency class, and capability of retrofitting with frequency converters.

Substitution of Eff 1-motors: In cooperation with the CEMEP[17], the European Union has developed a system of efficiency classes for electric motors. The three classes are below. [17]

- Eff 1 = standard motors
- Eff 2 = efficiency improved motors
- Eff 3 = high efficiency motors

The goals of the European Union are to completely remove Eff 1motors from the European market, to define Eff 2 motors as standard motors, and to significantly increase the number of Eff 3 motors.

Design measures such as a better plate quality, reduced magnetic stress, improved bearings, or better cooling can improve the efficiency of a motor.

Compared to standard motors, Eff 3 motors can reduce energy losses by 40% and Eff 2 motors can reduce energy losses by approximately 20%. Additional costs for these motors can be amortized within a year with adequate operating hours. In addition, the service life of the machines can be expanded. [16]

However, replacing functioning old motors by Eff 3, or Eff 2 motors is uneconomic. [16] Thus, austriamicrosystems should set a corporate guideline to check the end of service life for old motors and to replace all broken motors by Eff 2 motors or better in the future

[17] CEMEP = Comité Européen de Constructeurs de Machines Electriques et d'Electronique de Puissance, the European Committee of Manufacturers of Electrical Machines and Power Electronics

- **Cooling technology:** Approximately 12% of the total CO_2-emissions result from cooling and air conditioning processes. Here are some options that can help to reduce that amount.
    - **Retrofitting of free cooling in FAB A:** The same system as in FAB B could be used in FAB A. A free cooling system would reduce the operating hours of chillers and cooling towers by using outside air to recool the cooling water during the colder months of the year.
    - **Heat transfer between FAB A and FAB B:** FAB B delivers cooling water to FAB A during the year. However, the existing free cooling system in FAB B is not involved in this circle. Restructuring the flow scheme and installing additional regulation equipment could make the free cooling system of FAB B accessible.
    - **Solar cooling systems:** A very elegant way to produce cooling power is solar powered absorption cooling. Absorption cooling machines - in contrast to electric powered compressor cooling machines - use a "thermal compression" step to generate cooling energy. [18] In a solar cooling system, solar collectors can supply the heat required to reduce the necessary primary and secondary energy input to a minimum. Only a small pump is necessary for internal circulation. [18] The major disadvantage of this solar cooling is the high investment cost of approximately 5,000 Euros per kilowatt of installed cooling capacity. [19] While converting to this system in existing buildings is definitely uneconomic, an interesting option could be to install solar cooling into any new office buildings that austriamicrosystems might construct. This could reduce running energy expenses for cooling to a minimum and could support the image of an environmentally friendly company as a byproduct.
- **Retrofitting of air-handling units in FAB A:** The air-handling units in FAB A were designed to supply a wafer fabrication. This production no longer exists in FAB A, so the air-handling units have to be throttled. Replacing the large centralized units with smaller, local systems that are optimized for the prevailing situation could reduce energy consumption. The feasibility has to be checked in detail.
- **Expanding videoconference system:** Communicating with customers and suppliers via a videoconference system saves business travel. There are three systems in use at the plant in Unterpremstaetten. An internal survey should

investigate how much these systems are currently used and evaluate promoting their use to individual departments. Videoconferencing is an economic way to improve internal communication between worldwide austriamicrosystems locations: the headquarters, the test center, the design centers and the sales offices. A portable camera system at the test center in Calamba, for example, could be used to solve minor technical problems online. In addition to internal utilization, expanded use of videoconferencing with business partners should be introduced as a voluntary option.

- **Installation of a photovoltaic test system:** austriamicrosystems plans to expand its product range in the near future by designing chips for photovoltaic applications (PV). To gain first hand experience, a small grid-connected photovoltaic system could be installed at the headquarters in Unterpremstaetten. Such a system could be used as a small test laboratory and generate at least some green energy. Based on the average annual sunshine for Graz (1,890 hours), a system with a peak power of 4.7 kW could produce approximately 10,000 kWh of electric energy per year. [25]. According to the “Einspeisetarifverordnung 2006,” each kWh of electricity generated by photovoltaic plants with an installed peak power smaller than 5kW has to be refunded with 46 cents. [26] Thus, a grid-connected PV system of the described size could earn approximately 4,600 Euros per year. The investment sum for a 4.7 kWp plant is 25,000 Euros. For PV plants with a peak power of 5 kW - 10 kW and > 10 kW, the refund is 40 cents and 30 cents for each kilowatt-hour produced, respectively. [26] Including a PV system in a new office building could partly or fully – depending on the size – supply the electric energy for the building. Combined with a solar cooling/heating system or a heat pump, a building could be designed as a “zero emission office”.
- **Solar panels for CCC:** As a test and PR project, the 1000-liter hot water boiler in the CCC basement could be heated by solar collectors instead of the current electric heating system. However, it is not clear how complicated the installation of such a system into the existing building would be. “Sonnenkraft”, a solar system company, estimated that the total cost for the CCC area would be 10,000 Euros. This includes material and installation. Subsidies by the “Kommunalkredit” might also apply.
- **Heat recovery for UPS systems:** The UPS units constantly produce waste heat at a temperature level of 25° to 30° C. A heat pump could capture this energy and produce, for example, 65° C hot water. A reasonable application for this hot water

still has to be determined. The facility department will measure the actual hot water consumption for sanitary use to facilitate further decisions.

- **Measuring equipment**: As already discussed, one of the biggest problems in calculating the corporate GHG inventory was the lack of precise representative data. The installation of more measurement equipment, such as flow meters, operating-hour counters, and kilowatt-hour counters, would facilitate energy balancing and reduce the amount of assumptions that have to be made. This will be important for future reporting and official verification projects.
- **Change in parking lot organization:** During nighttime all three parking lots are completely lighted. If one or two parking lots are closed for a few hours, the lights there could be turned off. This would require making the closed areas inaccessible to employees and, more importantly, to external persons. Thus, some sort of barrier would have to be installed and a parking order would have to be issued. The economic value of such a measure still has to be determined.
- **Using enriched oxygen from gas farm:** The nitrogen production process also produces 40% enriched oxygen gas. This gas is released to ambient air and amounts to 360 m^3/h or 3.15 million m^3 per year at the moment. At the same time, the abatement systems use pure oxygen for PFC combustion. The 350,000 m^3/a of needed oxygen is delivered to the plant by tank trucks. One cubic meter of pure oxygen costs 0.252 Euros. So theoretically enriched oxygen from the gas farm could fully substitute for the pure oxygen. The technical feasibility has to be determined. A pipeline would be necessary from the gas farm to FAB B, which might be expensive. If the application of the entire amount of enriched oxygen is possible, this would annually save 88,200 Euros.

6.1.3 Organizational measures

- **Definition of corporate GHG policy and GHG goals:** For future GHG accounting, reporting and mitigation, it is highly recommended that austriamicrosystems defines a corporate GHG policy and develops a list of clear, realistic goals. The policy should be integrated into existing management guidelines and the goals should be broken down to the relevant department levels.
- **Raising employee awareness:** If the company decides to actively aspire to follow a GHG mitigation policy, every employee should be informed and involved. Some ideas are to have an information event in the CCC (i.e. austriamicrosystems green day) or to develop a good practice online leaflet on energy and GHG saving. Such

an online leaflet could describe some easy measures for everyone's workday. For example:

- Switch off lights when leaving a room, but make sure no one is still in there!
- Switch computer to stand-by during lunch break
- Turn off computer when you go home
- Turn off air condition when windows are open
- Unplug electric devices not in use
- Use public or company transportation
- Ride a bike
- Share a car

- **CO_2-cap for company cars:** The company could define a CO_2-emissions threshold for new cars and/or use hybrid cars as company vehicles. Lexus, for example, has the LS 600 and the GS 450. Both cars use hybrid engines and have 445 and 340 hp, respectively. The LS 600 emits 219 g CO_2/km and the GS 450 185 g/km. Both cars fulfill the requirements for company cars for upper management staff. [21] Audi's A6 by contrast, with a comparable power of 350 hp, emits 244 g CO_2/km. [22] If matching current car requirements is not the goal, Toyota's Prius could be a viable alternative. With 113 hp it only generates 105 g CO_2/km. [23]
- **Review of company bus system:** The public transport system in the village of Unterpremstaetten is not very developed. While there is a bus line and an express train through the village, the cycles and the connection to the plant make both inconvenient. Thus, austriamicrosystems decided to operate a company bus that runs between Graz and the plant. Unfortunately, this offer is not frequently used and mostly only shift personnel take advantage of it. The company should review the company bus system once more. Perhaps changing the routes or pick-up points could improve the situation. An employee survey could assist in finding alternatives.
- **Flight optimization:** In addition to reducing flight kilometers by expanding the use of videoconference systems, austriamicrosystems should also consider implementing a flight management system. Departments could use colleagues from other sections to settle smaller matters at certain destinations without sending an employee of their own to the same location. In addition, employees should think

ahead of future tasks and make sure to handle as many things as possible in one single trip. Multiple trips to the same destination should be avoided wherever possible.

- **Improve reporting system for GHG related information:** The communication system for GHG related information has to be improved if the company decides to continue determining and reporting its GHG emissions in the future. Departments that were involved in the present study should automatically store and report required data sets in the future. A team should be responsible for GHG data collection and check this process. A lot of technical activity was not available because the storage drives of the control systems are limited (i.e. operating hours only for the last two months). Expanding memory capacity and renewing computers in the control center could solve the problem.
- **Improve level of detail for reported GHG data:** A lot of assumptions had to be made during the data evaluation process due to a lack of detail. A GHG team should prepare standardized reporting forms for information required from the various operational units. For example, the logistics department could demand precise shipping addresses from the forwarding agents to forward to the GHG group.

6.1.4 Evaluation of measures

This chapter will try to estimate actual economic and environmental benefits of the measures budgeted for 2009.

- **Savings in compressed air systems:** The excess amount of CDA at the gas farm is 600 m^3/h. The production of 1 m^3 CDA consumes 0.413 kWh of electric energy[18]. This results in possible energy savings of 2170 MWh/a. This equals an amount of 699 tons CO_2/a. At the current price of approximately 70 Euros per MWh, 151,790 Euros could be saved per year. SMB made an offer of 25,000 Euros for the necessary pipeline installation and control system.
- **Lighting:** On average 4% of the electric energy consumption is used for illumination. In 2007 lights consumed approximately 2 GWh of electric energy. Results from the lighting project of the facility department show that motion detectors and timed switches could save 20% of that amount.

[18] Information provided by Linde Nippon Sanso.

This equals 400 MWh of saved electric energy or 28,000 Euros of saved annual expenses or 129 tons of CO_2 per year. In total 17,300 Euros have been budgeted for the necessary installations.

- **Wafer storage:** Saving 96 m^3 of nitrogen gas per hour would result in a total annual saving of 280,320 m^3. The formation of 1 m^3 of nitrogen consumes 1.8 times as much energy as the formation of 1 m^3 of CDA[19]. Changing the wafer storage could save 208 MWh per year. This amount equals 14,579 Euros per year or 67 tons of CO_2. There is no investment necessary as the dry room already exists.
- **Retrofitting of frequency converters:** As a first step, seven pumps of FAB A's air handling system will be equipped with frequency converters in 2009. On average the pumps consume an electric power of 15 kW each. They operate continuously, so at the moment they consume 131,400 kWh/a. The installation of frequency converters would reduce their energy consumption to at least 50% or 65,700 kWh. This means that each unit would save at least 4,600 Euros per year. In fact, it is very likely that the energy consumption is reduced to 1/3 of the original amount. So a total number of seven pumps could save roughly 460,000 kWh per year, a total of 32,193 Euros or 148 tons of CO_2.

6.1.5 Summary of budgeted measures

This section shall briefly summarize the effects of the budgeted measures for 2009.

Table 15: Savings of budgeted measures for 2009

	Investment cost [€]	Saved Electric Energy [MWh/a]	Avoided Expenses [€/a]	Avoided CO_2 [t/a]
Compressed air system	25,000	2,170	151,790	699
Lighting	17,300	400	28,000	129
Wafer Storage	17,300	208	14,579	67
Frequency Converters	35,000	460	32,193	148
TOTAL:	**77,300**	**3,238**	**226,562**	**1,043**

[19] 0.743 kWh/m^3

If the assumptions are correct, the total annual savings of these four measures will be quite significant. The saved electric energy of 3,655 MWh represents almost 7.2% of austriamicrosystems' total electric energy consumption. A saving of 1,043 tons of CO_2 means a reduction by 3.3% of austriamicrosystems' overall 2007 GHG emissions.

6.2 Targets

If austriamicrosystems decides to pursue its GHG initiative and voluntarily reports its emissions to the public, it should define clear and achievable targets. The GHG Protocol defines ten steps in setting a target. [2] The targets should be measurable in tons of CO_2. The corporate strategy to achieve these goals should mostly involve the various previously defined measures. Benefits to austriamicrosystems from setting GHG targets are:

- GHG targets help to raise internal awareness about risks and opportunities arising from climate change. GHG targets put the issue on the business agenda and assist in managing and minimizing business risks associated with climate change.
- GHG targets would guide the implementation of mitigation measures, which in turn would lead to cost savings and trigger innovations.
- Internal accountability and incentive mechanisms supporting the implementation of GHG targets could prepare austriamicrosystems to respond more effectively to future GHG regulations.
- Setting public corporate GHG targets is a commitment that demonstrates leadership and corporate responsibility. As global concerns about the effects of climate change grow, such a move would improve austriamicrosystems' standing with customers, employees, investors, business partners and the general public. [2]

7 “Green Chip Factory” (GCF)

The measures described and evaluated in Chapter 6 aim to increase the overall energy efficiency of austriamicrosystems and to reduce the total amount of GHG emissions related to the company. These measures, however, by far will neither reduce austriamicrosystems’ emissions to zero, nor completely offset them. If the company decides to become a zero-GHG-emission enterprise, it will have to consider other steps. In the literature, a zero-GHG-emission enterprise is referred to as being “carbon-neutral” or “green”. The next chapter describes and evaluates some options that could convert austriamicrosystems AG into a “Green Chip Factory”.

All numbers presented in this section are based on reference projects, manufacturer data or the literature. The figures are meant to give an idea of the technical characteristics and financial dimensions involved for the options presented and should be treated as assumptions. austriamicrosystems must conduct detailed feasibility studies to determine the precise applicability and costs of the projects it might be interested in pursuing.

7.1 Energy production

One way to become carbon-neutral is to self-produce the required energy in power plants using renewable energy. Here are four alternatives that could substitute 100% of austriamicrosystems’ energy needs. Data from reference projects was extrapolated to meet the energy consumption of austriamicrosystems in 2007: 51 GWh of electric energy and 2.8 million m^3 of natural gas.

7.1.1 Wind power plant:

A wind turbine only produces electric energy. Therefore, a separate renewable energy power plant would have to provide thermal power in order to substitute 100% of austriamicrosystems’ energy needs. To produce 51 GWh per year, wind turbines with approximately 25 MW of installed power have to be constructed at a site with sufficient wind speed. [26] Locations with decent wind speed are limited in Austria. Nevertheless, the Austrian Wind Power Lobby “IG Windkraft” estimates that the total capacity of installed wind power will be expanded from 1,000 MW to 3,500 MW by 2020.

On average the installation of 1 MW wind power costs 1.2 to 1.5 million Euros. This number includes the wind turbine itself, transportation, construction of the basement, erection and grid interconnection. [26] Thus, a 25 MW plant would cost between 30 and 37.5 million Euros not including the property. Modern wind turbines for land construction have a maximum power of 1.5 to 3 MW. [27] So in order to achieve 25 MW of total capacity, 9 to 17 turbines have to be installed. This is the size of an average wind park.

The Danish Wind Industry Association assumes maintenance costs of 0.01 USD for each kWh of produced electric energy. [28] At an exchange rate of 1.4 this amounts to 364,000

Euros of annual costs for 51 GWh produced. “IG Windkraft” assumes that for the first ten years of service maintenance costs are 5.7% of the installation costs and for the next ten years 7.9%. This amounts to annual maintenance costs of 255,000 Euros per year.

The generated electricity from a wind park is normally sold to the grid. If the wind power plant is constructed in Austria, the electric energy will be refunded at the rate of 7.55 Euro cents/kWh based on the renewable energy law of 2006. For wind park operators, this rate is not sufficient to work profitably at the moment. However, it might be changed to 9.5 cents/kWh in 2009, which would trigger new construction projects.[26]

7.1.2 Photovoltaic Power Plant

Photovoltaic (PV) cells convert solar radiation into electric energy. Due to high raw material prices and a sophisticated manufacturing process, PV-modules are still expensive. The average production cost for one Watt is €3.6 to E€3.9. The price is €5 to €6 per watt for readily installed systems. [29] Therefore, only few large-scale power plants have been constructed worldwide. The typical field application is smaller grid-connected home systems with 5 to 10 kW peak power or off-grid systems to supply remote buildings.

The amount of electricity generated from a PV module mainly depends on the number of sunlight hours per year and on the installed collector area. PV power plants need a huge construction area. The German Juwi group is currently building the world’s largest PV power plant close to Leipzig. Its installed capacity is 40 MW and the construction area is 220 hectares. The plant will produce 40 GWh of electricity per year and cost 130 million Euros. [20]

Taking these numbers and extrapolating them to the energy needs of austriamicrosystems provides a rough estimation of the project dimension if 100% is to be substituted. The installed capacity would have to be 51 MW. A construction area of 280 hectares would be necessary and the total project cost would be 165.8 million Euros.

7.1.3 Biogas Power Plant

A biogas power plant uses anaerobic degradation processes to convert biomass into methane and other side products. The methane is then burned in a combined heat power unit (CHP), which generates electric energy and thermal energy from the hot exhaust gases.

A power plant that generates 51 GWh of electricity per year would need an installed electric capacity of approximately 6 MW. Such a plant would also produce 32.2 GWh of thermal energy. This amount equals 2.83 million m^3 of natural gas. [30]

Biogas power plants can use a wide range of input materials. To ensure the internal material stream in the plant is of usable consistency a certain viscosity has to be maintained. Therefore, solid and liquid feedstocks have to be mixed. Possible input materials are organic municipal waste, animal excrements, agricultural waste, energy crops, slaughterhouse waste and wastewater. A possible feedstock mix for a 6 MW plant could be 40,000 tons of straw and 60,000 tons of liquid substrate (manure, dairy rejects etc.). [31]

The total investment cost for such a plant is approximately 11 million Euros not including the property. The plant needs a construction site of 30,000 m^2. The annual costs would roughly amount to 3.6 million Euros. This includes substrate costs, sludge disposal, insurance, maintenance and wages for the operating personnel. [31]

7.2 GHG offsetting

Another way to convert austriamicrosystems into a carbon neutral company is to invest in projects that generate renewable energy at other non-company locations or to create new GHG sinks by reforestation. These projects do not avoid the conventional energy uses at the austriamicrosystems plant itself, but offset the generated emissions by off-site actions.

austriamicrosystems can either generate a GHG sink on its own or it can charge another company with this task. There are numerous companies, called GHG project dealers, that offer GHG offset projects to individuals or enterprises and they all basically work the same way. They look at the total amount of CO_2 generation, derive a project size that could offset the emitted amount,, send the project details and cost estimate to the client, and carry out the project if approval is obtained. The client then gets a certificate and is enlisted in a publicly available registry.

One of these dealers is the English company CO2balance.com. It offers an online offset calculation tool on its website. Pasting in the total CO_2-emissions of austriamicrosystems, the system advised that to offset 36,000 tons of CO_2-equivalent, austriamicrosystems could invest in the following projects [32]:

- **African energy efficiency:** Cost: 401,760 Euros[20]; Replacement of inefficient light bulbs with energy saving lamps
- **Solar ovens and energy efficient stoves:** Cost: 401,760 Euros; Installation of solar-powered sun ovens and energy efficient wood stoves
- **Foret de Menez Fresk:** Cost: 446,400; Reforestation project in Brittany in France.

These projects are one-time annual offsets. Hence, the expenses have to be made every year.

austriamicrosystems could also invest directly in some sort of sink project. Sink projects are mostly reforestation or afforestation, which means that trees are planted where they have been chopped down before or where there have not been any before, respectively. Trees

[20] Price given in British Pounds; conversion rate used: 1.24 €/pound

work as CO_2 traps because they consume CO_2 while they grow. When they are cut and burned or when they die and decompose, CO_2 is released again.

Different species consume different amounts of CO_2. The domestic copper beech[21] consumes 2,190 kg of the gas during one year. The Asian catalpa[22] on the other hand consumes 4,710 kg per year. The trees do not store the entire amount taken in, but assuming that one tree “destroys” the given amount per year, austriamicrosystems would have to plant approximately 16,438 copper beeches. This would require approximately 100 hectares of wood.

Another option would be to donate to NGOs that conserve rainforest. The Austrian NGO “Regenwald der Oesterreicher” runs a national park in Costa Rica that preserves the local rain forest. With the donations it receives from Austria, the organization buys adjacent property from the farmers and integrates it into the park. This prevents the forest from being burned or cut down and has a twofold effect. “Regenwald der Oesterreicher” assumes that the burning of one hectare of rain forest emits 300 tons of CO_2 into the atmosphere. On the other hand, one hectare also stores 400 tons of CO_2. So if austriamicrosystems wants to offset its annual emission it has to buy approximately 90 hectares of rainforest per year. Donating 126,000 Euros to the NGO can do this. [33]

It is not quite clear how the effect of such projects can be verified. The offset dealers and most of the NGOs provide some sort of certification or registry entry. The acceptance of such certificates by official reporting or emission trading programs, however, is not determined. On the other hand, in addition to benefiting the environment, the public relations potential for all the projects mentioned in this section is huge. For example: “austriamicrosystems goes carbon neutral and saves 100 hectares of rainforest!”

7.3 Emission trading

Mandatory emission offsetting could be the result of national or European legislation changes. The EU implemented the Kyoto Protocol on February 16, 2005. The protocol is an international treaty of 143 nations signed in 1997. The signing nations agreed on reducing their total annual emissions of six defined climate relevant gases to 5% percent below the 1990 levels. [34]

Each nation negotiated its own reduction goal. The Austrian goal is 13% below its 1990 levels. The overall European goal is minus 8%. The protocol describes three different market mechanisms to achieve these goals: Emission Trading, Joint Implementation (JI) and Clean Development (CDM). These mechanisms use tradable emission certificates. Each certificate

[21] Rotbuche

[22] Trompetenbaum

allows the emission of one ton of CO_2 equivalent. The overall emissions for the European Union are allocated to individual countries and certificates are assigned to relevant industry sectors and companies. The total amount of assigned certificates will be reduced each year on a national and a European level. Thus, each year fewer certificates will be available and companies will be forced to reduce their emissions or pay. If companies exceed their allowed amounts, they will have to buy certificates from the market. Companies that do not need all their certificates can sell them on the market. The trade works between countries and companies. [34]

The first trading period (2005-2008) is designed to provide participating companies with some experience. In the second target period (2008-2012), the defined goals have to be fulfilled. During these first two periods only certain industry sectors are required to participate in the emission trading system. The affected sectors comprise energy intense production processes and industries with a predefined installed thermal capacity The threshold for total thermal capacity of combustion units is 20 MW. The total thermal capacity of the boilers installed at the austriamicrosystems plant in Unterpremstaetten is 18.6 MW. Therefore, austriamicrosystems does not have to participate in the system.

It is very likely, however, that the Kyoto Protocol and the emission trading system will be continued after 2012. Participating industry sectors and the threshold could be extended and reduced, respectively. This could easily affect austriamicrosystems. For example, if the thermal capacity limit were reduced to 10 MW, the company would have to buy certificates for GHG emissions from its boiler units. In 2007, 4,982 tons of CO_2 resulted from the combustion of natural gas.

At the moment the Energy Exchange Austria (EXAA), a stock exchange that only trades emission certificates, lists one ton of CO_2 for 23.25 Euros. [35] The price for one ton of CO_2 at the European Climate Exchange (ECX) varies between 22.2 and 27.9 Euros. [36] This means that austriamicrosystems would have to spend between 110,600 and 138,998 Euros annually to acquire the emission certificates for 100 % of its current 4,982 tons of CO_2-emissions from thermal sources.

The other two mechanisms of the Kyoto Protocol provide an interesting alternative to buying certificates on the market. JI and CDM projects are GHG mitigation projects in less developed and developing countries, respectively. Countries or companies can fund these projects and use the achieved emission reductions to offset their own balance. The required reductions are simply accomplished at a different location.

JI and CDM projects might be valid alternatives for austriamicrosystems to offset its total GHG emissions and provide other ways for austriamicrosystems to become a Green Chip Factory. The German emission-trading agency (DEHST), for example, offers different project opportunities on its homepage. The projects are divided into 12 different project categories and can be individually chosen. Their reduction potential can vary depending on the size and project type. Thus, austriamicrosystems could also fund a project that produces more emission reduction units than the company actually needs and in this way become carbon neutral.

8 Summary

austriamicrosystems, a microchip producer in Unterpremstaetten, Austria, is an environmentally aware company that has always strived in general ways to determine and soften its impact on the environment. To formalize and specify these aims, austriamicrosystems decided to set up a GHG project team to purposefully identify all its GHG related activities, calculate the resulting CO_2 emissions, and evaluate measures to minimize its carbon footprint.

First and foremost, the GHG team had to develop a structural design for the study. The operational boundary was defined to include all businesses that austriamicrosystems wholly owns. However, the only two sites with significant energy consumption, the headquarters in Unterpremstaetten and the main test facility in Calamba in the Philippines, were included in this study. Within these two sites, the GHG project team defined four operational areas for data collection: FAB A, FAB B, the Philippines, and Transport Processes. The first three, FAB A, FAB B, and the Philippines were then further divided into sub-areas containing machinery with the same function such as boilers, chillers, and cooling towers. Individual pieces of machinery were called units.

Next, existing data was retrieved and missing information was constructed by using the operational expertise of experienced staff and by making educated assumptions. The data was allocated to the relevant machine units and subareas of each operational area and converted into tons of CO_2 using calculations involving appropriate emission factors. A sum of the total CO_2 outputs provided the overall GHG balance for austriamicrosystems.

The results of the calculation process limited the field of action but also highlighted some weak points that offer a potential for GHG reduction. austriamicrosystems emitted approximately 35,633 tons of CO_2-equivalent into the atmosphere during its base year of 2007. The project team developed a list of efficiency improving measures that would cut GHG emissions. Some of these measures still have to be investigated for their economic and technical feasibility, but others are budgeted for 2009. The measures for 2009 could reduce the company's CO_2-emissions by 3%.

In addition to efficiency measures, there are other options that could convert austriamicrosystems into a carbon neutral company. Many of these, however, are huge projects that require a significant financial commitment and feasibility studies to evaluate their technical applicability and economic sense.

9 Indices

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9.4 List of Abbreviations

%	Percent
&	and
€	Euros
a	Year
CDA	Compressed Dry Air
CDM	Clean Development Mechanism
COP	Coefficient of Performance
ECX	European Climate Exchange
EXAA	Energy Exchange Austria
FFU	Fan Filter Unit
g	Gram
GHG	Greenhouse Gas
GWh	Giga Watt hour
GWP	Global Warming Potential
h	Hour
hp	Horse power
JI	Joint Implementation
kg	Kilogram
kmol	Kilo mole
kVA	Kilo Volt Amps
kW	Kilo Watt
kWh	Kilo Watt hour
m^2	Square Meter

m^3	Cubic Meter
mol	Mole
MW	Mega Watt
MWh	Mega Watt hour
NGO	Non Governmental Organization
PCW	Process Water
PFC	Poly Fluor Carbon
PV	Photo Voltaic
t	Ton
UPS	Uninterrupted Power Supply
UPW	Ultra Pure Water
UV	Ultra Violet
W	Watt

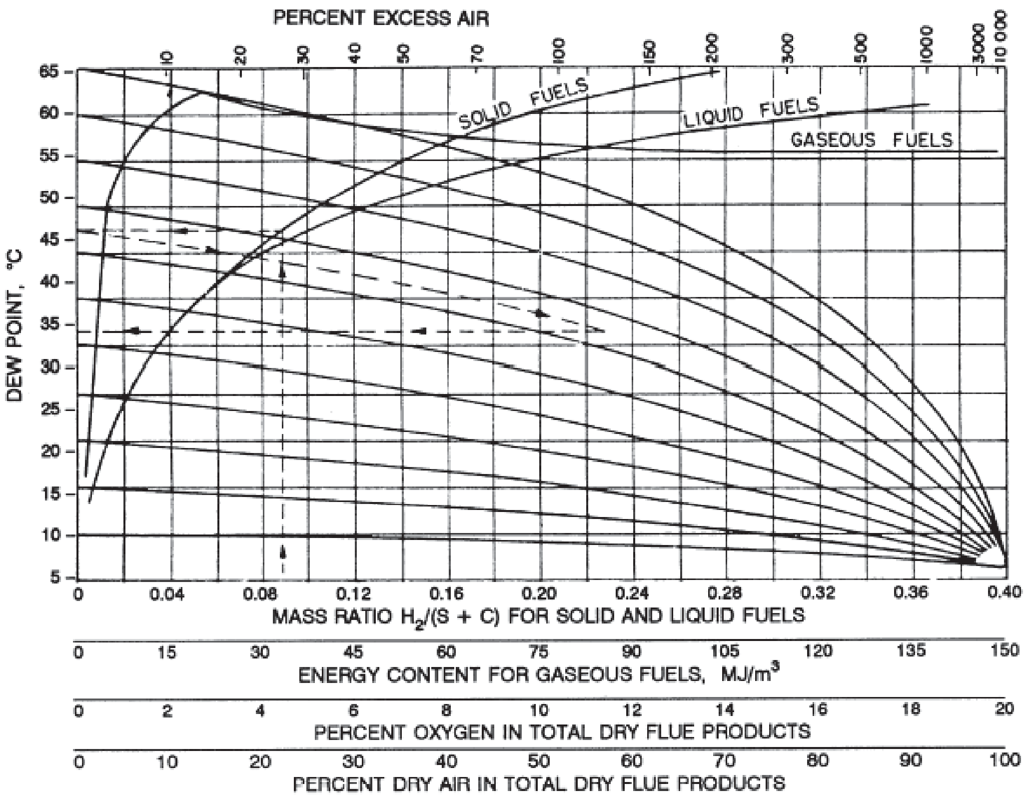
Appendix

Appendix I: Combustion

Combustion Reactions of common fuel constituents [7]

Constituent	Molecular Formula	Combustion Reactions	Stoichiometric Oxygen and Air Requirements: kg/kg Fuel[a] O_2	kg/kg Fuel[a] Air	m³/m³ Fuel O_2	m³/m³ Fuel Air	Flue Gas from Stoichiometric Combustion with Air: Ultimate CO_2, %	Dew Point,[c] °C	m³/m³ Fuel CO_2	m³/m³ Fuel H_2O	kg/kg Fuel CO_2	kg/kg Fuel H_2O
Carbon (to CO)	C	$C + 0.5O_2 \rightarrow CO$	1.33	5.75	b	b	—	—	—	—	—	—
Carbon (to CO_2)	C	$C + O_2 \rightarrow CO_2$	2.66	11.51	b	b	29.30	—	—	—	3.664	—
Carbon monoxide	CO	$CO + 0.5O_2 \rightarrow CO$	0.57	2.47	0.50	2.39	34.70	—	1.0	—	1.571	—
Hydrogen	H_2	$H_2 + 0.5O_2 \rightarrow H_2O$	7.94	34.28	0.50	2.39	—	72	—	1.0	—	8.937
Methane	CH_4	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	3.99	17.24	2.00	9.57	11.73	59	1.0	2.0	2.744	2.246
Ethane	C_2H_6	$C_2H_6 + 3.5O_2 \rightarrow 2CO_2 + 3H_2O$	3.72	16.09	3.50	16.75	13.18	57	2.0	3.0	2.927	1.798
Propane	C_3H_8	$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	3.63	15.68	5.00	23.95	13.75	55	3.0	4.0	2.994	1.634
Butane	C_4H_{10}	$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$	3.58	15.47	6.50	31.14	14.05	54	4.0	5.0	3.029	1.550
Alkanes	C_nH_{2n+2}	$C_nH_{2n+2} + (1.5n + 0.5)O_2 \rightarrow nCO_2 + (n+1)H_2O$	—	—	$1.5n + 0.5$	$7.18n + 2.39$	—	53	n	$n+1$	$\frac{44.01n}{14.026n + 2.016}$	$\frac{18.01(n+1)}{14.026n + 2.016}$
Ethylene	C_2H_4	$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	3.42	14.78	3.00	14.38	15.05	52	2.0	2.0	3.138	1.285
Propylene	C_3H_6	$C_3H_6 + 4.5O_2 \rightarrow 3CO_2 + 3H_2O$	3.42	14.78	4.50	21.53	15.05	52	3.0	3.0	3.138	1.285
Alkenes	C_nH_{2n}	$C_nH_{2n} + 1.5nO_2 \rightarrow nCO_2 + nH_2O$	3.42	14.78	$1.50n$	$7.18n$	15.05	52	n	n	3.138	1.285
Acetylene	C_2H_2	$C_2H_2 + 2.5O_2 \rightarrow 2CO_2 + H_2O$	3.07	13.27	2.50	11.96	17.53	39	2.0	1.0	3.834	0.692
Alkynes	C_nH_{2m}	$C_nH_{2m} + (n + 0.5m)O_2 \rightarrow nCO_2 + mH_2O$	—	—	$n + 0.5m$	$4.78n + 2.39m$	—	—	n	m	$\frac{22.005n}{6.005n + 1.008m}$	$\frac{9.008m}{6.005n + 1.008m}$
									SO_x	H_2O	SO_x	H_2O
Sulfur (to SO_2)	S	$S + O_2 \rightarrow SO_2$	1.00	4.31	b	b	—	—	1.0 SO_2	—	1.998 (SO_2)	—
Sulfur (to SO_3)	S	$S + 1.5O_2 \rightarrow SO_3$	1.50	6.47	b	b	—	—	1.0 SO_3	—	2.497 (SO_3)	—
Hydrogen sulfide	H_2S	$H_2S + 1.5O_2 \rightarrow SO_2 + H_2O$	1.41	6.08	1.50	7.18	—	52	1.0 SO_2	1.0	1.880 (SO_2)	0.528

Theoretical dew points of combustion products of industrial fuels [7]



Appendix II: Global Warming Potentials [3]

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W m^{-2} ppb^{-1}$)	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4×10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7×10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03×10^{-3}	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	0.32		2,030	595	181
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon SAR‡ (100-yr)	20-yr	100-yr	500-yr
Perfluorinated compounds (continued)							
PFC-218	C_3F_8	2,600	0.26	7,000	6,310	8,830	12,500
PFC-318	c-C_4F_8	3,200	0.32	8,700	7,310	10,300	14,700
PFC-3-1-10	C_4F_{10}	2,600	0.33	7,000	6,330	8,860	12,500
PFC-4-1-12	C_5F_{12}	4,100	0.41		6,510	9,160	13,300
PFC-5-1-14	C_6F_{14}	3,200	0.49	7,400	6,600	9,300	13,300
PFC-9-1-18	$C_{10}F_{18}$	>1,000[d]	0.56		>5,500	>7,500	>9,500
trifluoromethyl sulphur pentafluoride	SF_5CF_3	800	0.57		13,200	17,700	21,200
Fluorinated ethers							
HFE-125	CHF_2OCF_3	136	0.44		13,800	14,900	8,490
HFE-134	CHF_2OCHF_2	26	0.45		12,200	6,320	1,960
HFE-143a	CH_3OCF_3	4.3	0.27		2,630	756	230
HCFE-235da2	$CHF_2OCHClCF_3$	2.6	0.38		1,230	350	106
HFE-245cb2	$CH_3OCF_2CHF_2$	5.1	0.32		2,440	708	215
HFE-245fa2	$CHF_2OCH_2CF_3$	4.9	0.31		2,280	659	200
HFE-254cb2	$CH_3OCF_2CHF_2$	2.6	0.28		1,260	359	109
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	5.2	0.34		1,980	575	175
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	7.1	0.25		1,900	580	175
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	0.33	0.93		386	110	33
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$	3.8	0.31		1,040	297	90
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	0.77	0.3		207	59	18
HFE-43-10pccc124 (H-Galden 1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$	6.3	1.37		6,320	1,870	569
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	12.1	0.66		8,000	2,800	860
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	6.2	0.87		5,100	1,500	460
Perfluoropolyethers							
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	800	0.65		7,620	10,300	12,400
Hydrocarbons and other compounds – Direct Effects							
Dimethylether	CH_3OCH_3	0.015	0.02		1	1	<<1
Methylene chloride	CH_2Cl_2	0.38	0.03		31	8.7	2.7
Methyl chloride	CH_3Cl	1.0	0.01		45	13	4