An analysis of carbon capture and utilisation options in the Austrian industry

Master Thesis

by

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Submitted at the

Department of Economics and Business Management
at the
University of Leoben

Leoben, 11th of March 2013

CONCEPTUAL FORMULATION

Mr. **Christoph Niederseer** is assigned to elaborate a Master Thesis with the topic

„An analysis of carbon capture and utilisation options in the Austrian industry”

The focus of this work is the investigation of carbon capture and utilisation (CCU) technologies and their use in the Austrian industry.

In the first part of the thesis the theoretical background, which is necessary to work on the given topic, has to be elaborated. This concerns the problematic of carbon dioxide in the atmosphere, conventions and norms for CO_2 reduction and the current situation of carbon dioxide emissions in Austria. Furthermore carbon capture and utilisation technologies are discussed including their potentials, limitations and state of art. Finally the evaluation methods, especially the utility analysis and survey methods are presented.

Within the practical part of the thesis a survey conducted in the Austrian industry has to be carried out. The statistical analysis of the survey results should serve as the basis for a utility analysis. Due to the results of this analysis, the most appropriate CCU option for each industry sector should be identified.

Leoben, March 2012 O.Univ.-Prof. Dipl.-Ing. Dr. mont. Hubert Biedermann

Department of Economics and Business Management

EIDESSTATTLICHE ERKLÄRUNG

Ich erkläre an Eides statt, dass ich diese Arbeit selbstständig verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und mich auch sonst keiner unerlaubten Hilfsmittel bedient habe.

AFFIDAVIT

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

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(Christoph Niederseer)

Leoben, 11th of March 2013

ABSTRACT:

Carbon dioxide contributes to the "Greenhouse Effect" and global warming. Nowadays a lot of efforts are being done to reduce the amount of carbon dioxide in the atmosphere to counter this effect. The strategies towards this target include the prevention of CO_2, the reduction of the CO_2 amount through efficient use of fossil fuels, such as the CO_2 capture and storage or utilisation. “Carbon Capture and Utilisation" (CCU) technologies use carbon dioxide as a raw material for chemical and biological processes. Currently a lot of research and development work is carried out concerning these technologies. The aim of this study was to identify the most appropriate CCU-options for the Austrian industries. A utility analysis was applied to reach this task. The findings of the literature research served as the basis for creating a list of evaluation criteria for the implementation of this analysis, which was then complemented with expert interviews. A web-based industry questionnaire provided the information needed to place these criteria in a hierarchy of importance. The identification of the survey participating industries was based on the emission data of the Federal Environment Agency. The priorisation of the evaluation criteria in combination to the potentials and limitations of each technology was a crucial requirement for the utility analysis. The analysis conceded following results: CO_2 enhanced oil recovery could be for all industries the best carbon dioxide utilisation technology and was ranked as first. The further prioritisation turned in most cases as follows: carbonation, methanation and chemical feedstock. Two of the examined industries resulted in a different ranking. The first exception was the refractory industry, here was the methanation ranked second, followed by the production of chemical feedstock and the carbonation. The second exception was the cement and chalk industries. In this case, carbonation was ranked second followed by the production of chemical feedstock and methanation. The results presented in this thesis can support the industries in their CO_2 decision making management and furthermore visualize in which technologies research and development efforts should be intensified.

KURZFASSUNG:

Vergleichende Analyse der Kohlendioxidnutzungstechnologien am Beispiel der österreichischen Industrie

Kohlendioxid trägt zum Treibhauseffekt bei und ist hauptverantwortlich für die globale Erwärmung. In der Gesamtstrategie zur Verringerung der anthropogenen Treibhausgase stellt neben der Speicherung des industriell abgeschiedenen Kohlendioxids die Nutzung desselben eine wesentliche Option dar. Weltweit werden in diesen sogenannten „Carbon-Capture and Utilisation“(CCU) Verfahren erhebliche Forschungs- und Entwicklungsarbeiten unternommen um das Kohlendioxid als C1-Kohlenstoffquelle für Prozesse nutzbar zu machen. Ziel der Masterarbeit ist die Identifikation der geeignetsten CCU-Technologieoptionen für die einzelnen österreichischen Industriezweige mittels einer Nutzwertanalyse. Die zur Durchführung der Analyse erforderliche Festlegung von Bewertungskriterien erfolgte auf Basis der Literaturstudie ergänzt mit Experteninterviews. Die Identifizierung der relevanten Industriezweige für die Umfrage erfolgte auf Basis der Daten des Umweltbundesamtes. Eine Web-basierte Industrieumfrage lieferte dann die Gewichtung dieser Kriterien. Diese Reihung der Bewertungskriterien in Kombination mit den in der aktuellen Literatur festgehaltenen Potentialen und Grenzen der einzelnen Technologien wurde als Grundlage für die Durchführung der Nutzwertanalyse verwendet. Das Ergebnis der Studie war eine Prioritätsreihung der CCU Technologien für jeden Industriezweig, wobei die Reihung für die meisten Industriezweige wie folgt vorlag: tertiäre Erdölförderung vor Karbonatisierung, Methanisierung und Produktion von Chemierohstoffe. Für zwei der untersuchten Industriesektoren resultierte eine andere Reihung. Die erste Ausnahme war die Feuerfestindustrie, hier ist die Methanisierung als zweite gereiht, gefolgt von der Herstellung von chemischen Rohstoffen und der Karbonatisierung. Die zweite Ausnahme war die Zement-und Kalkindustrie. In diesem Fall ist die Karbonatisierung auf dem zweiten Platz, gefolgt von der Herstellung von chemischen Rohstoffen und der Methanisierung. Diese Ergebnisse sollten der Industrie in Ihrer Entscheidungsfindung bezüglich Kohlendioxids Managements unterstützen und darüber hinaus aufzeigen in welche Technologien geforscht und weiter entwickelt werden soll.

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My special acknowledgement is due to Mirella Klammer and my son Maximilian for the emotional support, the understanding, the motivation and acceptance of several weekends at work.

Christoph Niederseer

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LIST OF ABBREVIATIONS

BY	Base year
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
$CaSiO_3$	Wollastonite
CCGC	Carbon capture and geological storage
CCMC	Carbon capture and mineral carbonation
CCU	Carbon capture and utilization
CH_4	Methane
cm	Centimetre
CO	Carbon monoxide
CO_2	Carbon dioxide
COS	Carbonyl sulphide
DMC	Dimethyl carbonate
DME	Dimethyl ether
DNA	Deoxyribonucleic acid
DOF	Degree of fulfilment
EGR	Enhanced Gas Recovery
EOR	Enhanced Oil Recovery
et al.	et alii, et alteri (and others)
et seqq.	et sequentes (and the following ones)
ETS	Emission Trading Scheme
ft	Feet
GDP	Gross domestic product
GHG	Greenhouse Gases
GTL	Gas to liquid
H_2	Hydrogen
ha	Hectare (1 ha = 10.000 m^2)
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared radiation
MgO	Magnesium oxide
$MgCO_3$	Magnesium carbonate
Mg_2SiO_4	Olivine

$Mg_3SiO_5(OH)_4$	Serpentine
Mio.	Million
ml	Millilitre
MTBE	Methyl tert-butyl ether
MTG	Methanol to gasoline
N_2	Nitrogen
N_2O	Nitrous oxide
NISA	National Inventory System
OLI	Austrian Pollutant Inventory (Österreichische Luftschadstoff-Inventur)
PFCs	Perfluorocarbons
POM	Polyoxymethylene
PE	Polyethylene
PP	Polypropylene
ppm	Parts per million
PVC	Polyvinyl chloride
SF_6	Sulphur hexafluoride
SNG	Substitute Natural Gas
t	Tonnes
t/a	Tonnes per year
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
W/m^2	Watts per square meter

1 INTRODUCTION

At first it should be mentioned that some parts and results of this thesis were already presented in form of a poster as part of a scientific event in the year 2012. Moreover, it was also released as a contribution in a conference report.[1]

1.1 OBJECTIVE OF THE STUDY

Nowadays climate change is one of the greatest threats for humanity. It is scientifically proven and recently also clearly visible with increasing natural disasters in the last decades that climate change is happening and that it is very likely to be primarily the result of human activity. Because of its greenhouse properties and accumulation in the atmosphere carbon dioxide (CO_2) is considered to be the main reason for the climate change. Today we almost have forty percent more carbon dioxide in our atmosphere as before the industrial revolution, a level not experienced for at least the last 800,000 years. The origin of this high concentration of CO_2 in the atmosphere is mainly from the use of carbon-based fossil fuels by humans. In the short to medium term carbon-based fossil fuels will continue to play the major role of the world's energy sources, which leads to more CO_2 emissions. The result of this accumulation of emissions is seen in a continuous rising of the global average temperature. Without action to restrict greenhouse gas concentrations in the atmosphere, especially of CO_2, there is a very high risk of increasing the average temperature well beyond 2°C relative to pre-industrial times. Such global warming would increase the risk of accelerated or irreversible changes in the climate system, such as melting of the ice sheets of Greenland or West Antarctic, leading to major sea level rise, or the release of large natural stores of methane from oceans or melting permafrost, which could cause further warming.
These scientific predictions are crucial for the intense debates in recent times. Measures for avoiding carbon dioxide emissions and improving energy efficiency, as well as developing new energy sources and the partial conversion of the energy system from fossil fuels to renewable sources have the highest priority in this context. However, different scenarios for the development of the atmospheric CO_2 concentration are showing that strategies for avoiding carbon dioxide emissions alone are insufficient to stop the climate change.

So in addition to the prevention and storage, the use of the industrially separated carbon dioxide could strongly make its contribution to CO_2 management. These are the so called "Carbon Capture and Utilization" (CCU) methods. A lot of research and development work were made worldwide in these days for such CCU technologies. The methods are trying to use the CO_2 as a basic material for chemical and biological processes. The focus of the work is the investigation of these carbon capture and utilisation technologies and her possible use in the Austrian industry. In the first part of the thesis the theoretical background, which is necessary to work on the given topic, has to be elaborated. This concerns the problematic of carbon dioxide in the atmosphere, conventions and norms for CO_2 reduction and the current situation of carbon dioxide emissions in Austria. Furthermore carbon capture and utilisation technologies are discussed including their potentials, limitations and state of art. Finally the evaluation methods, especially the utility analysis and survey methods are presented. Within the practical part of the thesis a survey conducted in the Austrian industry has to be carried out. The statistical analysis of the survey results should serve as the basis for a utility analysis. Due to the results of this analysis, the most appropriate CCU option for each industry sector should be identified.

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[1]see Theodoridou V., Niederseer Ch. (2012)

1.2 STRUCTURE OF THE THESIS

Basically the diploma thesis consists of two parts, in the first the theoretical fundamentals are formulated and in the second the empirical work is described.

The theoretical fundamentals start with a general explanation of the carbon cycle. The role of carbon dioxide in this cycle is described and why it changes the global climate when it is accumulated in the atmosphere due to emissions from human activities. The next subchapter gives an overview of the political measures to curb the emissions, especially the amount of emissions in Austria are shown in context with the national reduction goals. This chapter is followed by an extensive overview about carbon capture and utilization technologies. In particular the potentials, limitations and the state of development of the different utilization methods are discussed. Finally the last topic of the theoretical fundamentals specifies the survey as a research method containing the different phases of a survey with a special focus on data acquisition methods. Also a short description of the different evaluation methods is included, especially with the focus on the utility analysis. For a better understanding a simple example of performing a utility analysis is illustrated. These instruments are implemented to find out the best carbon capture and utilization method for the Austrian industries.

The empirical part begins with the procedure how the survey is put into practice. The chapter informs the reader how the problem is structured, how the data is acquired, how the questionnaire is developed and how the data is analysed after the field phase. The realisation of the survey is followed by visualizing and describing the results. Also the outcome of the utility analysis for each Austrian industry is implemented and summarized to one table, which represents the core of this thesis.

Finally an extensive conclusion summarizes the findings, formulates some overall statements and gives recommendations concerning the study.

For a better understanding of the terms used, besides a list of abbreviations is available in the front part of the thesis.

2 THEORETICAL FUNDAMENTALS

In the year 2001 the Intergovernmental Panel on Climate Change (IPCC) published predictions about the change of the Earth's climate over the next hundred years. This Committee forecast an increasing global average temperature on Earth of about 1,4 to 5,8 °C from 1990 to 2100 and as a consequence also the temperature of the seawater increases which leads to a higher sea level. Most scientists held carbon dioxide responsible for the global warming and so a lot of attention is given to the release of CO_2. For policy decisions about measures to reduce the carbon dioxide concentration in the atmosphere a detailed research of the carbon cycle on Earth is absolutely essential.[2]

Carbon, the fourth most abundant element in the Universe by mass after hydrogen, helium and oxygen is the basic building block for all life. The total amount of carbon on earth is essentially constant and is about 65,500 billion metric tons. Carbon atoms are everywhere – we are made of carbon; we eat carbon; the stone we walk on is built on carbon.[3]
Carbon occurs in different ways in the atmosphere, biosphere, hydrosphere and lithosphere and can be stored in the various spheres in very different quantities. The biggest carbon reservoir represents the lithosphere with a percentage of 99,95% of carbon on the earth, whereby carbon is mainly stored inorganic in the form of carbonates and kerogen. But also organic compounds of carbon can be found in the lithosphere. These deposits of carbon were a mixture of many different organic compounds and were known as fossil fuels like coal, oil and natural gas. They were created by transformation of plant and animal remains under high pressure and temperature buried deep underground. Also in a small percentage carbon can be found elementary as diamond or graphite in the lithosphere. Compared to the lithosphere the share of carbon in the atmosphere, biosphere and hydrosphere is very low. The atmosphere includes carbon mainly as inorganic compounds like carbon dioxide (CO_2), carbon monoxide (CO) and in the organic form as methane (CH_4). It is the smallest reservoir for carbon, but has a very crucial role in the carbon cycle because of the relative high flow rates between the atmosphere and the other spheres. Due to its small size low influxes from other reservoirs leads to a relative high change in concentration. In the biosphere carbon is found in organic compounds, for example in carbohydrates, proteins and fats and is so an essential element of the biosphere; it is the stuff of life. All living tissues are composed of organic carbon compounds. Carbon can be also found in the ocean as dissolved carbon dioxide, hydrogen carbonate– and carbonate ions. The chemical equilibrium of these compounds depends on temperature, partial pressure of CO_2 as well as the pH value and the salinity of the water.[4]

[2] see Lucius E.R. (2005)
[3] see Riebeek H. (2011)
[4] see Lucius E.R. (2005)

2.1 THE CARBON CYCLE

One of the fundamental aspects of Earth's ecological and climate systems is in addition to the size and form of the carbon reservoirs the movement of carbon between the various spheres. All four spheres are interrelated, giving twelve exchange opportunities between all spheres. As the level of atmospheric carbon dioxide continue to increase, the need to understand the earth's ecosystem and climate becomes more urgent. The carbon cycle was initially discovered by Joseph Priestly and Antoine Lavoisier, and popularized by Humphry Davy.[5] It is one of the most important cycles on Earth. Carbon is moving always around our planet. From land to air to water, through living organisms and even the plant's crust, carbon - the backbone of life – is always on the move. It moves between reservoirs in an exchange called the carbon cycle, which is divided in a slow (geological) and fast (biological) cycle. The geological carbon cycle operates on a time scale of millions of years, whereas the biological carbon cycle operates on a time scale of days to thousands of years.[6] Natural fluxes in the cycle are shifting carbon out of one reservoir and putting more carbon in the other reservoirs.

Figure 1 shows the movements of the fast carbon cycle. The carbon cycle includes several reservoirs of carbon written in white in gigatons and the natural processes by which the various pools exchange carbon is shown with yellow arrows and text in gigatons of carbon per year. Human contribution, like emissions into the air, is marked in red. The problem by burning fossil fuels is that we don't create carbon; we just convert it from a hydrocarbon, which was previously buried under the earth's surface, to CO_2 in the atmosphere. CO_2 is a greenhouse gas which means that it prevents heat from leaving the earth. If there is too much CO_2 in the atmosphere, then the planet would trap too much of the sun's energy on the surface and life would die off because of the heat.[7]

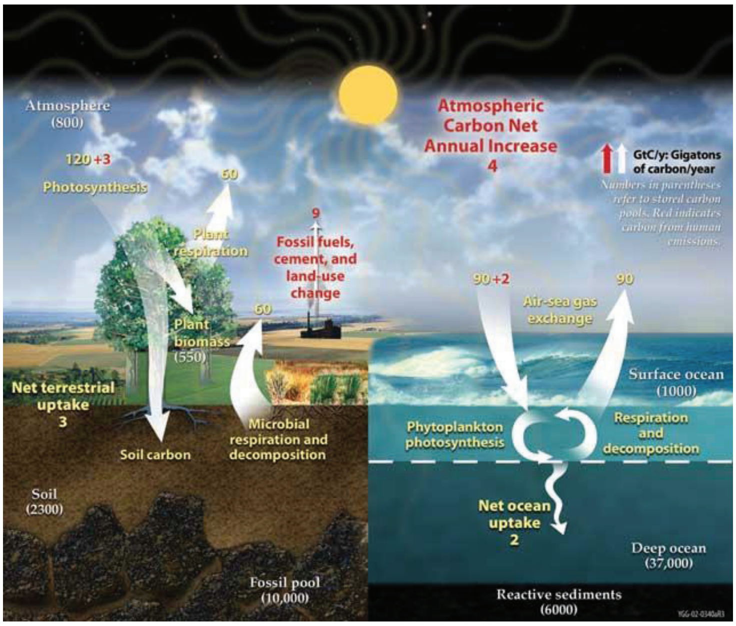

Figure 1 Fast Carbon Cycle[8]

[5] see Holmes, R. (2008)
[6] see Harrison J.A. (2003)
[7] see AKB (2009)
[8] source: http://earthobservatory.nasa.gov/Features/CarbonCycle/

Over the long term, the natural flows of carbon between the atmosphere, ocean and sediments seems to maintain a balance, so that carbon levels would be roughly stable without human influence.[9] This balance helps keep Earth's temperature relatively stable. This works over a few hundred thousand years, as part of the slow carbon cycle. For shorter time periods, tens to a hundred thousand years, the temperature on earth can vary and earth changes naturally between ice ages and warmer periods on these time scales.

2.1.1 THE SLOW CARBON CYCLE - GEOCYCLE

The geocycle occurs over millions of years through a series of chemical reactions and tectonic activity. In the slow carbon cycle every year about 10^{13} to 10^{14} grams (10-100 million metric tons) of carbon are moving between rocks, soil, ocean and atmosphere. In comparison, human emissions of carbon to the atmosphere are on the order of 10^{15} grams, whereas the fast biological carbon cycle moves 10^{16} to 10^{17} grams of carbon per year.[10]

Figure 2 is showing the geological components of the carbon cycle. The slow geocycle includes the processes of weathering and dissolution, precipitation of minerals, burial and subduction, and volcanic eruption.[11]

Carbon moves from the atmosphere to lithosphere by rain. In the atmosphere, carbonic acid is formed by a reaction with atmospheric carbon dioxide and water. The result is a weak acidic water. It reaches the earth's surface by rain and reacts with minerals. Due to chemical weathering it dissolves into their component ions. These ions are transported in streams and rivers eventually to the ocean, where they precipitate out as minerals like calcite ($CaCO_3$). Through continued deposition and burial, this calcite sediment forms the rock called limestone.[12]

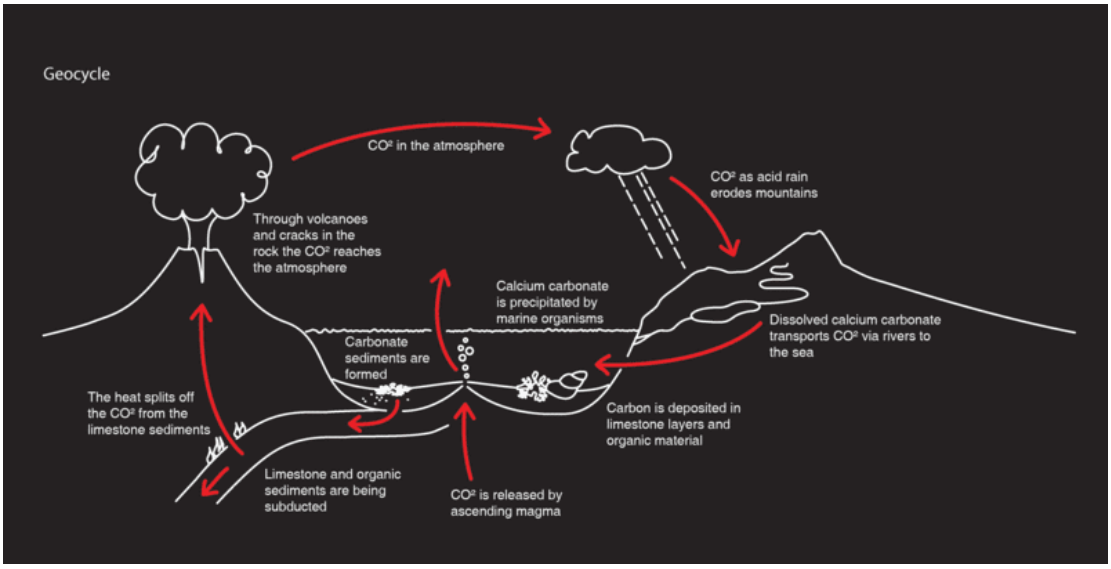

Figure 2 The slow geological carbon cycle[13]

[9] see Prentice, I.C. (2001)
[10] see Riebeek H. (2011)
[11] see Harrison J.A. (2003)
[12] see Riebeek H. (2011)
[13] source: http://www.co2-story.de

The cycle continues when plates collide at subduction zones. Earth's land and ocean surface is divided in several moving crustal plates. As seafloor carbon is pushed deeper into the earth by tectonic forces, it heats up, eventually melts, and can rise back up to the surface, where it is released as CO_2 and returned to the atmosphere. This return to the atmosphere can occur strongly through volcanic eruptions, or more gradually in seeps, vents, and CO_2 rich hot springs. At present, volcanoes emit between 130 and 380 million metric tons of carbon dioxide per year. For comparison, humans emit about 30 billion tons of carbon dioxide per year by burning fossil fuels. This is 100 to 300 times more than volcanoes.[14]

The balance between ocean, land, and atmosphere is regulated by chemistry. For example an increase in volcanic activity rise the carbon dioxide concentration in the atmosphere, which leads to more rain and this in turn dissolves more rock. Because of that more ions will be created that will eventually increases the carbon deposits on the bottom of the ocean. The rebalance of the geocycle through chemical weathering can take a few hundred thousand years.

The ocean is a faster component of the slow carbon cycle. CO_2 dissolves in and evaporates out of the ocean in a steady exchange with the atmosphere. Before the industrial age, the ocean vented carbon dioxide to the atmosphere in balance with the carbon the ocean received during rock weathering. However, since carbon concentrations in the atmosphere have increased, the ocean now takes more carbon from the atmosphere than it releases. Over millennia, the ocean will absorb up to 85 percent of the extra carbon people have put into the atmosphere by burning fossil fuels, but the process is very slow.[15]

Plate tectonics also affects the land. Deeply buried carbonate rocks can be pushed upwards, exposing them on the surface. One example of this occurs in the Himalayas where the world's highest peaks are formed containing sedimentary carbonate rich rocks which were once formed at the bottom of some ancient ocean. Once at the surface, the rocks are once again exposed to weathering and erosion and transported by wind and water back to the sea.[16]

2.1.2 THE FAST CARBON CYCLE - BIOCYCLE

Besides the slow geological carbon cycle there is a biological carbon cycle that is measured in a lifespan. The processes occur in a time frame from several days to several tens of thousands of years. So the biocycle is also termed the fast carbon cycle because this is fast compared to the time scale of the geocycle. It is largely the movement of about 10^{15} to 10^{17} grams carbon every year through life forms on Earth, or the biosphere.[17]

Carbon has the ability to form many bonds (up to four per atom) in an almost infinite variety of complex organic molecules and plays therefore an essential role in biology. A lot of organic molecules are structured of carbon atoms that have built strong bonds to other carbon atoms, combining into long chains and rings. Such carbon chains and rings are the basis of living cells. A good example is DNA, which is made of two intertwined molecules built around a carbon chain. The bonds in the long carbon chains contain a lot of energy. When the chains break apart, the stored energy is released. This energy makes carbon molecules an excellent source of fuel for all living things.

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[14]see Riebeek H. (2011)
[15]see Riebeek H. (2011)
[16]see Essay Web (2008)
[17]see Riebeek H. (2011)

The two main processes in the biocycle are photosynthesis and respiration, illustrated at figure 3. Almost all multicellular life on Earth depends on the production of sugars from sunlight and carbon dioxide (photosynthesis) and the metabolic breakdown (respiration) of those sugars to produce the energy needed for movement, growth, and reproduction. Plants pick up carbon dioxide from the atmosphere during photosynthesis and release CO_2 back into the atmosphere during respiration. The amount of carbon taken up by photosynthesis and released back to the atmosphere by respiration each year is about 1,000 times greater than the amount of carbon that moves through the geological cycle every year[18].

The main components of the fast carbon cycle are plants and phytoplankton, which take carbon dioxide from the atmosphere by absorbing it into their cells. Phytoplanktons are microscopic marine plants that form the base of the marine food chain.[19] Through photosynthesis, both plants and plankton use solar energy to turn atmospheric carbon dioxide and water into carbohydrates (sugars) and oxygen. The equation of the photosynthesis looks like:

$$6\,CO_2 + 6\,H_2O + Energy\;(sunlight) = \;C_6H_{12}O_6 + 6\,O_2$$

There are four ways to move carbon from a plant and return it to the atmosphere, but all involve the same chemical reaction, listed below. Plants and animals break down these sugar (and other products derived from them) through a process called respiration, the reverse of photosynthesis, to get the energy to grow. All living forms (animals and humans) eat the plants or plankton, and break down the plant sugar to get energy. Plants and plankton die and decay (are eaten by bacteria) at the end of the growing season or fire consumes plants. In each case, oxygen reacts with sugar to release water, carbon dioxide, and energy.[20]

$$C_6H_{12}O_6 + 6\,O_2 = \;6\,CO_2 + 6\,H_2O + Energy$$

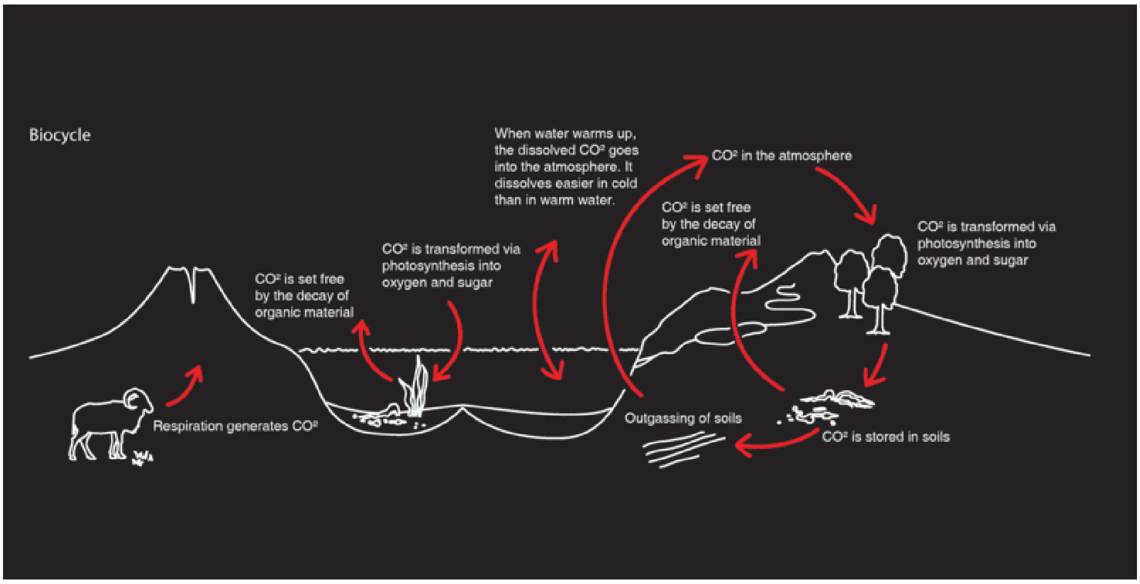

Figure 3 The fast biological carbon cycle[21]

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[18]see Harrison J.A. (2003)
[19]see Harrison J.A. (2003)
[20]see Riebeek H. (2011)
[21]source: http://www.co2-story.de

At the end of all four processes the carbon dioxide released in the reaction usually ends up in the atmosphere. The fast carbon cycle is so tightly bound to plant life. The growing season can be seen by the way carbon dioxide fluctuates in the atmosphere. In the northern hemisphere winter, when only few land plants are growing and most plants are decaying and losing their leaves, photosynthesis stops but respiration continues. This condition leads to an increase in atmospheric CO_2 concentrations. During the spring when plants begin growing again, photosynthesis resumes and atmospheric CO_2 concentrations is dropped. Figure 4 shows the monthly change in carbon dioxide concentration during a year.[22]

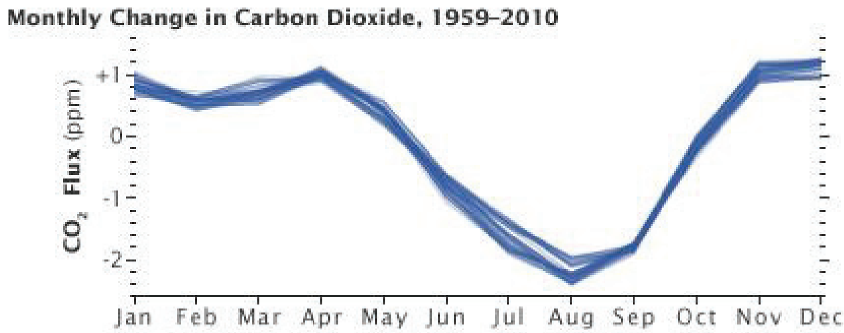

Figure 4 Monthly change in CO_2[23]

An additional factor has to be considered in marine environments. Phytoplankton use carbon to make shells of calcium carbonate ($CaCO_3$). These shells sink to the bottom of the ocean when the organisms die and are buried in the sediments. The shells of phytoplankton and other creatures can become compressed over time as they are buried and are often eventually transformed into limestone. Additionally, under certain geological conditions, organic matter can also be buried on the ocean floor and form deposits of hydrocarbons such as oil or gas and coal. It is the non-calcium containing organic matter that is transformed into fossil fuel. Both limestone formation and fossil fuel formation are biologically controlled processes.[24] The oceans can therefore serve as carbon sinks over geological time scales. Eventually, of course, all this carbon will also make its way to the surface due to plate tectonics. But relatively stable reservoirs can last for hundreds of millions of years.[25]

2.1.3 CHANGES IN THE CARBONCYCLE

In the past, the carbon cycle has changed in response to climate change. In predictable cycles of about 30,000 years, shifts in Earth's orbit are happening constantly. This variation in Earth's orbit influences the amount of energy the Earth receives from the sun. This leads to a cycle of ice ages and warm periods like Earth's current climate.[26] Ice ages developed when Northern Hemisphere summers cooled and ice built up on land, which in turn slowed the carbon cycle. In the meantime, a number of factors including cooler temperatures and increased phytoplankton growth may have increased the amount of carbon the ocean took out of the atmosphere.[27] Additional the drop of carbon content in the atmosphere causes cooling.

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[22]see Riebeek H. (2011)
[23]source: http://earthobservatory.nasa.gov/Features/CarbonCycle/
[24]see Harrison J.A. (2003)
[25]see Essay Web (2008)
[26]see Milankovitch M.
[27]see Riebeek H. (2011)

At the end of the last Ice Age, 10,000 years ago, carbon dioxide in the atmosphere increased dramatically, which leads to increase the temperature. In about 30,000 years, Earth's orbit will have changed enough to reduce sunlight in the Northern Hemisphere to the levels that led to the last ice age.[28]

Over the past 800,000 years, ice core data shows that carbon dioxide has varied from values as low as 180 parts per million to the pre-industrial level of 280 ppm. According to the core data, figure below shows that it is considered that variations in carbon dioxide concentrations are a fundamental factor influencing climate variations over this time scale.[29]

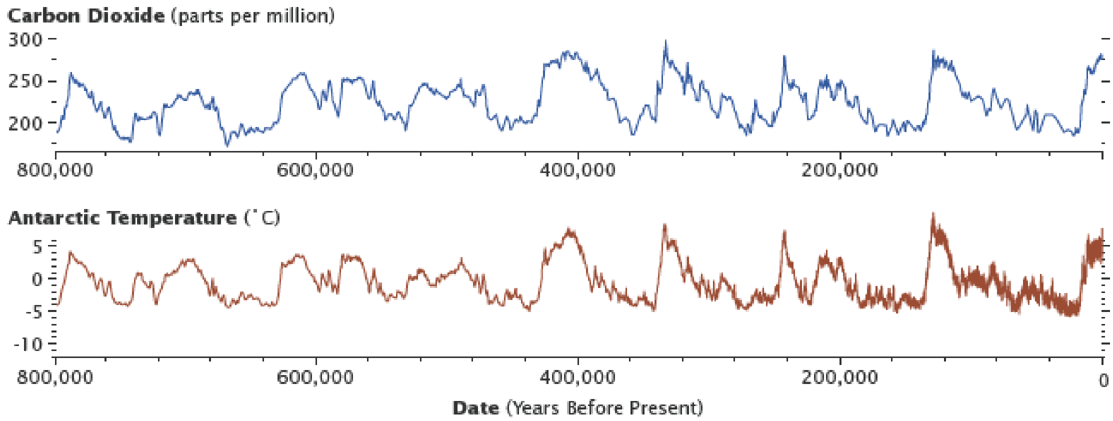

Figure 5 CO_2 concentration corresponds with temperature[30]

Since the beginning of the industrial age, human activities have seriously altered the global carbon cycle, most significantly in the atmosphere. Although carbon dioxide concentrations have changed naturally over the past several thousand years, human emissions of carbon dioxide into the atmosphere exceed natural fluctuations.[31]

Human influences

The total amount of carbon on earth is essentially constant. Imagine a piece of wood inside of a large sealed box filled with air. Weigh the entire box and its contents. Now cut the piece of wood up until it is just a pile of sawdust. Weigh the box again – it has the same weight. Now burn the sawdust inside until all is left as a pile of ash inside a smoke filled box. Weigh the box again. The weight is the same as before. So mass is not created or destroyed when you cut the piece of wood up or burn it. It simply changes form. If you are able to mark each atom of the original piece of wood, you would still be able to find every atom after it was cut up and burned. The atoms would be arranged differently but they would all be somewhere in the box. This box example applies to the earth too. Mass doesn't enter or leave earth. So if the number of carbon atoms on the planet is constant no matter what we do, then why is there suddenly a carbon problem? The problem is that we are converting a lot of carbon from one form to another.[32]

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[28] see Riebeek H. (2011)
[29] see http://en.wikipedia.org/wiki/Greenhouse_effect
[30] source: http://earthobservatory.nasa.gov/Features/CarbonCycle/
[31] see http://en.wikipedia.org/wiki/Greenhouse_effect
[32] see AKB (2009)

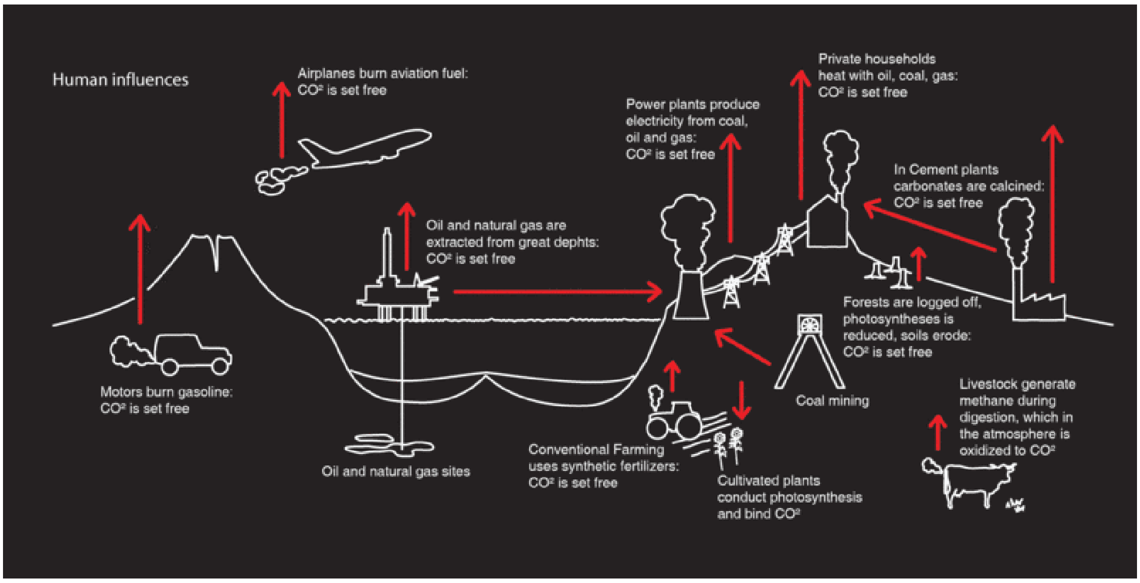

Figure 6 Human influences of the carbon cycle[33]

Today, changes in the carbon cycle are happening because of people. Figure 6 shows how the human disturb the carbon cycle by the two main reasons, burning fossil fuels and clearing land. Other emissions from human activities are mainly from cement production.

The natural flux of carbon stored in fossil fuels to the atmosphere would leak slowly through volcanic activity over millions of years in the slow carbon cycle. In the long term, the flow of carbon stored in fossil fuels to the atmosphere was nearly zero. So the fossil fuel storage represented a "dead-end" for the carbon cycle. The Industrial Revolution increased the use of coal, oil, and natural gas.[34] By burning coal, oil, and natural gas, we accelerate the process, releasing huge amounts of carbon (carbon that took millions of years to accumulate) into the atmosphere every year. By doing so, we move the carbon from the slow cycle to the fast cycle. In 2009, humans released about 8.4 billion tons of carbon into the atmosphere by burning fossil fuel.[35]

The combustion of fossil fuels is not the only flow in the carbon cycle affected by economic activity. Prior to the expansion of human civilization, the amount of carbon stored in flora and fauna changed very slowly from year to year because the amount taken up through photosynthesis was nearly equal to the amount emitted through respiration and decomposition. But human activity has disturbed the biological reservoir.[36] Over the last several hundred years, humans have reduced the area covered by forests, a process known as deforestation. By reducing the number of trees through burning and/or chopping them down and allowing them to decay, deforestation reduces the amount of carbon stored in the biota. This carbon flows to the atmosphere.[37] Humans are currently emitting just under a billion tons of carbon into the atmosphere per year through land use changes.[38]

[33]source: http://www.co2-story.de
[34]see DuHamel J. (2011)
[35]see Riebeek H. (2011)
[36]see DuHamel J. (2011)
[37]see Pidwirny M. (2010)
[38]see Riebeek H. (2011)

All of this extra carbon from people needs to go somewhere. So far, about 55 percent of these emissions are removed by the fast carbon cycle each year, while about 45 percent has stayed in the atmosphere. Eventually, the land and oceans will take up most of the extra carbon dioxide, but as much as 20 percent may remain in the atmosphere for many thousands of years.[39] Each reservoir is influenced by the changes of the carbon cycle. Too much carbon in the atmosphere warms the planet and helps plants on land grow more and excess carbon in the ocean makes the water more acidic, which is a serious problem for marine life.[40]

Atmosphere

Showing in the figure below emissions of carbon dioxide by human activity, primarily from burning fossil fuels, cleaning land and cement production, have been growing steadily since the beginning of the industrial revolution.

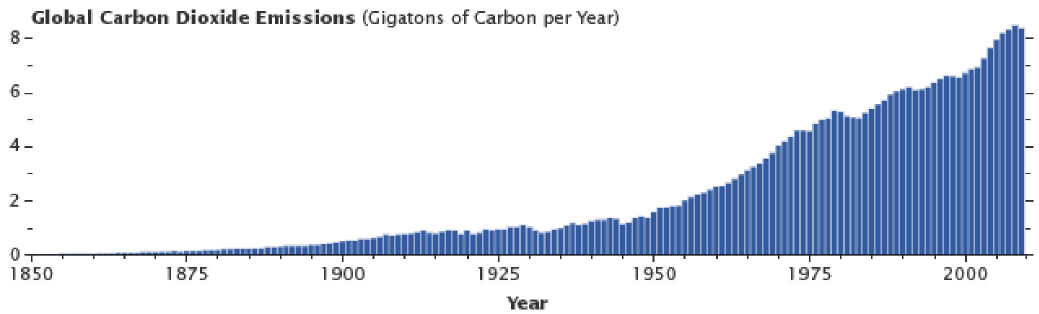

Figure 7 Global CO_2 Emissions[41]

Carbon dioxide concentrations in the atmosphere have risen from about 278 parts per million in 1750 to 389,6 parts per million today, a 39 percent increase. This means that for every million molecules in the atmosphere, 389,6 of them are now carbon dioxide—the highest concentration during the last 800.000 years.[42] This significant increase in the last hundred years can be seen in ice core data. Also methane concentrations have risen from 715 parts per billion in 1750 to 1.774 parts per billion in 2005, the highest concentration in at least 650.000 years.[43]

Greenhouse effect

Life on Earth depends on energy from the sun. Our Earth receives most of its energy from it. The sun radiates huge quantities of energy into space, across a wide spectrum of wavelengths. Most of the radiant energy from the sun is concentrated in the visible and near-visible parts of the spectrum. The narrow band of visible light, between 400 and 700 nanometres, represents 43% of the total radiant energy emitted. Wavelengths shorter than the visible account for 7 to 8% of the total, but are extremely important because of their high energy concentration. The shorter the wavelength of light, the more energy it contains. Thus, ultraviolet light is very energetic. The remaining 49 - 50% of the radiant energy is

[39]see Riebeek H. (2011)
[40]see Riebeek H. (2011)
[41]source: Robert Simmon, http://earthobservatory.nasa.gov/Features/CarbonCycle/
[42]see Global Carbon Project (2011)
[43]see Riebeek H. (2011)

spread over the wavelengths longer than those of visible light. These lie in the near infrared range from 700 to 1000 nm; the thermal infrared, between 5 and 20 microns; and the far infrared regions. Various components of earth's atmosphere absorb ultraviolet and infrared solar radiation before it penetrates to the surface, but the atmosphere is quite transparent to visible light as it is shown in the figure below.[44]

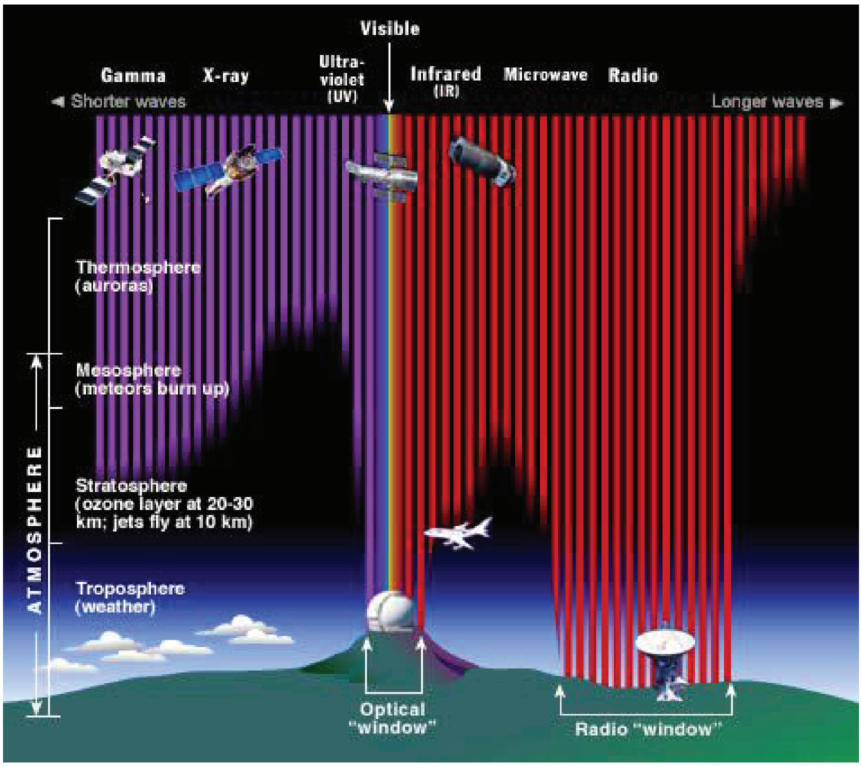

Figure 8 Solar radiation penetrate Earth's atmosphere[45]

Absorbed by land, oceans, and vegetation at the surface, the visible light is transformed into heat and re-radiates in the form of invisible infrared radiation. In this case the Earth would heat up during the day, but at night, all the accumulated energy would radiate back into space and the planet's surface temperature would fall far below zero very rapidly. The reason why this doesn't happen is that earth's atmosphere contains molecules that absorb the heat and re-radiate the heat in all directions. This reduces the heat radiated out to space. These molecules are the so called greenhouse gases because they serve to hold heat in like the glass walls of a greenhouse.[46] They are responsible for the fact that the earth enjoys temperatures suitable for our active and complex biosphere and keeps our entire planet from freezing. Without the greenhouse effect, life on earth as we know it would not be possible. Comparing to Mars and Venus – Mars has minimal greenhouse gas molecules in its atmosphere due to low atmospheric pressure, and is cold. By contrast with too many greenhouse gases, Earth would be like Venus, where the greenhouse atmosphere keeps temperatures around 400°C. So temperature increases as greenhouse gas concentration increases.

[44]see UCAR
[45]source: NASA
[46]see UCAR

Figure 9 shows the global heat flow on earth. The top of Earth's atmosphere receives on average 342 watts per square meters of energy in form of sunlight. 107 W/m^2 of that is reflected back into space by clouds and the Earth's surface. So the amount of energy income is 235 W/m^2, which must be radiated outward to achieve equilibrium. From the 235 W/m^2 of incoming energy 67 W/m^2 is absorbed by the atmosphere and another 168 W/m^2 is adsorbed by Earth's surface. When energy is adsorbed, it raises the temperature of the substances that adsorb it, in this case the atmosphere and the surface of the earth. This causes those substances to radiate away that heat in the form of infrared radiation (IR). Note that the outgoing infrared radiation of 390 W/m^2 starts upward from the surface. By 168 W/m^2 coming in, the extra energy comes from the trapped infrared radiation by greenhouse gases in the atmosphere before it can escape and return to space. So the atmosphere is warmed by the 67 W/m^2 of incoming sunlight plus most of the infrared radiation trying to escape from the surface to space. All of this generates infrared radiation emissions from the atmosphere. Some of this IR from the atmosphere does escape to space (the 165 W/m^2 arrow flowing upward from the atmosphere plus the 30 W/m^2 flowing upward from clouds). Most, however moves back down towards the surface. That's what the 324 W/m^2 of "back radiation" is all about. This downward flow is what really pumps up the surface temperature to the point that it can radiate 390 W/m^2 of energy upward.[47]

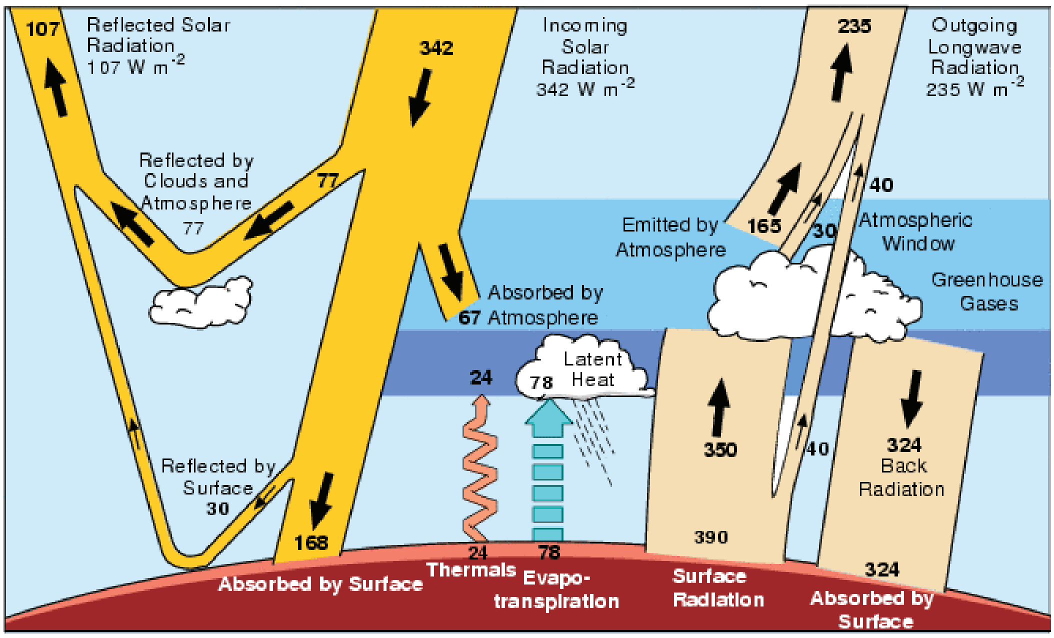

Figure 9 The Greenhouse effect[48]

While the earth's temperature is dependent upon the greenhouse-like action of the atmosphere, the amount of heating and cooling are strongly influenced by several factors just as greenhouses are affected by various factors.[49]

In the atmospheric greenhouse effect, the type of surface that sunlight first encounters is the most important factor. Forests, grasslands, ocean surfaces, ice caps, deserts, and cities

[47] see Russell R. (2007)

[48] source: Kiehl and Trenberth, 1997, "Earth's Annual Global Mean Energy Budget", Bulletin of the American Meteorological Association 78: 197-208)

[49] see UCAR

all absorb, reflect, and radiate radiation differently. Sunlight falling on a white glacier surface strongly reflects back into space, resulting in minimal heating of the surface and lower atmosphere. Sunlight falling on a dark desert soil is strongly absorbed, on the other hand, and contributes to significant heating of the surface and lower atmosphere. Cloud cover also affects greenhouse warming by both reducing the amount of solar radiation reaching the earth's surface and by reducing the amount of radiation energy emitted into space.[50]

The huge majority of the atmosphere is not composed of gases that cause the greenhouse effect. Molecular nitrogen (N_2) and oxygen (O_2) make up roughly 98 % of our atmosphere, and neither is a greenhouse gas. So although a very small fraction of Earth’s atmospheric gases generate the very powerful greenhouse effect.[51]

By knowing the wavelengths of energy each greenhouse gas absorbs, and the concentration of the gases in the atmosphere, scientists can use models to calculate how much each gas contributes to the greenhouse effect. Carbon dioxide causes about 20 percent of Earth’s greenhouse effect; water vapor accounts for about 50 percent and is actually the dominant greenhouse gas; and clouds account for 25 percent. The rest is caused by small particles (aerosols) and minor greenhouse gases like methane.[52]

The reason why the desert can get very cold at night is because of a lack of water vapor. The same is true for Antarctica. The extreme cold in Antarctica is due to lack of water vapor and clouds in the atmosphere, which results in almost all of the incoming radiation returning immediately to space.[53]

Water vapor concentrations in the air are controlled by Earth’s temperature. Warmer temperatures evaporate more water from the oceans, expand air masses, and lead to higher humidity. Cooling causes water vapor to condense and fall out as rain or snow.[54]

Carbon dioxide is one of the greenhouse gases. It consists of one carbon atom with an oxygen atom bonded to each side. When its atoms are bonded tightly together, the carbon dioxide molecule can absorb infrared radiation and the molecule starts to vibrate. Eventually, the vibrating molecule will emit the radiation again, and it will likely be absorbed by yet another greenhouse gas molecule. This absorption-emission-absorption cycle serves to keep the heat near the surface, effectively insulating the surface from the cold of space.[55]

Carbon dioxide, on the other hand, remains a gas at a wider range of atmospheric temperatures than water. Carbon dioxide molecules provide the initial greenhouse heating needed to maintain water vapor concentrations. When carbon dioxide concentrations drop, Earth cools, some water vapor falls out of the atmosphere, and the greenhouse warming caused by water vapor drops. Likewise, when carbon dioxide concentrations rise, air temperatures go up, and more water vapor evaporates into the atmosphere—which then amplifies greenhouse heating. So while carbon dioxide contributes less to the overall greenhouse effect than water vapor, scientists have found that carbon dioxide is the gas that sets the temperature. Carbon dioxide controls the amount of water vapor in the atmosphere and thus the size of the greenhouse effect.[56]

[50]see UCAR
[51]see Russell R. (2007)
[52]see Schmidt G.A. (2010)
[53]see Watts A. (2009)
[54]see Riebeek H. (2011)
[55]see UCAR
[56]see Riebeek H. (2011)

Atmospheric scientists first used the term "greenhouse effect" in the early 1800s. At that time, it was used to describe the naturally occurring functions of trace gases in the atmosphere and did not have any negative connotations. It was not until the mid-1950s that the term greenhouse effect was coupled with concern over climate change. And in recent decades, we often hear about the greenhouse effect in somewhat negative terms. The negative concerns are related to the possible impacts of an enhanced greenhouse effect.[57]

The warming due to greenhouse gases is expected to increase as humans add more greenhouse gases to the atmosphere. As greenhouse gas concentration increases, the total number of collisions with greenhouse gases molecules increases.[58] This makes it more difficult for infrared radiation to escape. In order to maintain equilibrium, the temperature has to increase.

Charles Keeling, an oceanographer at the Scripps Institute of Oceanography, is responsible for creating the longest continuous record of atmospheric CO_2 concentrations, taken at the Mauna Loa observatory in Hawaii. His data (now widely known as the "Keeling curve") revealed that rising carbon dioxide concentrations are already causing the planet to heat up. At the same time that greenhouse gases have been increasing, average global temperatures have risen 0.8 degrees Celsius since 1880 shown in the keeling curve below.[59]

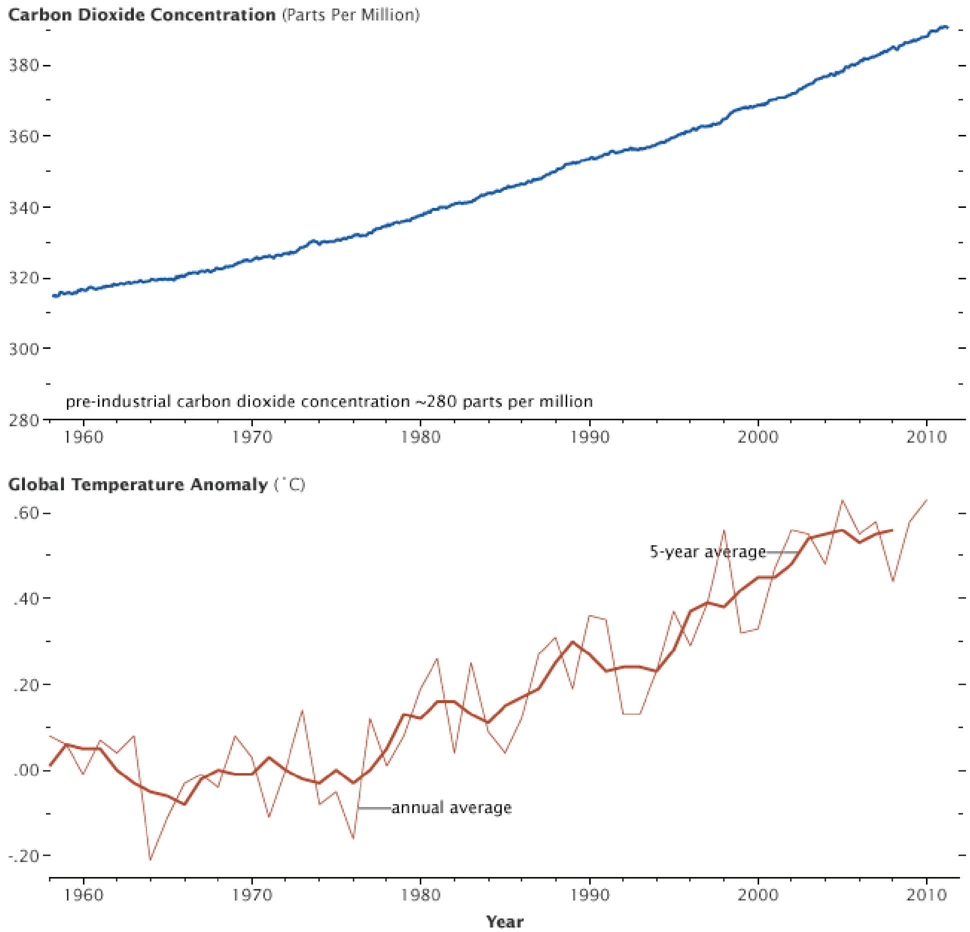

Figure 10 Global average temperature rises with CO_2 concentration[60]

[57]see UCAR
[58]see Watts A. (2009)
[59]see Harrison J.A. (2003)
[60]source: Robert Simmon, http://earthobservatory.nasa.gov/Features/CarbonCycle/

This rise in temperature isn't all the warming we will see based on current carbon dioxide concentrations. Greenhouse warming doesn't happen right away because the ocean soaks up heat. This means that Earth's temperature will increase at least another 0.6 degrees Celsius because of carbon dioxide already in the atmosphere. The degree to which temperatures go up beyond that depends in part on how much more carbon humans release into the atmosphere in the future. Any response by the earth to measures that we might take today will not be effective tomorrow, nor the day after tomorrow, it will take centuries (see next figure)[61]

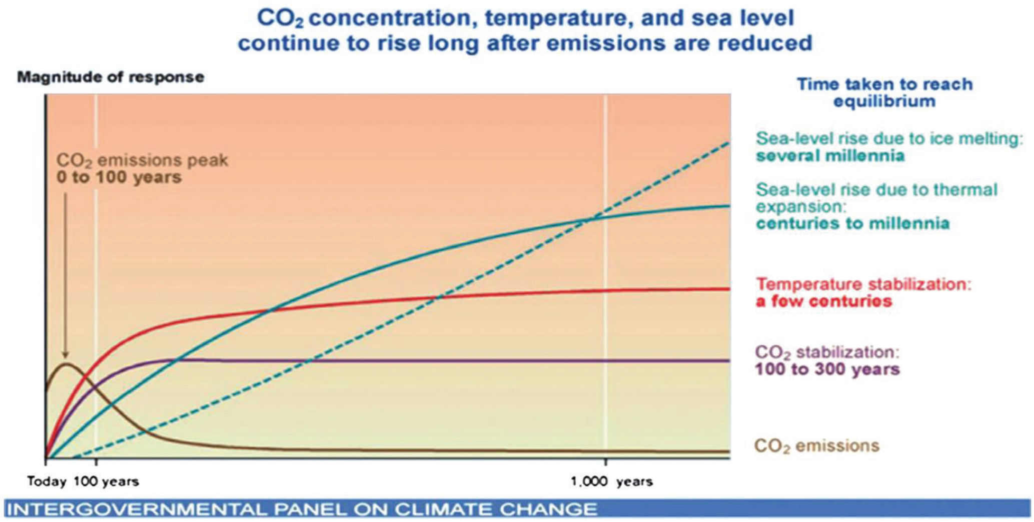

Figure 11 CO_2 concentration rise long after reducing emissions[62]

Ocean

Thirty percent of the emitted CO_2 from human activity has diffused by direct chemical exchange into the ocean and forms carbonic acid, which leads to a higher acidity of the seawater. The pH value of the ocean's surface has dropped by 0.1, a thirty percent change in acidity. This affects marine organism in two ways. First, the resulting carbonic acid reacts with carbonate ions to bicarbonates. But those carbonate ions where needed from corals to create calcium carbonate shells and with less carbonate in the water, the shells end up being thinner and weak. Second, the more acidic water dissolves better calcium carbonate and allows the ocean to soak up excess CO_2 in the long term. The increased acidity water dissolves more rock, release more carbonate ions, and the ocean can absorb more carbon dioxide. In the meantime, though, more acidic water will dissolve the carbonate shells of marine organisms, making them scarred and fragile. Phytoplankton grows better in cool, nutrient-rich waters. A warmer ocean is a product of the greenhouse effect and limits so the ability to take carbon from the atmosphere through the fast carbon cycle. On the other hand an increase in CO_2 could increase the growth of phytoplankton and ocean plants, which need carbon dioxide for growth. However, most species have no advantage by the increased concentration of carbon dioxide.[63]

[61]see Aresta M. (2010)
[62]see Aresta M. (2010)
[63]see Riebeek H. (2011)

Land

The amount of carbon that plants on land absorb varies from year to year, but in general the world's plants have increased the amount of carbon they take up since 1960. But only a small number of this increase occurred as a direct result of human emission. About twenty five percent of the CO_2 emissions that human put into the atmosphere were absorb by plants on land. The increasing carbon dioxide concentration in the atmosphere allows plants to grow more by converting the CO_2 to plant matter in photosynthesis. This effect is known as carbon fertilization. Simulations predict a more growth from 12 to 76 percent if the carbon dioxide concentration is doubled and nothing else limits their growth, like water shortage for example. Plants need more than carbon dioxide to grow. They also need water, sunlight, and nutrients, especially nitrogen. Is one of this missing, the plant won't grow regardless of how abundant the other necessities are. So scientists don't know how much carbon dioxide is increasing plant growth in the real world. Plants have a limit to take out carbon from the atmosphere, and this limit varies around the world. So far, it appears that carbon dioxide fertilization increases plant growth until the plant reaches a limit in the amount of water or nitrogen available.[64]

In the Northern Hemisphere more carbon absorption resulted from recent land use decisions. We can grow more food on less land by intensive agriculture. Abandoned farmland is reverting to forest, which stores more carbon, both in wood and soil, than crops would. Humans often extinguishing wildfires, which prevents carbon from entering the atmosphere. All these measures lead to allow woody material to store human-released carbon.

Unfortunately, forests in the tropics are being destroyed and removed, often through fire, and this allows CO_2 to enter the atmosphere. In the year 2008 deforestation accounted for about 12 percent of all human carbon dioxide emissions.

Climate change has the biggest influence in the land carbon cycle. As already explained CO_2 increases temperatures and extends the growing season and increases humidity. Both led to additional plant growth. However, plants need more water to survive for the longer warmer growing season and so warmer temperatures also stress plants. It is proven that plants in the Northern Hemisphere slow their growth in the summer because of warm temperatures and water shortages.[65]

Plants with water shortage are also more susceptible to fire. In the far north the forests have already started to burn more, releasing the stored carbon in the plants and the soil into the atmosphere. Also tropical forests may be extremely susceptible to drying. With less water, tropical trees slow their growth and take up less carbon, or die and release their stored carbon to the atmosphere.[66]

The global increase on average surface temperature may also heat the soil. This is of particular concern in the far north, where frozen soil, permafrost, releases carbon by thawing. Permafrost contains rich deposits of carbon from plant matter that has accumulated for thousands of years because the cold slows decay. When the soil warms, the process is accelerating and the organic matter decays and emits carbon in the form of methane and carbon dioxide. It is estimated that permafrost in the Northern Hemisphere holds 1,672 billion tons of organic carbon. If just 10 percent of this permafrost were to thaw, it could

[64]see Riebeek H. (2011)
[65]see Riebeek H. (2011)
[66]see Riebeek H. (2011)

release enough extra carbon dioxide to the atmosphere to raise temperatures an additional 0.7 degrees Celsius by 2100.[67]

2.1.4 STUDYING THE CYCLE

The atmosphere now contains more carbon than at any time in at least two million years. Each reservoir of the cycle will change as this carbon makes its way through the cycle. Likewise, changes in the carbon cycle will impact the way we live. Most of us, however, will observe changes in the carbon cycle in a more personal way. For us, the carbon cycle is the food we eat, the electricity in our homes, the fuel in our cars, and the weather we see. We are a part of the carbon cycle and so it is essential to understand our role in the carbon cycle. The knowledge empowers us to control our personal impact and to understand the changes we are seeing in the world around us.[68]

[67]see Riebeek H. (2011)
[68]see Riebeek H. (2011)

2.2 GREENHOUSE GASSES IN AUSTRIA

Absorbing infrared radiation greenhouse gases have a significant contribution to the greenhouse effect. Carbon dioxide (CO_2) is mainly responsible for this. Other gases are methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (HFCs, PFCs and SF_6). Preventing the climate change caused by anthropogenic greenhouse gas emissions is one of the most urgent challenges of our time. In the past 150 years an increase in average annual temperature of 1.8°C was recorded in Austria. That is significantly higher than the global average which is about 0.7 °C. In the coming decades further increase in global average temperature is unavoidable.[69] This climate change will have far-ranging economic, social and environmental consequences for all countries in the world, especially if global warming rises by more than 2°C above pre-industrial levels.

2.2.1 CONVENTIONS AND NORMS

On 9 May 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was agreed and put into force in 1994. The aim was to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent the climate system from an anthropogenic disorder. In the year 2009 it was decided that to achieve the objectives of the Convention a limit of a global average temperature rise of 2°C is necessary. This was also discussed in the context of the UN Climate Change Conference 2010 in Cancun and actions to achieve this long-term goal have been decided.[70] At European level a roadmap was developed to achieve reductions to an 80%-95% level compared to the level in the year 1990.[71]

The Kyoto Protocol

The Kyoto Protocol was agreed on 11 December 1997 in Kyoto, Japan and came in the year 2005 in operation. For the first time internationally binding greenhouse gas reduction targets for industrialized countries were established. The members should reduce their total emissions of greenhouse gases within the period 2008-2012 by at least 5% based on the emissions base year 1990. The European Union obligated to reduce their greenhouse gas emissions by 8%, in which Austria has a reduction target of 13%. The first Kyoto fixation duration ended with the year 2012.[72]

The climate and energy package of the EU (Effort Sharing)

The EU has set itself the goal of reducing greenhouse gas emissions by 20% in the year 2020 compared to the level of the base year 1990. To achieve these targets, the sectors covered by the emission trading scheme (ETS) and those not covered (non-ETS) pursue different approaches. The predominately part of the emission reductions must be achieved in the emissions trading sector. For sources outside the ETS (e.g. transport, space heating and agriculture) the climate and energy package provides a reduction of GHG emissions till 2020 by 10% compared to the reference year 2005. This commitment was separated in the Effort Sharing Decision (Decision 406/2009/EG) among the Member States according to their per-head GDP. Austria must reduce GHG emissions which are not covered by the emissions trading sources by 16% till 2020. Another target is to raise the share of renewable energy sources in the gross final energy consumption across the EU up to 20%. Austria

[69] see IPCC 2007
[70] see UNFCCC 2010
[71] see EC 2011
[72] see Umweltbundesamt REP-0393, p.51

has to achieve a share of 34% in 2020. Also a minimum of 10% of energy input from renewable energy sources has to be achieved in the transport sector. To reduce energy consumption, it is planned to improve energy efficiency by 20%. To achieve the objectives of the climate and energy package in a cost-efficient way the Austrian energy strategy was developed in the year 2010.[73] The final energy consumption should stabilize at the levels of 2005 and the share of renewable energy has to be increased up to 34% to reduce greenhouse gas emissions.[74]

In 2011 also in Austria the Climate Change Act was established, which dictates the maximum amounts of emissions and the methods to achieve the targets for those sectors that are not covered by the emissions trading. [75]

At the UNFCCC conference in Durban in 2011 a limiting global temperature increase of less than 2°C was defined. To achieve this goal, a greenhouse gas emission reduction of at least 80% by 2050 will be necessary in the industrialised countries. The European Commission published an Energy Roadmap 2050 which includes several possible scenarios for reducing CO_2 emissions. The Energy Roadmap includes possible measures for achieving this target, which will mostly be driven by the world market prices of fossil energy sources and the global CO_2 price. On the whole, the scenarios are regulated by prices – such as the carbon dioxide price for non-ETS sectors which, in the period after 2020, will be the same as the ETS carbon dioxide price. For 2050, CO_2 prices will be between 234 and 310 €/t CO_2. At the moment there are no binding targets for a reduction of greenhouse gases or a promotion of renewable energy sources beyond 2020. Without additional measures, any progress on the target pathways set out in the Roadmaps for achieving the 2 °C target seems unrealistic. The resulting need for action in Austria is that Austria develops its own perspective with a view to the 2050 targets as soon as possible.[76]

Accredited regularity agency

Austria is obligated by the ratification of the Kyoto Protocol to collect complete and accurate its greenhouse gas emissions and report the data to the climate change secretariat of the United Nations (United Nations Framework Convention on Climate Change, UNFCCC). The National Inventory System Austria (NISA) was established to fulfil the high requirements of the Kyoto Protocol. It is based on the Austrian Air Pollutant Inventory (OLI) and ensures transparency, consistency, comparability, completeness and accuracy of the inventory.[77]

[73]see Ministry of Life & BMWFJ 2010
[74]see Umweltbundesamt REP-0393
[75]see Klimaschutzgesetz KSG
[76]see Umweltbundesamt REP-0391
[77]see Umweltbundesamt REP-0393, p. 10

2.2.2 EMISSION TRENDS IN AUSTRIA

The latest report from the Federal Environment Office Austria includes the development of greenhouse gas emissions till the year 2010. Therefore the following data and charts in this chapter are also limited to the year 2010.

In 2010, 84.6 million tons of carbon dioxide equivalent greenhouse gas emissions were caused in Austria. This is 8.2% more than in the Kyoto base year 1990. Mainly responsible for this increase in greenhouse gas emissions are the growing fossil fuel use and the resulting increase in CO_2 emissions. However a total downward trend of the Austrian GHG emissions can be observed since 2005. Especially from 2008 to 2009 a significant reduction in emissions can be observed, mainly due to a lower activity caused by the financial and economic crisis. The rebound of the economy from 2009 to 2010 entail an increase in goods traffic, power consumption and the industrial production of energy-intensive products (e.g. steel). This and the cold weather led again in 2010 to an increase in GHG emissions by 6.1% compared to 2009.[78]

The following figure depicts the trend of Austria's GHG emissions and excludes emission sources and sinks from the land use, land use change and forestry sector.

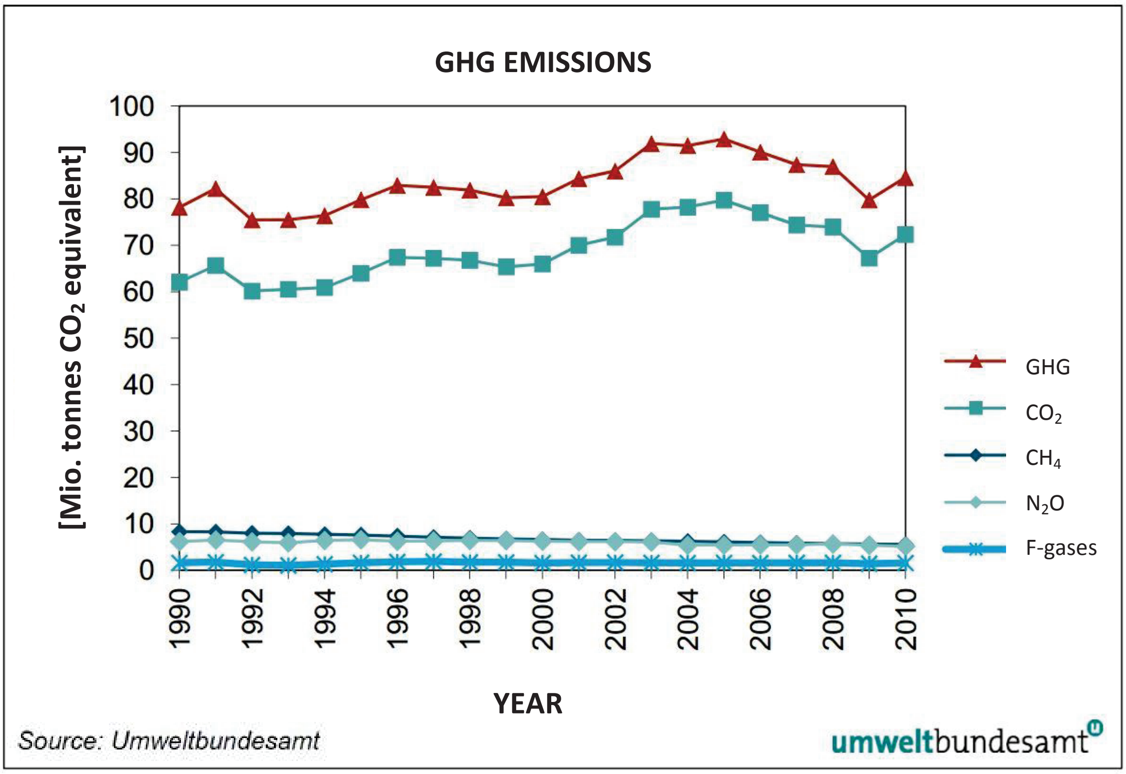

Figure 12 Trend of the GHG Emissions in Austria[79]

Mainly responsible for the total greenhouse gas emissions is carbon dioxide, with a share of 85.5% in 2010. The CO_2 emissions primarily result from combustion activities. Methane, which most arises from stock farming and waste disposal, contributes 6.6% of the green-

[78]see Umweltbundesamt REP-0393, p. 52

[79]source: Umweltbundesamt REP-0393, p. 53

house gas, nitrous oxide 6.1%. The remaining 1.8% is due to emissions of fluorinated compounds.[80]

CO_2 emissions increased from 1990 to 2009 by 8.8% and till 2010 even by 16.5%. One reason is the increase in energy consumption and the use of fossil fuels. Energy efficiency measures and the use of renewable energy in recent years, however, results in a reduction of CO_2 emissions. The sharp decrease from 2008 to 2009 is mainly due to the economic crisis and the associated low energy consumption.

From 1990 to 2010 the CH_4 emissions are reduced by 32.9%. Reductions can be seen in waste disposal and agriculture, the two main sources of methane. The decrease of N_2O emissions by 16.9% is mainly due to activities in the chemical industry and the declining livestock (mainly cattle) and mineral fertilizer use in agriculture. Fluorinated gases decreased by 1.5% from 1990 to 2010. It is important to note that also this trend analysis is without emissions and sinks from the land use. In the last decades the biomass of the Austrian forest area is increasing and acts as a sink. The figure below illustrates the trends of the different greenhouse gas emissions in index form. The base year 1990 is defined by a value of 100.[81]

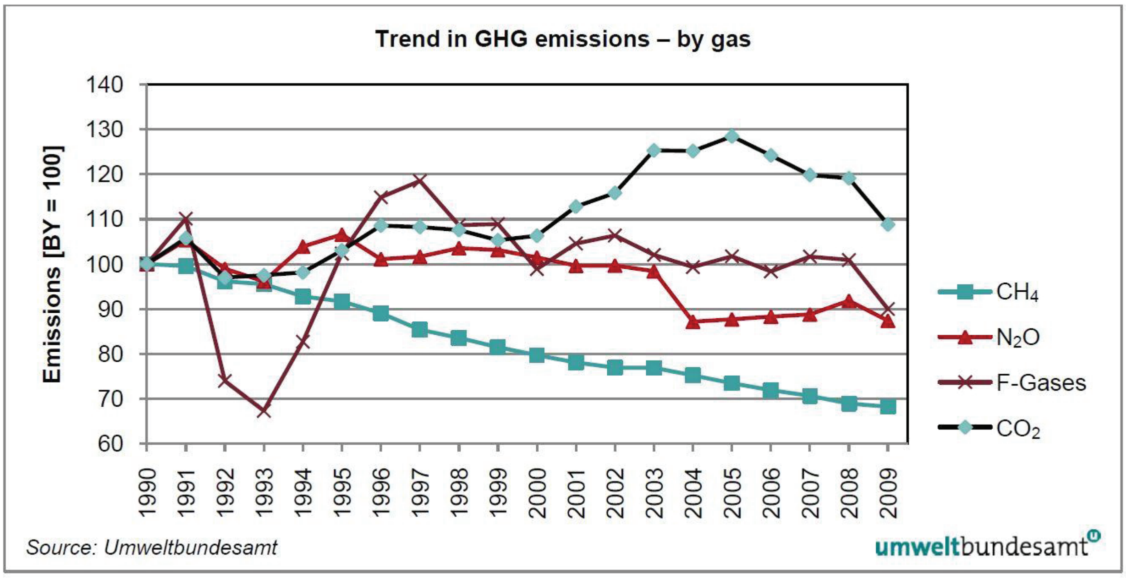

Figure 13 Trend of the different greenhouse gas emissions 1990-2009[82]

[80]see Umweltbundesamt REP-0393, p. 53

[81]see Umweltbundesamt REP-0393, p. 53 et seq.

[82]source: Umweltbundesamt REP-0308, p. 50

2.2.3 POLLUTERS

In 2010, the main sources of greenhouse gas emissions were the sectors industry and manufacturing industry (29.2%), transport (26.6%), energy production (16.9%), space heating and small consumers (13.5%). In the sectors industry and manufacturing industry, as well as in energy production, about 79% of the emissions were caused by companies covered by the emission trading scheme.[83]

From 1990 to 2010 the transport sector showed the strongest growth by far in GHG emissions (+60.0%), followed by industry (+14.9%). In the energy sector emissions rose up with 4.6%. In the sector others (-47.9%), small consumer (-20.9%) and agriculture (-12.9%) however, reductions could be achieved.[84]

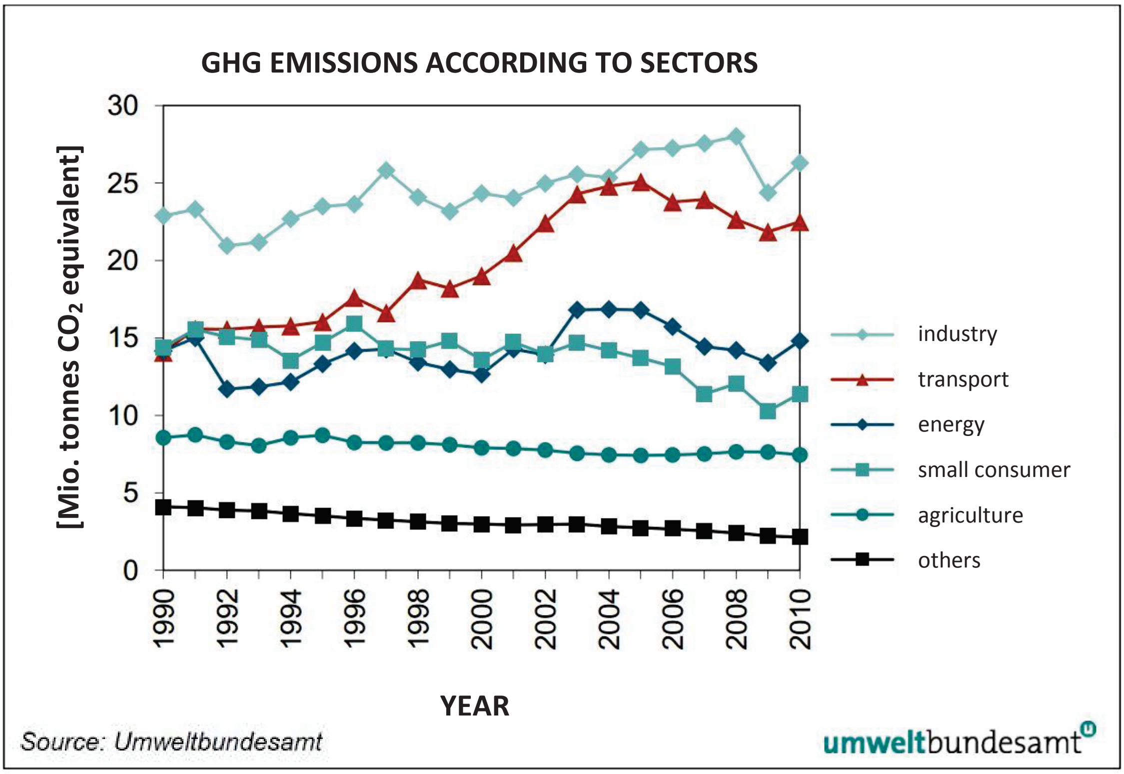

Figure 14 Trend of the GHG Emissions according to the sectors[85]

As mentioned before the industrial sector is the largest emitter of greenhouse gases. Mainly responsible for the rise since 1990 is the production increase in the iron and steel production, the mineral processing industry, chemical engineering and other industries. The increasing use of low carbon fuels (mainly gas) and renewable energy sources and efficiency improvements led to a better outcome. As already mentioned the strong emission reduction from 2008 to 2009 is due to the economic crisis. With the increase in production from 2009 to 2010 however the emissions increased again by +7.9%. The most important measure is emission trading. Companies included in the national allocation plan for the period

[83]see Umweltbundesamt REP-0308, p. 14
[84]see Umweltbundesamt REP-0393, p. 54
[85]source: Umweltbundesamt REP-0393, p. 54

2008-2012 were responsible for about 76% of the emissions in this sector in 2010. Achievement of the climate strategy target seems unrealistic.

Reasons for the sharp increase in transport emissions since 1990 are the increasing traffic on Austrian roads and fuel exports, which is caused to the relatively low fuel prices in Austria. The significant decrease in emissions from 2005 to 2006 is mainly due to the obligatory substitution of fossil fuels with biofuels. Reasons for the decrease in emissions 2008-2009 are the weak economy, the increased use of biofuels and the increased efficiency in passenger transport. After a downward trend the emissions in the transport sector were up again in 2010. Additional measures from the climate strategy are still not, or only partially, implemented, with the result that the climate strategy target is missed.

In the energy production sector, the power and heat production in thermal power plants is the largest emitter of greenhouse gases. The main driving force for the GHG emissions is the domestic electricity consumption. Reductions in emissions can caused by reduced oil and coal use, increased use of gas and biomass and the use of renewable energy sources (particularly hydropower in Austria). A not insignificant factor is also the weather. For the sector energy production the central measure to achieve the sectorial climate strategy targets is the emission trading system (ETS). Companies included in the national allocation plan for the period 2008-2012 are responsible for 85% of the emissions in this sector. The target from the climate strategy will not be achieved.

The emissions of the sector small consumer are highly dependent on the temperature profile and related heating costs. The trend towards to renewable fuels, the increased use of district heating and improved thermal quality of the buildings has led to a general reduction of emissions.

The main reason for the reduction in GHG emissions in the sector agriculture is due to the decline in livestock numbers and the reduced use of mineral nitrogen fertilizers.

The decline in annual deposit waste and the decreasing organic content in the waste, and also the sharp increase since 1990 in landfill gas collection are primarily responsible for the decline in emission trends in the sector other. The 2010 climate strategy was achieved as it had been in 2008 and 2009.[86]

[86]see Umweltbundesamt REP-0393, p. 55 et seq.

2.2.4 CARBON DIOXIDE

CO_2 is produced mainly in the sectors of transport, industry, energy supply and lower consumer through the combustion of fossil fuels like natural gas, oil and coal. Emission from carbon dioxide depends primarily from the fuel type and quantity of fuel. In the year 2010 Austria polluted 72.3 million tons of CO_2. This is an increase of 7.5% compared to the year 2009, and an increase of 16.5% compared to the base year 1990.[87] The sector agriculture does not cause anthropogenic CO_2 emissions, because the operation of equipment and space heating are included in the field of small consumer.

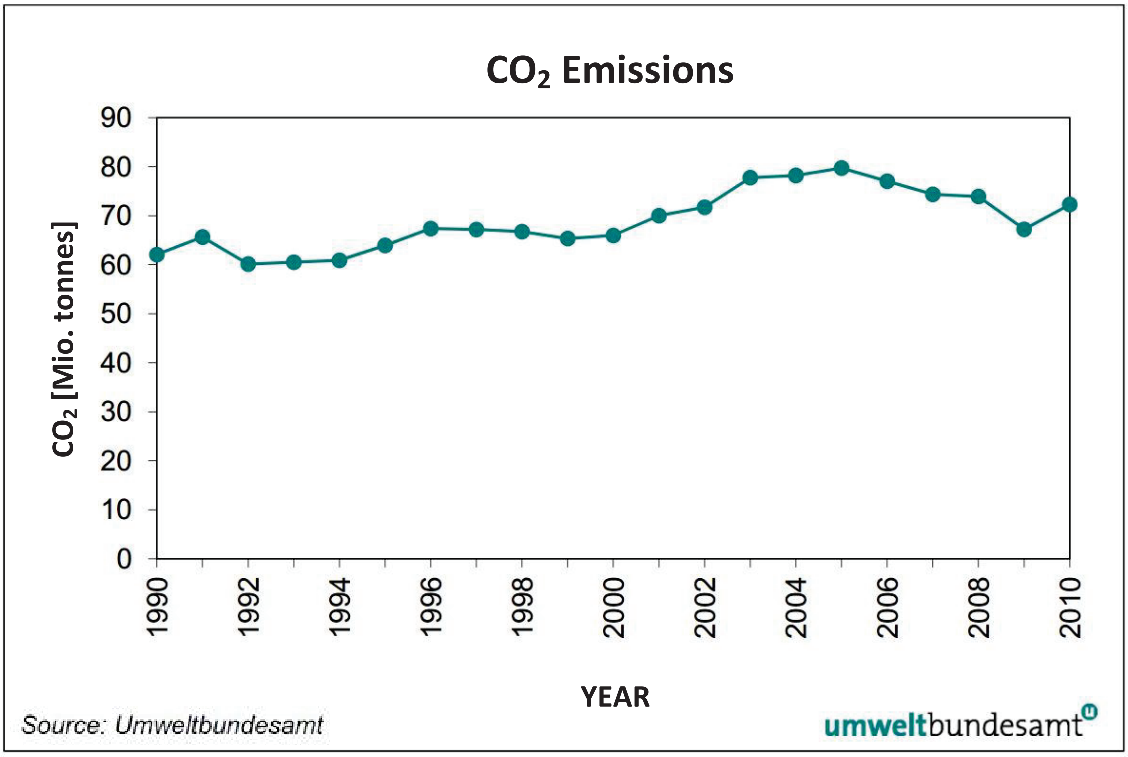

Figure 15 Trend of the CO_2 emissions 1990-2010[88]

For a material use of carbon dioxide particularly sources with high CO_2 concentration and purity are of interest, because an additional purification is energetically costly and has to be avoided. Carbon capture is primarily discussed in the power plant area, but also in other industrial processes carbon dioxide accumulates in considerable quantities as mentioned above. Carbon capture and utilization makes no sense for the transport sector. The sector is responsible for a lot of carbon dioxide emissions, but the emitters are many small and mobile sources which are not suitable for carbon dioxide capture. The same applies also for the sector lower consumer. So only two sectors are left over. The sectors of interest for CCU technologies are the energy sector and industry sector. They are divided in special industries listed in the table. For this thesis all industries are considered except the lumber and automotive industry.

[87]see Umweltbundesamt REP-0393, p. 56

[88]see Umweltbundesamt REP-0393, p. 56

Sector	Industry
Energy	Electricity industry District heating Petroleum industry
Industry	Steel industry Cement industry Paper industry Chemical industry Chalk industry Refractory industry Brick making industry Food industry Glass industry Lumber industry Engineering- and automobile industry

Table 1 Overview of the sectors and industries[89]

By observing figure 16 it is seen that there are a few major polluters in Austria. This includes the electricity industry, steel industry, petroleum industry, cement industry, paper industry as well as the chemical industry. These industries represent also the focus of the investigated industries by this study.

General, in the electricity industry the concentration of carbon dioxide in the flue gas varies greatly with the type of power plant. For gas turbine power plants the CO_2 share is about 3-4% of the waste gas, for coal fired power plants and oil fired power plants with integrated gasification it is about 14 %. The gas of power plants can't be used directly for chemical utilization without extensive treatment because of the low concentration and the existence of catalyst poisons in the gas. The CO_2 concentration in the emissions of steel production is with 20 to 27% clearly higher than in power plants and is therefore suitable for CO_2 capture and an additional use. But also a treatment (removing SO_2, NO_x and so on) is needed for a material utilization. The cement industry contains 14-33% of carbon dioxide in the waste gas. It applies also for capture and utilization but has also to be removed from SO_2, NO_x and so on. The carbon dioxide concentration in refineries depends on the process and is between 3-13%. Chemical processes are also very energy intensive. In various processes CO_2 occurs as byproduct and in some of these processes carbon dioxide is obtained in high purity. This pure CO_2 is already used for various industrial purposes, but the available amount exceeds currently the demand. Thus would be a great feedstock for further utilization of carbon dioxide.[90]

[89] see Ministry of Life (2007), p. 17
[90] see Ausfelder F. (2008), p. 8 et seqq.

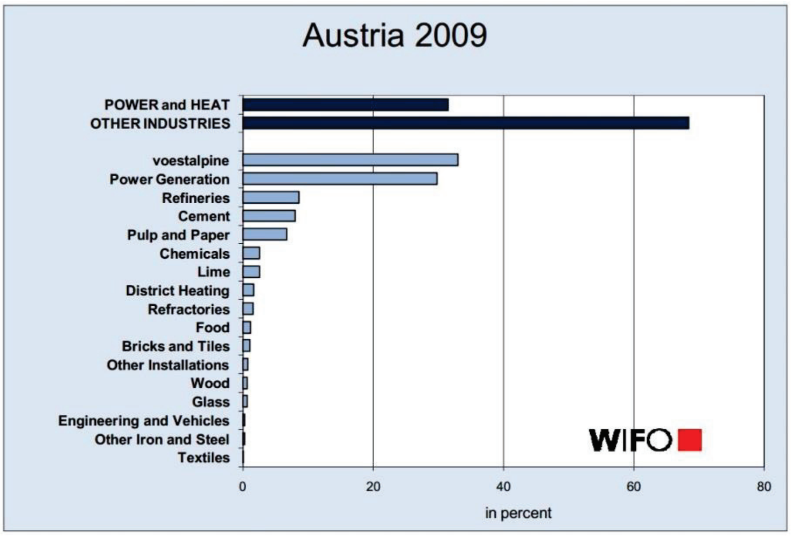

Figure 16 Share of the industries in Austria of the total emissions[91]

2.2.5 STATUS QUO

2010 was the third year of the five-year Kyoto period. In 2010 greenhouse gas emissions in Austria amounted to 84.6 million tons of carbon dioxide equivalents. Emissions in 2010 were thus 15.8 million tons above the annual mean value of the Kyoto target defined for 2008 – 2012 (minus 13% below 1990 levels, i.e. 68.8 million tons CO_2 equivalents). In 2010, emissions were 8.2% above the levels of 1990.

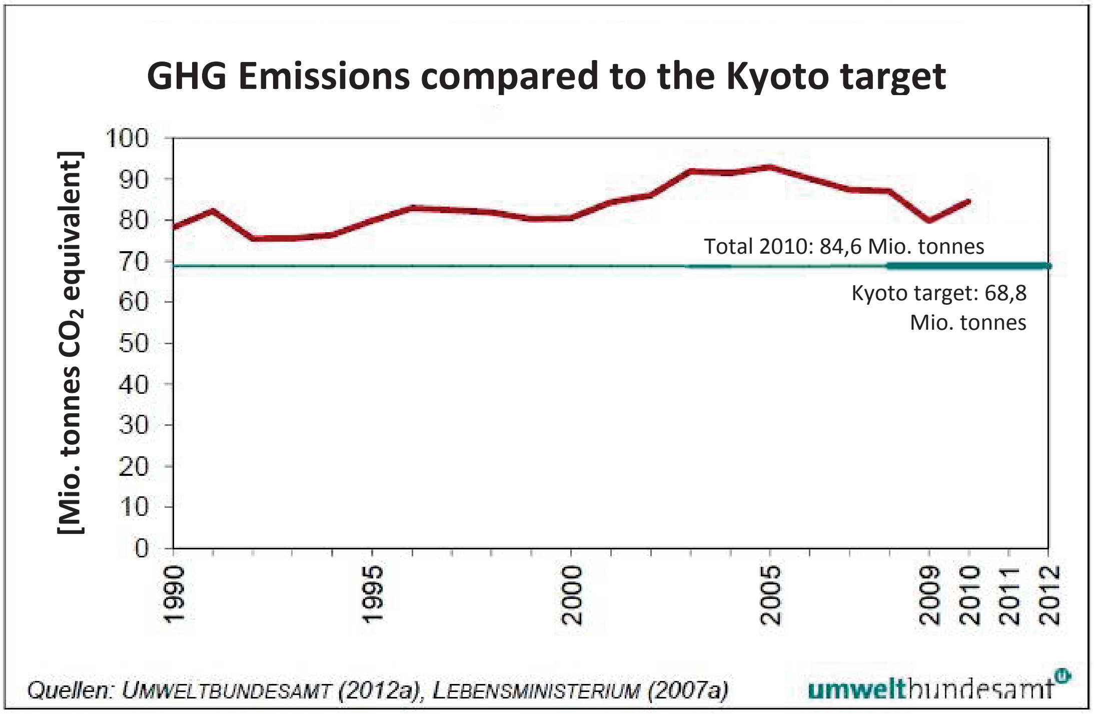

Figure 17 GHG emissions in Austria compared to the Kyoto target[92]

[91] see Anzinger B. (2010), p. 26

Overall a decreasing trend in Austrian greenhouse gas emissions has been observed since 2005. The sharp decline in greenhouse gas emissions during 2008 – 2009 which was mainly due to the economic crisis did not continue in 2010 when, because of the economic recovery, emissions went up by 6.1%. However, they were 2.7% below the levels of 2008, which means that the overall downward trend since 2005 has continued. The decline is mainly due to an increased use of renewable energy sources and the implementation of energy efficiency measures.

In 2011 and 2012, emission reductions achieved through the implementation of climate strategy measures are expected to be compensated, in part, by economic growth, resulting in a gap which is estimated to correspond to the average of 2009 and 2010, and a total gap of 30 million tons CO_2 equivalents for the period 2008–2012. With some uncertainties considered the total gap would range between approximately 26 and 42 million tons CO_2 equivalents. It is intended to close this gap and to achieve compliance with the Kyoto commitment by purchasing further emission reduction units.

A serious interesting option to help reducing carbon dioxide emissions in Austria could be one of a carbon capture and utilization method. It is proven that strategies for avoiding CO_2 emissions alone are not enough. The thesis explains in the following chapters the different carbon capture and utilization methods, finally showing the result of possible technologies to use in the Austrian industry.

[92]see Umweltbundesamt REP-0391, p. 18

2.3 CARBON CAPTURE AND UTILIZATION TECHNOLOGIES

2.3.1 GENERAL

The material use of CO_2 is based on his application as a carbon source for chemical, biochemical reactions or its direct use as an industrial gas to achieve a value added[93]. CO_2 is an energetic end product of combustion processes with a free standard enthalpy of -393 kJ / mol. The activation (reduction) of CO_2 as a reversal of the combustion and is correspondingly energetic complex. In the extreme case, an energy input is required, which is higher as the obtained energy from the combustion. So every concept has to be tested according to the energy expenditure. The use of CO_2 as C1 building block requires innovative upstream and downstream steps. This includes for example intelligent synthesis of high energy reaction agents for CO_2.

CO_2 as a raw material is in large quantities available and has advantages regarding to toxicity and ecotoxicity compared to other reaction partners. But the material use of CO_2 can only serve as an additional carbon sink because of their relatively small fixation potential compared to the total CO_2 emissions.[94] The interest in the use of carbon dioxide is rather the fact that CO_2 is a potential recyclable material with an interesting value-added potential for the industry and his economic usage can have a positive impact on the valuation of strategies for the reduction of CO_2 emissions. In this way the greenhouse gas CO_2 can be a resource for the material value chain.

Potential use of the material and the recycling of CO_2

The annual global anthropogenic CO_2 emissions through the use of fossil fuels & cement production was about 33,4 billion metric tonnes in the year 2010.[95] In contrast is currently a material utilization of almost 130 Mio. t, with approximately 110 million attributable to the usage of CO_2 as a raw material and 20 million to the usage as industrial gas. Figure below illustrates most of the current and potential uses of carbon dioxide.

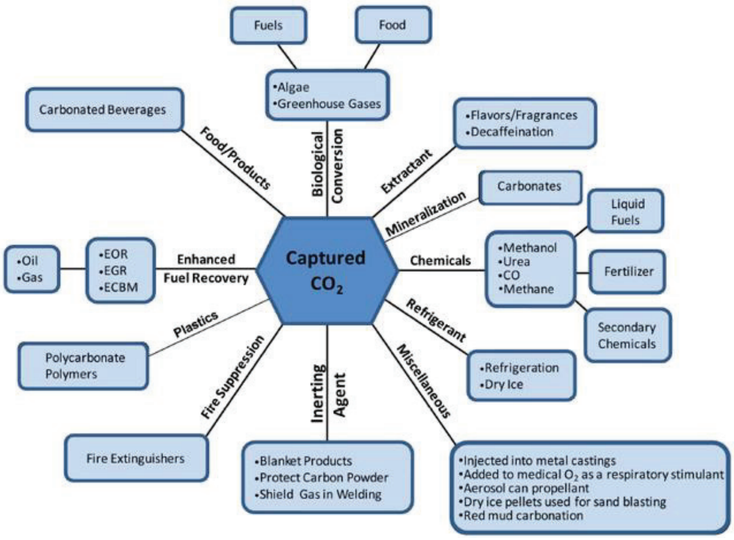

Figure 18 Illustration of the uses of CO_2[96]

[93]see Aresta M. (2010)
[94]see Ausfelder F. (2008)
[95]see CO2Now.org (2010)
[96]source: http://www.netl.doe.gov/technologies/carbon_seq/corerd/co2utilization.html

By far the biggest established CO_2 reaction product is urea (146 Mio. t) with a CO_2 use of 107 Mio. t.[97] Next is methanol (30 Mio. t) with a use of about 2 Mio. t CO_2.[98], the rest of the carbon originates far from conventional synthesegas. Also interesting is the production of cyclic carbonates with a CO_2 consumption of about 0,04 Mio. t and of salicylic acid with a CO_2 consumption of about 0,03 Mio. t.[99]

20 Mio. t CO_2 were applied as industrial gas, where the most use is predominantly physical, such as inert gas, extraction agent, or in the beverage industry.[100]

The biggest hurdle for the industrial implementation of a recycling is the low energy level of CO_2. This has the result that energy must be supplied in the form of light, electric power or heat. Alternatively, also high-energy reactants can be used for the chemical reaction, such as hydrogen, small circular molecules or unsaturated compounds. Target molecules, such as organic carbonates, should be lower in energy than the starting compounds.[101]

CO_2 sources and purity

There are various sources for material use of CO_2. In the chemical industry CO_2 is accrued in relatively pure form. In this way 120 Mio. t CO_2 occur every year in the ammonia synthesis and 5,1 Mio. t CO_2 in the ethylene oxide production as a by-product.[102] Furthermore pure CO_2 also arise as a by-product in the synthesis gas generation, in refineries and in the gas-cleaning. Suitable sources are also fermentation processes, such as bioethanol production. The purity of the carbon dioxide from ammonia production and the fermentation is almost sufficient for all synthetic purposes.

As mentioned a chapter before the purity of CO_2 is an important requirement for its use as a raw material. Thinkable is also to separate CO_2 from power plants for a later material use. Due to the possible contamination of the accruing flue gas in power plants, it is maybe necessary to clean the CO_2 before it can be used. Impurities in flue gases can be of different nature, for example O_2, N_2, H_2O, H_2S, CO, CO_2, SO_2, NO_x, heavy metals or hydrocarbons.

It is necessary to consider certain criteria in the purification of flue gases. The stability of used catalysts against catalyst poisons plays a particularly important role and must be checked. Also an economic consideration is important because costs incurred by further purification of CO_2. From an ecological view, the additional energy required for CO_2 purification also plays a crucial role.

The art of the pollution of the CO_2 determines subsequent application areas of the products. The areas of application can be sensitive with certain impurities or a very high purity is required due to certain preconditions as in the manufacture of active pharmaceutical ingredients. In classical chemical syntheses more purification steps are followed after fitting CO_2.

For the use of CO_2 in the oil and gas industry the purity of the CO_2 stream is not particularly important. More important is the CO_2 purity at other approaches of the physical use.

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[97]see International Fertilizer Association (2009)
[98]see Dittmeyer et al. (2005)
[99]see Dittmeyer et al. (2005)
[100]see Ausfelder F. (2008)
[101]see Sakakura et al. (2007)
[102]see Ausfelder F. (2008)

Because CO_2 is used often in goods of the food industry without further reprocessing steps, so CO_2 impurities can play in this application a crucial role.

Evaluation criteria for use of CO_2

In addition to the required purity, there are other factors that play an important role in the evaluation of a potential material CO_2 usage. Most notably are the quantity and duration of CO_2 fixation, energy- and CO_2-balances and value creation.

The value added of a product can only be considered based on the current state. It is extremely difficult to estimate the development of markets and the associated change to the value added of a product.

Creating a full energy- and CO_2 balance for processes and products is also very complex. This starts with the definition of system boundaries in order to ensure comparability with other balances. The acquisition of all required data for accurate balancing is currently often the limiting step.

Also the determination of the duration of CO_2 fixation is not trivial, because the duration depends highly on the subsequent application of the product. For example if CO_2 is built into urea and this is used as fertilizer, so you can fix large amounts of CO_2, but it will be released immediately after the application again. In contrast polymers can fix less CO_2, but the duration of the fixation can be years or even decades. In fine chemicals only small amounts of CO_2 can be fixed, but depending on the use, it could be fixed also for years.

Due to the rapid release of CO_2, the physical use is the least attractive one in terms of the duration of fixation. But the amounts of physical usable CO_2 could be sizable.

2.3.2 CHEMICAL FEEDSTOCK

There are many chemical reactions that can be built on the organic molecules from CO_2.[103] The figure gives an overview of possible chemical uses of CO_2.

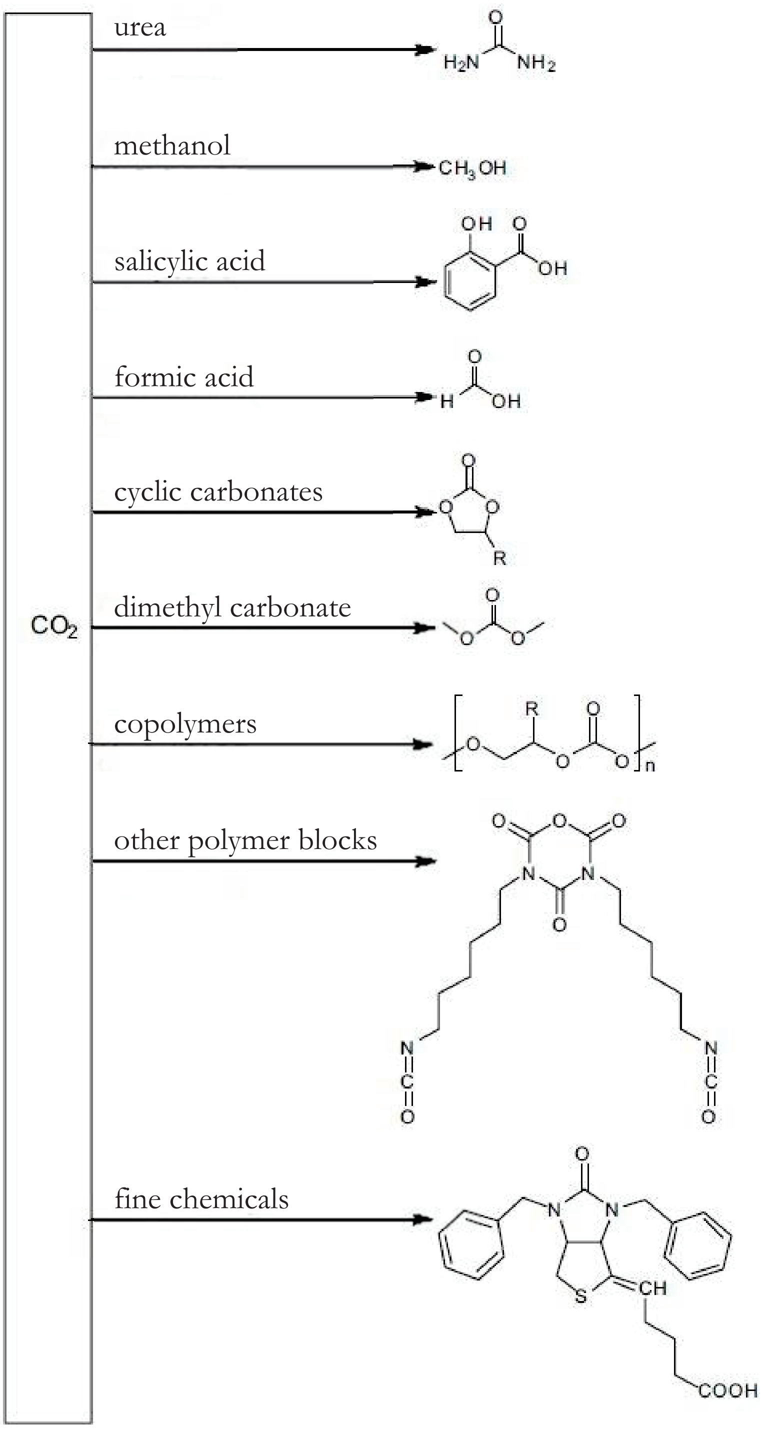

Figure 19 Overview of possible chemical uses of CO_2[104]

[103]see Sakakura & Kohno (2009)

[104]source: Kuckshinrichs W. (2010), p. 65

Synthesis of urea

Under high pressure and temperature ammonia and CO_2 form together urea. Normally the urea production takes place near an ammonia synthesis facility, because of their accumulation of large pure CO_2. volumes.

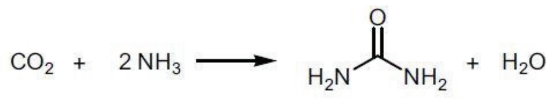

Figure 20 Production of urea[105]

The used starting materials and their preparation have to be included to calculate the overall energy balance. For the future alternative hydrogen sources can be considered, because ammonia is formed under hydrogen consumption.

The urea synthesis is relatively insensitive to contamination and has no special requirements in terms of CO_2 purity. Depending on the application of the urea there are different requirements. For the use of urea as a fertilizer, exposure to heavy metals is problematic. In the production of cosmetics very high purities are required.

Urea is quantitatively the most important product of the chemical industry where CO_2 is used as a C1 building block. 107 Mio. t CO_2 where used for the annual production of 146 Mio. t urea.[106]

The largest amounts of urea are currently used as agricultural fertilizer. In the pharmaceutical industry urea is used as a moisturizer. To make the smoke alkaline, urea is added to increase adsorption of nicotine in cigarette tobacco. Furthermore urea is given as an additive to combustion processes in power plants and trucks, to reduce the nitrogen oxide content of the exhaust emissions.

Urea is also used in the synthesis of fine chemicals. Applications are bleacher for cellulose, textiles, paper and tooth whitening.[107] The nitrate of urea is used as the starting material for nitro urea, which is employed as an explosive or as a mild nitrating.[108] Due to its ease manufacture urea nitrate itself is increasingly used as an explosive. In the previously mentioned applications of urea the CO_2 fixation times are rather short.

Aminoplast as a reaction product of urea has a higher CO_2 fixation potential. Urea-formaldehyde resin (UF-resins) represents approximately 80% of the amino resins and the rest is almost covered from the melamine-formaldehyde resins (MF-resins).[109] The main applications of the amino resins are binders for wood, glues, paints and textile auxiliaries. Amino resins have generally a high CO_2 fixation potential, which could be possibly decades.

Urea-formaldehyde resins (UF-resins) are formed by reaction of urea with formaldehyde, which is derived from methanol. Melamine is needed for the production of melamine-formaldehyde resins (MF-resins), which is the most important derivative of urea. Melamine is produced from urea and ammonia under high pressure and high temperature.

[105]source: Kuckshinrichs W. (2010), p. 66
[106]see International Fertilizer Industry Association (2009)
[107]see Wielicka et al (2003)
[108]see Almog et al. (2006)
[109]see Althaus H.J. (2007)

Most promising applications of urea are his derivatives such as urea-formaldehyde resins and melamine-formaldehyde resins. They have already a CO_2 fixation potential of several million tonnes and it could increase with expanding applications to approximately 10 million tonnes.

Synthesis of methanol

The classic production of methanol is based on synthesis gas. These are mixtures of CO and H_2 in various mixing ratios. There are also often small amounts of CO_2 present in the mixtures.

Synthesis gas is an important intermediate product in the manufacture of various chemical products. Methanol is one example. The relevant formulas (idealised) for the formation of synthesis gas are:

Partial oxidation of coal:

$$C + 0{,}5\ O_2 = CO_2 \qquad \text{Equation 1}$$

Boudouard equilibrium:

$$C + CO_2 = 2\ CO \qquad \text{Equation 2}$$

Water-gas reaction:

$$C + H_2O = CO + H_2 \qquad \text{Equation 3}$$

Water-gas shift reaction:

$$CO + H_2O = CO_2 + H_2 \qquad \text{Equation 4}$$

Partial oxidation of methane:

$$CH_4 + 0{,}5\ O_2 = CO + 2\ H_2 \qquad \text{Equation 5}$$

Steam methane reforming:

$$CH_4 + H_2O = CO + 3\ H_2 \qquad \text{Equation 6}$$

Dry methane reforming:

$$CH_4 + CO_2 = 2\ CO + 2\ H_2 \qquad \text{Equation 7}$$

Often reaction (1) and (3) are combined, where reaction (1) provides the energy for the reaction (3). That’s why equation (5) and (6) also are combined. Steam reforming is the combination of equation (5) and (6), which is used for the large-scale industrial production of hydrogen. For large scale realization of the reaction (7) still research is needed. To produce hydrogen, all reactions delivering carbon monoxide are combined with reaction (4), which results to hydrogen and carbon dioxide. After that CO_2 capture is performed.

Starting from synthesis gas methanol is the main follow-on product. Today it is almost exclusively produced with the help of heterogeneous catalysts from syngas.

$CO + 2\, H_2 = CH_3OH$ Equation 8

$CO_2 + 3\, H_2O = CH_3OH + H_2O$ Equation 9

$CO_2 + \; H_2 = \; CO + H_2O$ Equation 10

The first two reactions (8) and (9) are exothermic; reaction (10) is endothermic and is equivalent to the reversal of the water gas shift reaction (4). The produced CO from reaction (10) can be converted with H_2 according to reaction (8) to methanol. Overall, reaction (9) is the sum of the two others. All reactions are reversible and are depending on temperature, pressure and composition of the synthesis gas.[110]

Methane from biogas provides a carbon dioxide free access to reaction (8). Syngas is produced with reaction (5) and (7). Reaction (7) is particularly attractive because biogas is in idealized form a 1:1 mixture of methane and carbon dioxide. Since the synthesis gas is rich in CO after reaction (7) more hydrogen can be gained due to the water gas shift reaction (4). In this context also the Sabatier process seems particularly interesting, in which CO_2 and hydrogen is converted into methane and water.

Sabatier process:

$CO_2 + 4\, H_2 = CH_4 + 2\, H_2O$ Equation 11

This reaction (11) offers the ability to convert carbon dioxide into methane, which could either be fed into the gas grid or added to biogas. For more details see chapter methanation.

Reaction (9) also allows a carbon dioxide fixation when it is used for the production of methanol. Requirement is that hydrogen comes from renewable sources, for example electrolysis of water.

Hydrogen, which is produced from synthesis gas, is currently used in ammonia production. The used reactions are (5) and (6) with a carbon dioxide sequestration. Air is deployed for the oxidation, nitrogen remains in the gas mixture. The resulting mixture N_2/H_2 has the right composition for the ammonia synthesis according to the Haber-Bosh method.

The global demand for methanol is currently estimated about 30 million tonnes. More than 70% of the produced methanol is used in the chemical synthesis.[111]

In many applications of methanol there is beyond the use no fixation of CO_2. This applies particularly to the application in the fuel sector as biofuels or biodiesel (methyester), even if they consume large quantities of methanol. However under some circumstances fuels can provide interesting storage possibilities with a longer fixation. In the area of fuels there are many application areas for methanol. Methanol can be used as fuel for combustion machines itself or in the form of dimethyl ether. Also established is the conversion of methanol to MTBE (Methyl-tert-butyl ether).[112] It is used as an anti-knock additive for motor fuel. Furthermore it is possible to convert methanol to hydrocarbon mixtures in the so

[110]see Olah G.A. (2006)
[111]see Althaus H.J. (2007)
[112]see Althaus H.J. (2007)

called MTG process (methanol to gasoline). The direct synthesis of hydrocarbons (alkanes, alkenes and alkanols) from synthesis gas is possible with the Fischer-Tropsch process.

An important follow-on product of methanol which is produced in large quantities in the chemical industry is formaldehyde, which makes also a long term carbon dioxide fixation possible. Formaldehyde synthesis of methanol is carried out by air-oxidation in an exothermic reaction, so there is no significant energy consumption from methanol.

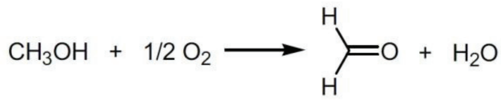

Figure 21 Production of formaldehyde[113]

Formaldehyde is used to manufacture amino resins such as UF resins (urea formaldehyde resins), MF resins (melamine formaldehyde resins) and PF resins (phenol formaldehyde resins). The resulted duromers have their usage in for example varnish, wood materials, composites and foams.

An already established technical thermoplastic is polyoxymethylene (polyformaldehyde, POM). POM is already an established material with a production of approximately 0,5 million tonnes per year.

Acetic acid is another follow-on product from methanol and carbon monoxide. The production in the year 2000 was about 2.7 million tonnes.[114]

Synthesis of salicylic acid and p-hydroxybenzoic acid

The synthesis of salicylic acid occurs with the Kolbe-Schmitt process, where sodiumphenolate and CO_2 are converted under high temperature and pressure. Potassium phenolate supplies almost exclusively p-hydroxybenzoic acid (PHB).

Salicylic acid is used in the manufacture of acetylsalicylic acid. The period of CO_2 fixation is rather low, because CO_2 is released immediately after the application. p-hydroxybenzoic acid is used primarily for the production of its ester, the parabens, which are known as a preservative. A CO_2 fixing application is the production of LC-polyesters (liquid crystalline polyester), which is mainly used in the electronic industry as a high performance material, where often p-hydroxybenzoic acid is the main component.

Both products can be used also in the production of polysestercarbonate.[115]

[113]source: Kuckshinrichs W. (2010), p. 76

[114]see Althaus H.J. (2007)

[115]see Kuckshinrichs W. (2010), p. 79 seqq.

Synthesis of formic acid

Formic acid is usually prepared by reaction of CO with alkali hydroxides or methanol followed by saponification of the methyl ester. The CO can be produced by the Boudouard-equilibrium of CO_2 and coal. Further routes were developed for selective hydrogenation of CO_2 to formic acid.[116]

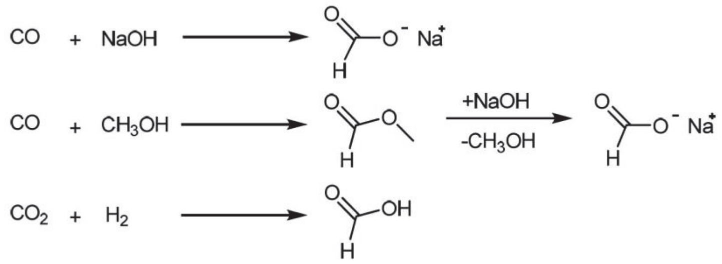

Figure 22 Production of formic acid[117]

The global market for formic acid is about 0,6 million tons per year.[118] Formic acid and its salts are used as a preservative and a de-icer. The acid is used for descaling, as mordant and as adhesive solution for polyamides. Dimethylformamide (DMF) and formamide can be produced from methyl formate. DMF serves as a solvent, e.g. for the spinning of polyacrylonitrile. Formamide serves as a reactant in a process for manufacturing hydrocyanic acid or as a stabilizing agent for single stranded nucleic acids.

Innovative seems the use of formic acid as a reducing agent, for example at soldering or in the Leukart-Wallach reaction. Here acts formic acid as hydrogen equivalent. Formic acid can be used as fuel in a fuel cell, either directly or after cleavage into CO_2 and hydrogen. CO_2 serves thereby as a reversible delivery vehicle for hydrogen, because it can be hydrogenated to formic acid and can deliver the hydrogen elsewhere.[119] The storage density is, however, limited.

Formic acid may be used in the future in special applications for operating in fuel cells.

Synthesis of cyclic carbonates

For the synthesis of five ring carbonates (e.g. ethylene carbonate or propylene carbonate) carbon dioxide reacts with epoxides. The production of epoxides also requires energy. Ethylene carbonate is used as solvent, for example as solvent for lithium salts in lithium batteries. Propylene carbonate has similar application examples and in addition also the application as a plastic softener or core sand binder which is required in the foundry industry. Up to now a not large-scale application of ethylene is the trans-esterification of methanol to dimethyl carbonate and continued with phenol to diphenyl carbonate. In this use carbon dioxide could be bound for the duration of years to decades in the carbon unit as polymer material.[120]

[116] see Leitner W. (1995)
[117] source: Kuckshinrichs W. (2010), p. 81
[118] see Ausfelder F. (2008)
[119] see Ritter S.K: (2007)
[120] see Kuckshinrichs W. (2010), p. 82 seqq.

Synthesis of dimethyl carbonate

Dimethyl carbonate is an intermediate product for the organic synthesis and polymer manufacture. As mentioned before, it can be produced by the trans-esterification of ethylene carbonate with methanol or by conversion of methanol with urea.[121] The most common application of dimethyl carbonate is as a methylation agent. In this use the bounded carbon dioxide is released again. Polymer applications are leading to CO_2 fixation.

Synthesis of polymers via copolymerization and CO_2

The products of this process are used in the ceramic industry as a pore forming material, or in the building industry as building materials and insulating materials or foams. An advantage of this application is the fixation of CO_2 over long periods. An application area with great future prospects could be the use as thermoplastics. Thereby a big market in terms of volume could be developed, which includes a high carbon dioxide fixation.[122]

[121] see Fujita S. et al. (2005)
[122] see Kuckshinrichs W. (2010), p. 85 seq.

Evaluation of innovative solution approaches

Carbon dioxide is used already as material for various applications. There are a lot of innovative ideas and solutions how CO_2 can be used as C1 source in the future. A distinction of the direct fitting of carbon dioxide in the products and the technologies used is needed.

Innovative products

The most promising currently seems the placement of carbon dioxide into polymers. Here are particularly such polymers attractive, which already have a market in the rage of hundreds of thousands to millions of tons. Urea formaldehyde resins (UF resins) and melamine formaldehyde resins (MF resins) have the highest carbon dioxide fixation potential from polymers. The annual production amounts to several million tonnes and the carbon can be deployed into existing processes by fixed CO_2. Areas of application could be for example wood materials and insulators in the electricity. Increased application in the field of thermal insulation could lead to a significant reduction in emissions through energy savings.

Interesting for niche applications are copolymers from epoxides and carbon dioxide. Unlike most ways to place CO_2 into polymers, copolymerization of epoxides and CO_2 doesn't premise the reduction of CO_2 to oxalic acid or formaldehyde.

p-hydroxybenzoic acid can be made into different plastic products and has a large carbon dioxide fixation potential in million tonnes range.

The polycondensate polyoxymethylene (POM) is an engineering thermoplastic that could be made of CO_2 via the intermediate product formaldehyde. POM could substitute polypropylene and polyethylene. Additional costs, for example compared to polypropylene, could be compensated by higher quality, longer durability and mechanical properties. Thus polyoxymethylene had a million-ton potential.

Overall, about 200 million tonnes of plastics is produced every year. When only 10% could be replaced with materials from technically fixed CO_2 then this would correspond, with an installation rate of 20 % by weight, a fixation of about 4 million tonnes of CO_2 per year. This would correspond to the annual carbon dioxide emissions of a modern coal power plant.[123]

The production of methanol is the most important potential access to the non-fossil C1 chemistry. Due to the CO_2 balance hydrogen must be available from non-fossil sources. The fitting of secondary products of methanol in the field of polymer chemistry promises a huge amount of fixation and also long fixation duration. The most important product of methanol for the polymer chemistry (POM, thermosets) is formaldehyde, which is by an exothermic oxidation of methanol accessible. Furthermore, methanol can be converted to synthesis gas. This leads to many products of the organic chemistry.

Oxalic acid is found in many plants (cocoa, spinach, and beetroot). It is technically used as rust remover and bleaches. In principle, oxalic acid provides a good introduction to the organic chemistry of CO_2 and would complementary illustrate to other ways addition into the non-fossil C2 chemistry.

[123]see Kuckshinrichs W. (2010), p. 119

Innovative technologies

Innovative technologies are required to manufacture products, in which CO_2 might play a role as a C1 source. Currently four interesting technologies are discussed:

1. fitting of CO_2 in polymers,
2. hydrogenation of CO_2,
3. electro catalytic activation of CO_2
4. and photo catalytic activation of CO_2.

Most ways to place CO_2 into polymers requires a CO_2 reduction to oxalic acid or formaldehyde. An exception is the alternating copolymerization of epoxides and carbon dioxide.

The hydrogenation of CO_2 represents another innovative technology for carbon dioxide utilization. A requirement for a significant reduction of CO_2 emissions from this type of CO_2 use is the production of hydrogen from non-fossil sources. With hydrogen from non-fossil sources, there would be different approaches to fix CO_2, for example, the production of CO- and formic acid. The methanol production would also be an interesting and economically relevant way for carbon dioxide fixation. When using methanol as a raw material for formaldehyde instead of the fuels the market of CO_2 containing polymers could be significantly enlarged.

Methods for the electrochemical reduction of carbon dioxide have been studied for a long time. Several products are described, for example CO, formic acid, methane, methanol, ethane, ethylene, ethanol, acetone, hydrocarbons and hydrogen as an unwanted byproduct. To ensure sufficient electron transfer in laboratories precious metal cathodes were used for the reduction of CO_2 to C1 molecules. At these cathodes high voltages were applied. Today electro catalysts are inefficient for producing higher energy products or they need an additional sacrifice molecule. [124] An industrial scale realization of electrochemical carbon dioxide reduction is therefore not expected in the short term.

Attractive seems the direct photo reduction of carbon dioxide to CO, methane, other hydrocarbons or methanol. There are different types of possible photo catalysts for this reaction, for example titania (TiO_2) based systems, indiumtantalat ($InTaO_4$) and platinum metal complexes (preferable ruthenium or rhenium). First approaches for photocatalytic reductions are described in the literature, but there is still considerable need for development.[125] A short and medium term technical implementation seems difficult.

Atom efficient syntheses with involving carbon dioxide are known as “Dream Reactions”. Direct hydrogenation with hydrogen to higher alcohols, or the copolymerizations with olefins are examples of dream reactions. The direct methods are not yet successful or problems arise with the treatment of the reaction products. However, there are considerable research activities worldwide in this area.[126]

[124] see Ausfelder F. (2008), p. 20
[125] see Osterloh F.E. (2008)
[126] see Lehner M. et al.

2.3.3 METHANATION

The target of a future energy system is a full sustainable supply from renewable resources. Thereby the final energies, electricity, heat and fuel, have to be available at any time without restrictions. Renewable energy sources such as wind power or solar power, however, are fluctuating. While worldwide more and more electricity is gained from wind and sun, new approaches in storage are needed. Because when the wind blows very strong, the wind power plants feeding more current into the electricity grid as needed. The massive development on the basis of wind and solar power is increasingly leading to more and more fluctuations in the electricity grid, for which reason an additional possibility of storage is essential. The development of pump storages is limited. Moreover, the application of pump storage plants is usually the current storage for several hours up to days. For a supply with renewable electricity also long term storages are required. At present only chemical energy sources such as hydrogen or methane are considered for long term storage to balance the seasonal fluctuations of renewable energy. The amount of storage capacity required in the future depends on the development of renewable energy sources, national and international energy management, and is very difficult to estimate.

The volumetric energy density of methane is 3 times greater than that of hydrogen. Methane has also the advantage that the existing natural gas infrastructure can be used. [127] To inject methane in the natural gas distribution system for transportation and storage it must meet the relevant quality criteria. This is defined in Austria in the ÖVGW directive G31. Conditioned gas which satisfies all quality criteria is called synthetic natural gas (SNG, substitute natural gas).

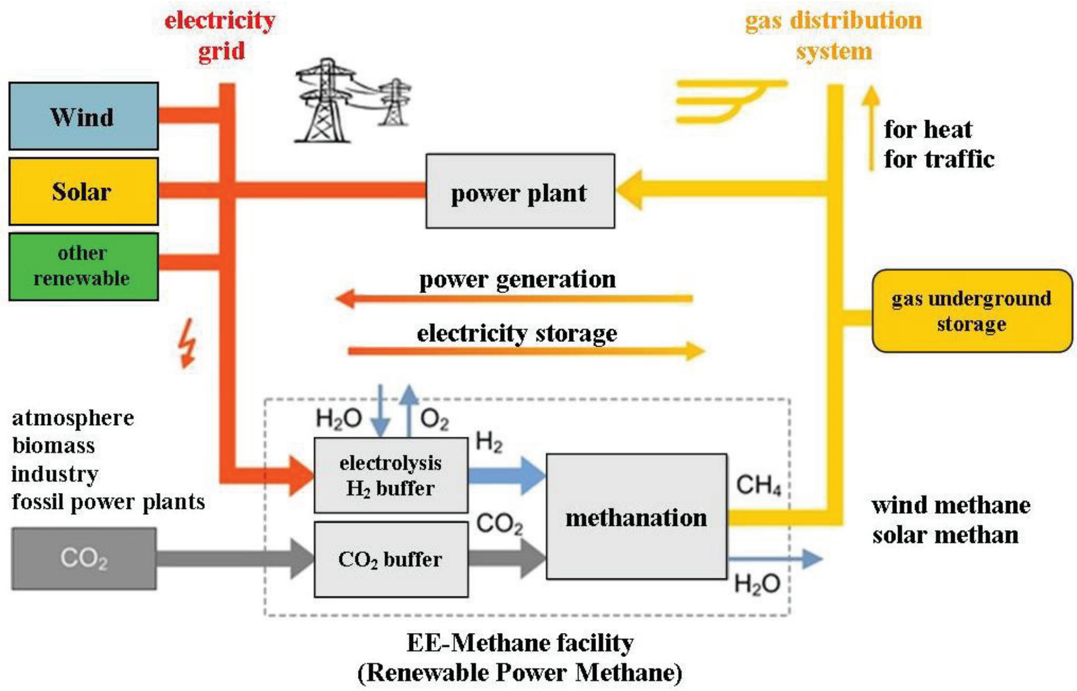

Figure 23 The principle of mehtanation[128]

[127] see Bajohr et al. (2011)

[128] source: Welt der Physik „Erneuerbares Methan: ein möglicher Langzeitspeicher“

Substitute Natural Gas can be produced in a variety of ways:

1. gasification of fossil fuels as Syngas
2. "wet" biomass for anaerobic fermentation (biogas-to-SNG)
3. "dry" biomass for thermochemical gasification (bioSyngas-to-SNG)
4. renewably produced electricity for the electrolytic production of hydrogen combined with carbon (di) oxide from various biogenic and non-biogenic sources (EE gas, windgas or solargas)
5. combination of the methods

The concept envisages using electrolysis to convert excess electricity from fluctuating sources into hydrogen, then into substitute natural gas in a subsequent synthesis step with CO_2. The two steps are:

1. Electrolysis: splitting of water into hydrogen and oxygen with the help of electric energy according to the formula.

$$2 * H_2O + electric\ energy \leftrightarrow 2 * H_2 + O_2$$

2. Methanation is a chemical reaction where hydrogen and carbon monoxide or carbon dioxide is transformed into methane. The reaction of carbon dioxide to methane was developed by Paul Sabatier and J.B. Sendersen in the year 1902 and is also called the Sabatier process.[129] The reaction is described by the following equations:

$$CO_2 + 4 * H_2O \leftrightarrow CH_4 + 2 * H_2O$$

The lower the temperature, the more complete the reaction, but the slower it is. This is why the reaction has to be accelerated by suitable catalysts.

$$CO \quad + 3 * H_2 \leftrightarrow CH_4 + H_2O$$

The reactions proceed exothermically and are connected with the water-gas-shift-reaction and the Boudouard equilibrium according to the formula:

$$CO \quad + H_2O \leftrightarrow H_2 + CO_2$$

$$2 * CO \quad \leftrightarrow C + CO_2$$

A key challenge for the process is to manage the heat of the reaction and designing a catalyst system that can maintain its activity after prolonged exposure to high

[129] see http://de.wikipedia.org/wiki/Methanisierung

temperatures. The reactor temperatures are between 250 and 500 °C and the catalysts are almost nickel.[130]

For the production of EE-gas very pure CO_2 is required. There are hardly any pure CO_2 waste streams from the industry which are necessary for methanation. A very pure form originates as a by-product in the ammonia and ethylene oxide synthesis. In the power plant sector, the chemical industry, the cement industry or metallurgical industry the CO_2 must be removed and cleaned before methanation.

The most part of hydrogen generation is worldwide from natural gas, only a small part of 4 %[131] is from electrolysis. For methanation it's necessary that the hydrogen is obtained by water electrolysis with renewable energy to cause a corresponding contribution to the climate balance. In the short to medium term there is no hydrogen market in Austria. Also cheap excess current lacks in Austria. Just if the expansion of solar and wind energy is well advanced, there will be a need for long term storages, which can be met with the production of methane or liquid hydrocarbons.

The efficiencies are declining at every single process step due to the losses. Therefore it is meaningful to use the produced methane directly for example in the traffic, as to convert it again in electricity.

Methanation from coal gasification is industrially developed and tested on an industrial scale, but has no strategic importance for Austria. Methanation from biomass gasification is currently under investigation in several pilot and demonstration plants. From an energetic view it is the most meaningful method to produce SNG, because the CO_2 comes directly from renewable sources. A problem with the use of biomass could be the existing potential. Methanation of CO_2 from biogas is interesting for Austria, as there are numerous biogas plants.

[130]see Graf F. (2010)
[131]see D. Krieg (2012)

2.3.4 FUELS

In addition to the chapter synthesis of methanol fuels from carbon dioxide are discussed briefly again. CO_2 can be used as a potential source of carbon for the reaction hydrogen to liquid fuels, gas-to-liquid (GTL) products and methanol. The reactions are only useful if hydrogen is from renewable resources available. The highest potential in terms of quantity has the production of synthesis gas, which is a mixture of CO and H_2.

Syngas can be used via the Fischer-Tropsch synthesis for the production of fuels like gasoline or diesel. Methanol as a follow-on product of syngas also has a potential in the fuel sector, especially in the form of derivatives, MTBE, dimethyl carbonate (DMC), and dimethyl ether (DME). Methanol and DMC represents alternatives to the currently used gasoline, DME can be used as a substitute for diesel fuel.

A disadvantage in the production of fuels is a substantial additional requirement of energy (for example for refining) and the associated CO_2 emissions. The synthetic Fischer Tropsch fuels also have an unfavourable CO_2 balance.

Technical challenges in CO_2 conversion to fuels are especially in the field of catalysis and reaction engineering. Energetic efficient methods for capturing CO_2 with a high degree of purity from flue gases have to be developed. The same applies to the manufacture of DMC from methanol and CO_2.[132]

[132]see Ausfelder F. (2008)

2.3.5 CO_2 AS A RAW MATERIAL FOR BIOGENIC PROCESSES

Biogenic processes in terms of carbon capture and utilization means the capture and use of carbon dioxide in industrial processes for an artificial use of the photosynthesis by microorganism. The focus is on autotrophic microorganisms, which are using carbon dioxide to build up biomass. They need also energy from sunlight and additional nutrients such as nitrogen, phosphor, potassium and sulphur. The CO_2 concentration in the atmosphere is normally enough for building up biomass, but higher concentrations, however, can increase significantly in some plants the production. Systems such as glass houses with higher carbon dioxide concentrations or the fertilization of agricultural areas with CO_2 is practical insufficient. For this reason, aqueous biological systems are considered for a potential carbon dioxide recycler.

The focus is currently on microalgae. Microalgae's are mono- to multi cellular organisms. They are and were used for the production of dietary supplements, as basic material for the chemical industry, the pharmaceutics and cosmetics, as well as additives for the agriculture. In addition to the material use of microalgae the fixation of carbon dioxide in connection with an energetic utilization of cultivated biomass is recently in the viewpoint of science. In both cases fossil source materials are replaced, which can contribute to a reduction of CO_2 emissions. As long as the separated carbon dioxide comes from the combustion of fossil energy sources we are strictly speaking of anew use of the fossil carbon with a delayed release of the carbon dioxide into the atmosphere. But also CO_2 savings can be achieved by the double use. Therefore the CO_2 has to come from renewable sources (e.g. combustion from biomass) to get a real circuit closure in terms of carbon dioxide neutral energy carrier.

The main reasons for the use of algae are the high growth rates and thus yields to a higher biomass production compared to land plants. They grow about 10 – 30 times faster because every single algae cell is involved in the photosynthesis.[133] Growing areas are also possible in agriculturally less fertile areas as long as the light intensity is sufficient. Furthermore, they have low requirements on environmental conditions. Depending on the stem, salt-, sweet- and wastewater is possible as culture medium. Another advantage is that they are not very sensitive to exhaust components such as NO_x, SO_x, and heavy metals.

The cultivation of biomass takes place in open or closed ponds or reactors. In the aqueous milieu the free floating microorganisms are optimally supplied with the necessary nutrients and light. Carbon dioxide is delivered through appropriate gas distributor and converted through photosynthesis in biomass. The microalgae grow and proliferate and can be continuously separated from the suspension. Currently open systems dominate (called Raceway Ponds, see figure 24). These are artificial surface ponds of 10 to 20 cm depth. The productivity in open systems is limited with 8 to 12 grams per square meter and day. An open system is for example in Kona, Hawaii, operated by Cyanotech Corp. Algae is cultivated over an area of about 35 ha since 1985 and is sold as dietary supplements. The total production of biomass is about 300 tons per year.

Closed photobioreactors in the form of miles of pipes or large plates have been realized only in the pilot scale. In contrast to open systems, closed photo bioreactors allow higher area use and targeted process control (controlled temperature, CO_2- and fertilizer addition, no contamination by other algae), but are significantly more expensive in acquisition and operation (complex construction, pressure losses). The major problems with closed systems are the energy requirements to maintain the turbulence in the reactors and the oxygen inhibition.

[133]see Brauer Th. (2009)

In many cases a combination of both (bioreactors and open systems) could make sense. Bioreactors serve as a pure culture station for microalgae, which are periodically emptied into open ponds in order to continue to build biomass. Currently there are various constructions of photobioreactors, from classic tube- to a plate reactor (figure 25). EON Hanse in Hamburg operates a pilot bioreactor system. Here new photobioractors are tested to utilize carbon dioxide from a natural gas power plant.[134]

Figure 24 An open pond system in Kona, Hawaii[135] [136]

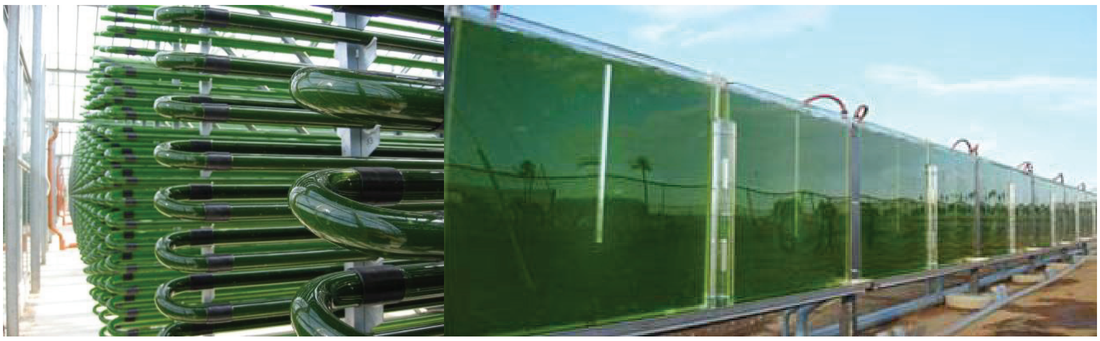

Figure 25 Examples for bioreactors[137] [138]

The lower Austrian supplier EVN tests a pilot facility at the caloric power plant in Dürnrohr to capture CO_2 from the flue gas with the Post Combustion Capture method and then use it commercial. The test will run until 2015 and is in operation since March 2011. Research focus is to produce bioplastics made from microalgae. A global market already exists for bioplastic. Biogas should be recovered as a by-product. It's a new method, which must be developed. Within three years a pilot plant should be built. EVN project manager Gerald Kinger doesn't worry about the disposal of bioplastics, because several large beverage companies announced to convert their plastic bottles to bioplastics. Other applications range from biodegradable packaging to the use in the automotive industry.

[134]see Brauer Th. (2009)
[135]source: Brauer Th. (2009)
[136]source: http://www.bizjournals.com/pacific/news/2011/10/11/cyanotech-decides-to-expand-after-dr.html
[137]source: http://chlorelle.wordpress.com/
[138]source: http://biofuels.asu.edu/biomaterials.shtml

The following table summarizes the pros and cons of open systems in comparison with photo bioreactors.

open pond systems	tube- and plate reactors
been used in large scale plants	laboratory scale, not commercial
large land footprint	reduced footprint
subject to contamination from predator strains	allow single species culture
evaporation losses	water loss can be managed
temperature control difficult (day/night, summer/winter)	better process control, but need larger amounts of energy
lower biomass concentration	higher biomass production
high nutrient consumption	allow easier and more accurate provision of nutrients
much cheaper	expensive compared to open ponds

Table 2 Comparison of open systems and photobioreactors[139]

As already briefly mentioned the next discussion goes into detail about the applications of microalgae. The illustration below shows an overview of the currently popular utilization pathways for algal biomass from the cultivation of exhaust gas to the point of production of biofuels. The paths can be combined differently each other. The success of utilization depends on location, local conditions and current market situation. But each process starts with the culture of microalgae.

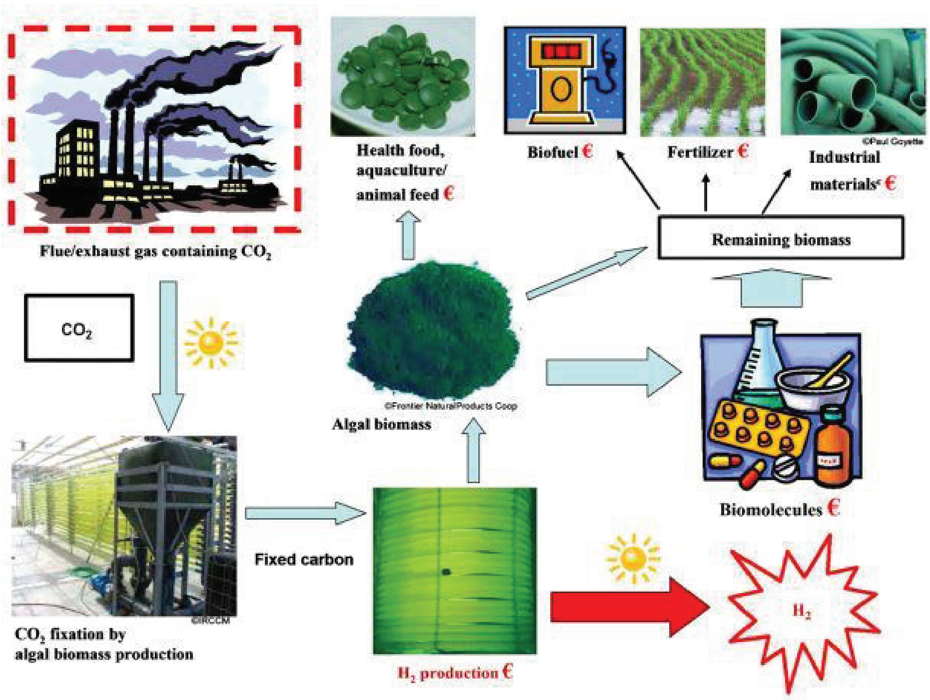

Figure 26 Applications of microalgae[140]

[139]see Brown A. (2010), p. 4

Carbon dioxide through production of algae biomass

Previous studies have shown that some algae stems can grow at very high CO_2 concentrations and can simultaneously have some tolerance against SO_x and NO_x, both common pollutants in exhaust gases from the combustion of fossil energy carriers. Therefore partly also the usage of power plant exhaust gases is possible without CO_2 separation or removing of SO_x and NO_x.[141] In Austria cultivation of algae with cement plant exhaust gases have been tested with very positive results.[142] The industry trend in the utilization of exhaust gas is the use of closed systems although they are difficult to realise economically.

Hydrogen production using sunlight and microalgae

Algae can produce hydrogen in the lack of sulphur by photolytic cleavage of water via sunlight and special catalysts. Although it is the most powerful biological hydrogen generation (5 ml hydrogen per liter algae suspension and hour can be reached), but calculations have shown, however, that at least a hundred times amount of H_2 per hour has to be generated to make it competitive. Currently an efficient recovery of biohydrogen by biophotolysis fails mainly on poor efficiency.

Algae biomass as food supplement

Algae biomass is mainly used due of its high nutritional value in the Asian region since centuries. Algae products in form of tablets and powder are increasingly entering into western markets. Especially in the area of food production as animal feed algae biomass is a valuable nutrient source. Worldwide production is estimated about 7,000 – 7,500 tonnes per year with a fast growing market.[143]

Extraction of biomolecules

Depending on the stem microalgae can synthesize different biomolecules, which have a constitutional effect. Some algae contain omega 3 and similar unsaturated fatty acids, which in part have a higher quality comparable to fatty acids derived from fish. Some molecules also represent interesting raw materials for industrial usage. These raw materials are used as nutrient additive, in the cosmetic, as raw material for plastics and for thickeners.[144]

Production of biofuels

These are thermo-chemical processes such as the combustion for a source of heat, electricity and mechanical energy, the gasification to calorific gases like methane and hydrogen, the pyrolysis to gaseous fuels, oils or the liquefaction of biomass to hydrocarbons. The bound CO_2 is ultimately released to the atmosphere by all processes.

Composite materials for the building industry

Another possibility to bind carbon dioxide for decades is their use for production of construction materials. The usage of natural fibres for amplifying plastics is widespread and represents a growing market due to environmental considerations, as well as weight and cost reduction of building materials. The possibilities for manufacturing composites from PP, PE and PVC by admixture of algae biomass has been shown in different studies and appears to be a viable way for the utilization of algae.[145]

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[140]source: Skjanes K. (2007)
[141]see Maeda, K. (1195)
[142]see Borkenstein, C. (2010)
[143]see Skjanes K. (2007)
[144]see Skjanes K. (2007)
[145]see Skjanes K. (2007)

Algae biomass is also long been used as a fertilizer in the coastal region, which affects the water retention of the soil and the mineral composition positive.

Another possibility to use carbon dioxide by biogenic processes is the production of methane by Archaea. These microorganisms form from hydrogen and CO_2 the energy source methane, which can be utilized directly as a fuel or injected into the natural gas grid. In this area still research is needed. Assumption of this technology is the presence of hydrogen from renewable sources.

Table below summarize the pros and cons of biogenic methods to utilize carbon dioxide in comparison to chemical methods.

	chemical methods	biogenic methods
pros	high pressure	atmospheric pressure
	high temperature	low temperature
	high conversion rate	low conversion rate
cons	hydrogen required	no need of hydrogen
	lower biomass concentration	sunlight as energy source
	catalysts not available (dream reactions)	robust methods available

Table 3 Comparison between chemical and biogenic methods[146]

[146]see Kinger G. (2011)

2.3.6 MINERAL CARBONATION

The basic idea of carbon mineralisation is the conversion of CO_2 to insoluble carbonates using chemical reactions. In this process, alkaline and alkaline-earth oxides such as magnesium oxide (MgO) and calcium oxide (CaO), are chemically reacted with CO_2 to produce compounds such as magnesium carbonate ($MgCO_3$) and calcium carbonate ($CaCO_3$, commonly known as limestone). Magnesium and calcium carbonates have a lower energy state than CO_2. Therefore, at least theoretically, the process not only requires no energy inputs, but also can actually produce energy. The carbonation reaction can be shown by the simple reaction of MgO and CaO.

$$\mathrm{CaO} \quad + \mathrm{CO_2} \leftrightarrow Ca\mathrm{CO_3} \qquad \Delta H = -179\ \mathrm{kJ}\ /\ \mathrm{mole}$$

$$\mathrm{MgO} \quad + \mathrm{CO_2} \leftrightarrow Mg\mathrm{CO_3} \qquad \Delta H = -118\ \mathrm{kJ}\ /\ \mathrm{mole}$$

These exothermic carbonation reactions release substantial heat. For comparison, the heat released in the combustion of carbon is 400 kJ/mole. In nature mineral carbonation is called silicate weathering and is a very slow process. It takes place on a geological time scale. The main candidate minerals for carbonation are olivine, serpentine and wollastonite. They are typically found in silicate minerals. For common calcium and magnesium containing silicate minerals the reaction is still exothermic but the heat released is less.

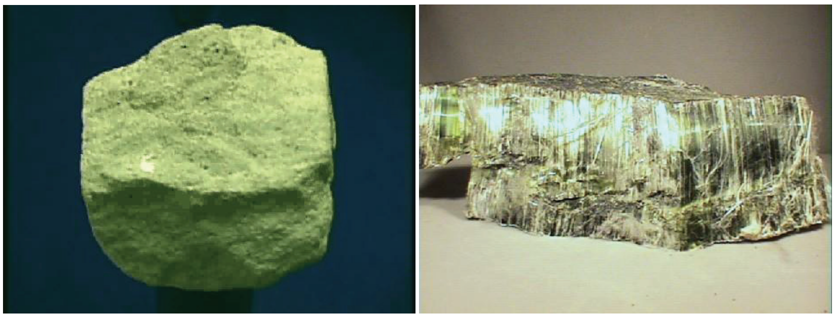

Figure 27 Olivine and serpentine[147] [148]

In the case of silicate rocks, carbonation can be carried out either in-situ or ex-situ. In-situ storage of CO_2 (CCGC Carbon capture and geological storage) includes the CO_2 segregation, injection and storage in geological structures. Potential storage sites are depleted oil and gas reservoirs, enhanced oil recovery sites, deep saline formations, deep unmineable coal seams, CO_2-driven coal bed methane recovery, and deep saline-filled basalts and other formations (see figure 28). Since the 23th August of 2011 the underground storage of CO_2 has been forbidden in Austria except small research projects. And so it's not relevant for a more detailed viewing for this thesis.

[147] http://www.mchenry.edu/depts/EAS/courses/eas170/minerals/pages/Olivine.htm

[148] http://www.galleries.com/Serpentine

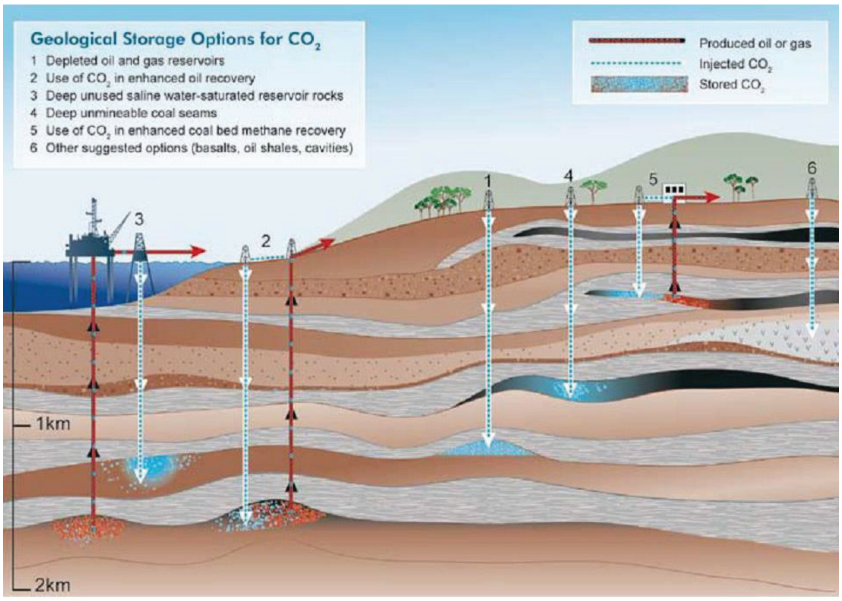

Figure 28 Geological Storage Options for CO_2[149]

When we talk about CCU technologies in matters of mineral carbonation then the ex-situ bond of CO_2 (CCMC Carbon capture and mineral carbonation) is meant. Ex-situ bonding of CO_2 is the mineral carbonation in an extra chemical processing plant. The industrial processing steps involved in the mineral carbonation are shown in figure below. It involves three major activities. At first the reactant minerals have to be prepared by mining, crushing and milling and then transported them to a processing plant. The next step is reacting the concentrated CO_2 steam from anthropogenic sources with the prepared minerals. Finally the carbonate products have to be separated and stored them in a suitable repository.

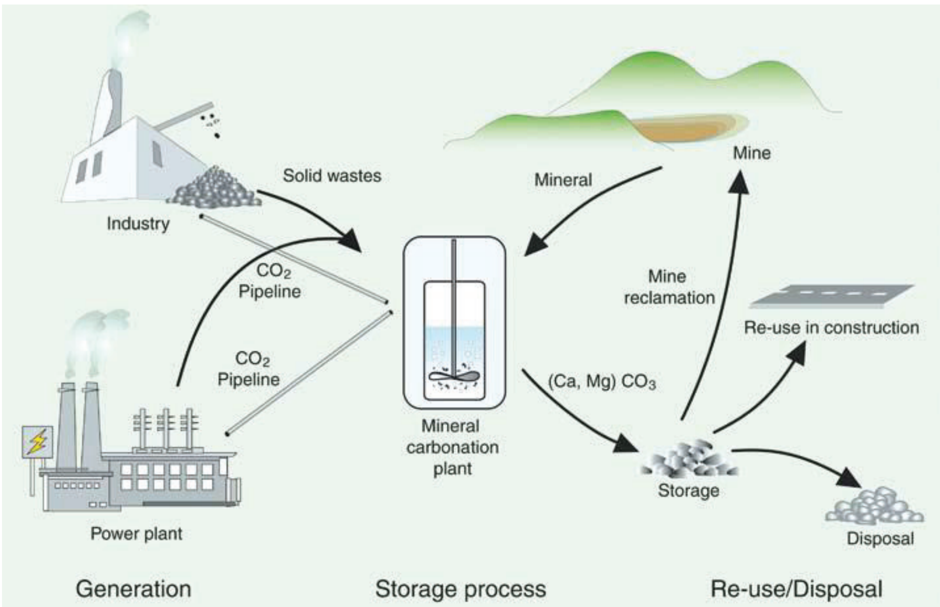

Figure 29 Mineral carbonation[150]

[149]source: IPCC (2005)

Natural minerals as well as industrial wastes can be used for the carbonation. As mentioned before olivine (Mg_2SiO_4), serpentine ($Mg_3SiO_5(OH)_4$) and wollastonite ($CaSiO_3$) are the best attractive minerals due to their reactivity and are found in large quantities. Olivine occurs mainly in the following stones: dunit, peridotite, basalt and gabbro. Serpentine is the main constituent of the serpentinites, a metamorphic rock. Wollastonite is not interesting in terms of CO_2 binding because of his low deposits. So the suitable rocks are mafic rocks (e.g. gabbro, basalt), ultramafic rocks (e.g. peridotite) and metamorphosed ultramafic rocks (e.g. serpentinite). Suitable industrial residues are ash, fly ash, slag, construction waste and colliery wastes. They represent a very interesting alternative in addition to the naturally occurring rocks. Compared to the rocks they have a lot of advantages. They are available in industrial areas, have often higher reactivity's compared to the rocks, industrial residue and CO_2 accumulate together for example in steel plants and the costs are lower. Slags from steel plants are qualified best for mineral carbonation, because of their high potential for CO_2 binding.[151]

Before the conversion the mineral oxides must be treated because they are relatively inert. The technical preparation consists in the mechanical crushing of minerals. At present the energy need for achieving a reasonable reaction rate reduces the efficiency of the method. The minerals used can be made more reactive by mechanical or thermal treatment. This requires an additional quite considerable energy expenditure.

Mineral type	MgO (wt%)	CaO (wt%)	R_C (kg/kg)	R_{CO2} (kg/kg)
Olive	57.3	0.0	6.5	1.6
Serpentine	40 – 48		8.4	2.3
Wollastonite	0 - 1	43 - 48	13.0	2.6
Talc	34.7	0.0	7.6	2.1
Basalt	6.2	9.4	26	7.1

R_C = mass ratio of rock needed for CO_2 fixation to carbon burned.

R_{CO2} = corresponding mass ratio of rock to CO_2

Table 4 Composition of various minerals and their carbonation characteristics[152]

The table above shows the corresponding mass ratios of rock to CO_2. That means: using olivine which has the highest concentration of magnesium, 1.6 tons of olivine is needed to fix one ton of CO_2., producing 2.6 tons of carbonated product to be handled. In serpentine the magnesium concentration is lower, and typically 2.3 to 3.6 tons of serpentines is needed to fix one ton of CO_2 resulting in 3.3 to 4.7 tons of solid material.[153]

A different viewing of the calculation above means that a mineral carbonation of CO_2 emissions from a 600 MWe coal fired power plant, approximately 4 Mt CO_2 per year, will result in a mining activity 6 to 8 times bigger than the coal mining activity needed for a power plant of the same size. Many Mg-silicate rocks contain iron. Large amounts of iron oxides are obtained when these materials are being mined for mineral carbonation. It has been suggested that magnesium carbonate and silica may find uses as soil enhancers, road fill, construction work or filler for mining operations. However, once mineral carbonation has grown to its full potential it will saturate any potential market for application of the

[150]source: Countesy IPCC CCS technical summary report

[151]see Huijgen (2007)

[152]see Huijgen (2007)

[153]see IPCC (2005)

products. Therefore, it is realistic to assume that the carbonation products could only be used for refilling the mining site.

For binding CO_2 in carbonates there are two main process routes, the direct route and the indirect route.[154] The simplest approach to mineral carbonation is the direct carbonation. The reactive component, e.g. serpentine or a Ca/Mg rich solid residue is carbonated in a single process step. If the process of mineral carbonation is divided into several steps it is classified as indirect carbonation. Indirect carbonation means that the reactive component (usually Mg or Ca) is first extracted from the feedstock (as oxide or hydroxide) in one step and then, in another step, it is reacted with carbon dioxide to form the desired carbonates.[155] The direct "single" step aqueous mineral carbonation-route is the most promising and the most developed CO_2 mineralisation process route to date.[156]

The application of the produced carbonates depends essentially on the chemical purity, particle size and on the rock specific parameters. Carbonates have in addition to the idea of binding CO_2 a wide usage. Magnesium carbonate is one of the most important raw materials for the refractory industry. But magnesium carbonate is not directly used for refractory products, instead magnesium oxide which is obtained from the carbonate by sintering. CO_2 is released by this process again. Magnesium carbonate is used also for filling and insulating material, in pharmaceuticals, in food additives, feedstuff additives and in agriculture. The usage options for calcium carbonates are much higher than for magnesium carbonates.

High carbonation ratios and acceptable reaction rates have been achieved in lab scale test rigs. However, despite more than twenty years of development work, the technology has yet to reach the pilot stage due to poor economic feasibility of the process to date. Nevertheless, the direct aqueous route will be used to assess the technical feasibility of mineral carbonation as an alternative use for CO_2 or as an alternative for geological storage of CO_2.

As a short summary the advantages and disadvantages for mineral carbonations are:

Advantages

1. large storage potential for CO_2
2. availability of the rocks
3. storage takes place on a geological time scale and is safe
4. extra value-added from by-products
5. industrial wastes can be reused
6. technological bases are extensively researched
7. The purity of the CO_2 plays essentially no role, depending on the application

Disadvantages

1. energy intensive production (mining, transport, preparation)
2. costs

[154] see Zevenhoven R. (2009)
[155] see Bodor M.
[156] see Sipilä J. (2008)

2.3.7 PHYSICAL USE

Enhanced Oil Recovery / Enhanced Gas Recovery (EOR/EGR)

The primary objective of this technique is to increase the recovery from existing oil or gas fields. When a reservoir pressure is depleted through primary and secondary production, carbon dioxide flooding can be an ideal tertiary recovery method. CO_2 flooding belongs to the miscibility modification processes of EOR methods. These processes enhance recovery by injecting fluids that are directly miscible with oil or generate miscibility in the reservoir. It is particularly effective in reservoirs deeper than 2,000 ft., where CO_2 will be in a supercritical state, with API oil gravity greater than 22-25° and remaining oil saturations greater than 20%.[157] Carbon dioxide flooding is affected by the reservoir characteristics. Water is injected into the reservoir until the pressure is restored to a desired level, then carbon dioxide is introduced into the reservoir through these same injection wells. As the CO_2 is forced into the reservoir a zone of miscible carbon dioxide and light hydrocarbons forms a front that is soluble with oil, making it easier to move toward production wells. A part of the dissolved CO_2 comes back to the surface and must be separated from the oil/gas – carbon dioxide mixture.

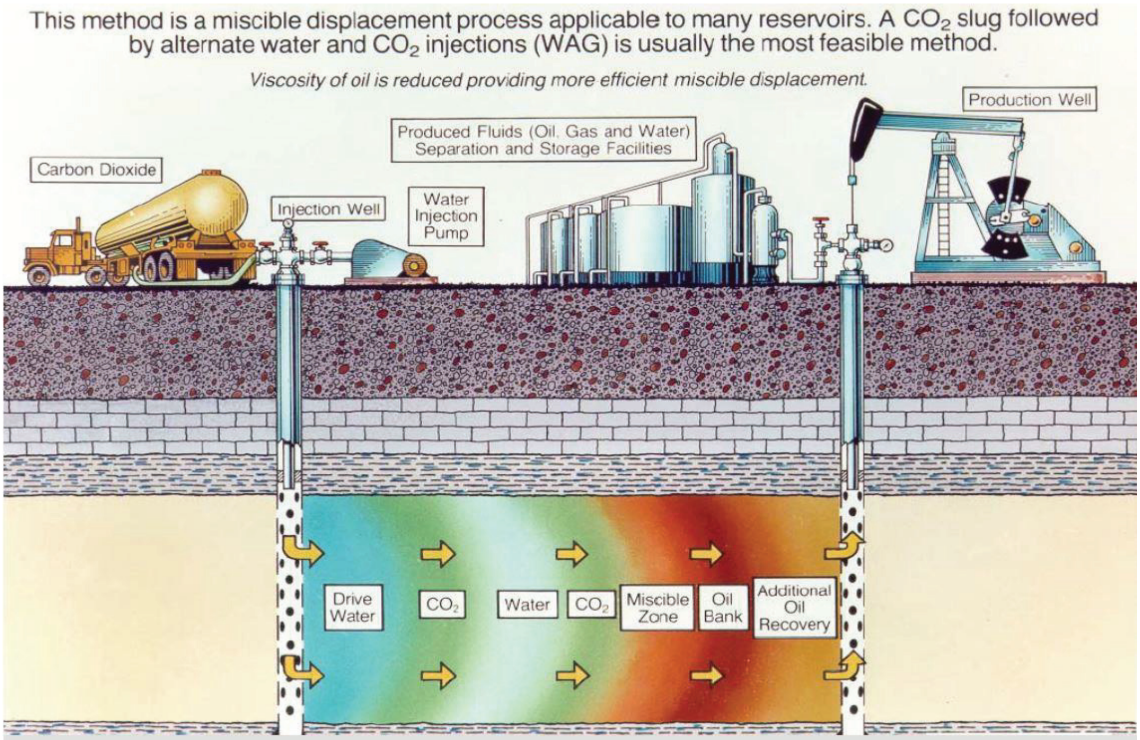

Figure 30 EOR CO_2 flooding[158]

By injecting CO_2 in oil fields up to 15% more oil can be gained, which can make the use of carbon dioxide economically attractive. Utilization of carbon dioxide as an EOR method has been practiced for many years. The method has reached a mature state of art.

[157] see http://en.wikipedia.org/wiki/Carbon_dioxide_flooding

[158] see Matthäi St. (2012)

So far, the focus of EOR/EGR is on maximizing of the amount of produced hydrocarbons. An evidence of a safe disposition of the CO_2 is missing in some projects. Currently it is not sufficiently cleared if the carbon dioxide comes up the surface and enters the atmosphere in the long term. Measurements and monitoring procedures have to clarify if a save enclosure can be guaranteed. This evidence and monitoring options are different for each individual project.

CO_2 flooding is the second most common tertiary recovery technique and is used around the world. The Weyburn Oil field in Canada is a famous example where this method is applied in financially interesting conditions. At the on-going second phase of the project 5,000 tons of carbon dioxide per day are transported over a 320 km long pipeline from a synthesis plant in Dakota (USA) to the oilfield Weyburn in Canada and is commercially used for enhanced oil recovery.[159]

Use in the beverage and food industry

The key requirement for applications in the beverage and food industry is the purity of the carbon dioxide. Special sensor systems were developed for the beverage industry to detect possible contaminations such as COS, H_2S or benzene.[160]

Cleaning agent and extractant

Long established is the extraction of hop with supercritical carbon dioxide to produce hop flavours. Also well-known is the decaffeination of coffee. Some materials can be obtained in a smaller scope by the extraction with carbon dioxide from vegetable raw materials, as for example corn oil from corn, wine flavours from wine or perfumes from different plants.[161]

Use as impregnating

The impregnation of wood, leather or textile fibers is the most common application.

Inert gas

The largest application is the usage of carbon dioxide for the storage of fruits and vegetables under controlled atmosphere conditions. This is the storage in oxygen depleted and carbon dioxide enriched atmosphere to slow respiration processes and thereby to increase the durability. Ripening, flavour conserving and preserving of important ingredients (e.g. vitamins) play a major role.

Carbon dioxide is used as add on to argon in plasma- or electric arc welding. Sometimes dry ice is used as a cooling medium. A widespread application of CO_2 is the use in extinguisher.[162]

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[159]see IEA GHG Weyburn
[160]see Duran C. et al. (2008)
[161]see Kuckshinrichs W. (2010), p. 95
[162]see Kuckshinrichs W. (2010), p. 96

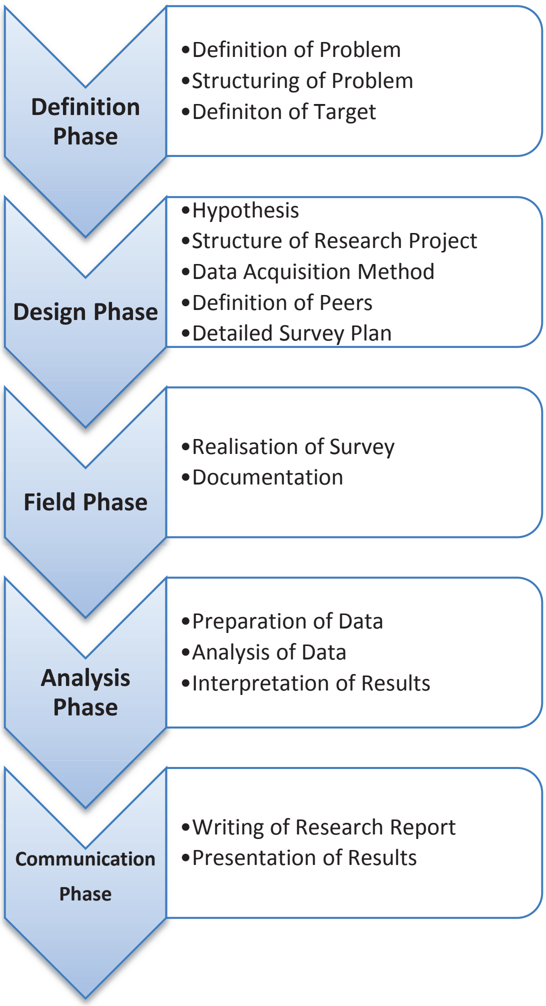
2.4 RESEARCH BY SURVEY

The task of the diploma thesis is to identify the most suitable CCU technologies for each Austrian industry using a utility analysis. A survey, an empirical method of research, is used to collect the necessary data to construct the utility analysis.

2.4.1 PHASES OF THE SURVEY

The realization of a survey can be structured ideally in five phases, whereby each phase has his specific tasks and process steps:

1. **Definition phase:** problem definition and structuring, setting the targets
2. **Design phase:** construction, survey method, -units, -plan, sample collection
3. **Field phase:** organization, execution and control of the data collection
4. **Analysis phase:** screening, evaluation, interpretation
5. **Communication phase:** report, presentation, implementation of the results



The flowchart (figure 31) demonstrates the detailed phase model of a survey within the scope of a market research.[163]

Figure 31 Phase model of a survey

[163] see Nieschlag/Dichtl/Hörschgen (1997), p. 685

2.4.2 DATA ACQUISITION

The collection of data is critical for the success of an empirical research. There are basically two different types or researches. The first one is the quantitative method. It usually involves collecting and converting data into numerical form so that statistical calculations can be made and conclusions drawn. The quantitative methods to acquire data are mainly restricted to interviews and questionnaires. The second form of research is the qualitative method. It is about recording, analysing and attempting to uncover the deeper meaning and significance of human behaviour and experience, including contradictory beliefs, behaviours and emotions. Researchers are interested in gaining a rich and complex understanding of people's experience and not in obtaining information which can be generalized to other larger groups. For the thesis in hand the survey method used is the quantitative type.

Furthermore, it must be distinguish between several basic forms of a survey:

- classification according to the target audience
  - expert survey
  - merchant survey
  - consumer survey
- classification according to the survey method
  - written survey
  - interview by phone
  - face to face interview
- classification according to the number of examination subjects
  - one topic survey
  - more topics survey[164]

This study is a one topic expert survey. According to the survey method it is a combination of written and interview method, which is explained in detail on the next pages.

Interview

Interviews are a systematic oral way of talking and listening to people and are a way to collect data and gain knowledge from individuals through conversations.[165] They can be done either in a standardised form using a fixed questionnaire or in a form without fixed question formulations or sequences called non-standardised interviews. The last belongs to the qualitative data acquisition.[166]

Interviews are made face to face or by phone. The personal direct contact between interviewer and proband on the same place and at the same time has actually no time limit. It allows also giving some help to sophisticated questions, but the influence of the interviewer in the answers of the respondent could be too high. Other disadvantages are the higher costs and time effort of this method.

Telephone interviews are getting more and more popular due to the numerous pros. The influence of the interviewer is not as high as by interviews made face to face. One of the biggest advantages is that phone interviews are independent on time or place of candidates. It is a flexible method in terms of sequence of questioning, number of contacts and interruptions. Also it is a cost saving method. Moreover it is suitable to ask for delicate subjects.

[164] see Hüttner (1997), p. 67 et seqq.
[165] see Kvale (1996), p. 14
[166] see Stier (1999), p. 184 et seqq.

Nevertheless there are also some cons to consider. Interviews by phone have to be shorter and there is no possibility for visualisation of the topic.[167]

Questionnaire

The questionnaire is send either by post or by email to the target persons. Many pros and cons have to be considered when this survey method is used. The application of this method has some risks. The key date of the survey is not uniform, as hardly any influence can be exerted when the respondents fill out the questionnaire. In general the survey is carried out when there is most time for that, which can also be on weekends. The scope of the questionnaire must be less. The duration of an oral interview seems not so long as to fill out a long questionnaire. At least a long questionnaire seems daunting. The risk of misunderstanding, both in terms of the proper understanding of the issues and the importance of the answer is greater than in a verbal or telephone conversation. Also some certain complex information's are very difficult to determine. It is also impossible to explain questions or to advise the receiver orally. So experience has shown that the response rate is in general relatively low. Therefore, there is a series of arrangements for improving the return rate, which were also partially used for this study:

- announcing of the questionnaire
- questionnaire has to be optical perfect
- repeat the sending of the questionnaire with a polite reminder

Before sending a questionnaire, one question has always to be clarified: "Which use has the proband by filling and sending back the questionnaire?" When this can be answered and communicated to the responders, an above-average return rate can be achieved.[168]

However, there are also many advantages to perform a questionnaire. The fact that there is enough time to think about a question can be in certain cases conductive to the purpose of the survey. Difficult reachable target groups (e.g. shift worker) can also be detected and they have the possibility to answer the questionnaire whenever they are mood and without time pressure, which can have positive impact on the quality of answers. If the respondents are geographically distributed over large areas, this tool can save a lot of money compared to the oral method. Also the number of respondents can be very large in contrast to oral surveys.[169,170]

[167]see Scheffler (2000), p. 70
[168]see Kamenz (1997), p. 83 et seq.
[169]see Wilk (1975), p. 187 et seqq.
[170]see Hüttner (1997), p. 70 et seq.

Comparison of Survey Methods

Questionnaires demand answers in a written form while interviews can be done orally (face to face) or by phone. The table below demonstrates the general difference of the methods.

	written survey	interview by phone	face to face interview
response rate	-	+	+
uniform survey date	-	+	+
measuring the response time	-	+	~
influence of not involved persons	-	O	+
extent of the questionnaire	-	-	+
risk of misunderstandings	-	+	+
complex information	-	-	+
influential of the interviewer	+	O	-
difficult reachable target groups	+	O	-
spatial representation	+	+	-
costs	+	+	-
Denotation: + Advantage, - Disadvantage, O Indifference			

Table 5 Comparison of survey methods[171]

For this study the survey method is a combination of phone and written form. Basically a online questionnaire is used to get the necessary data for the thesis, but to get a better fly-back rate phone calls are also made.

[171]see Hüttner (1997), p. 77

2.4.3 THE DESIGN OF THE QUESTIONS

Questions play in any form a very important role in all survey methods. Therefore the formulation is crucial for a better understanding of the questions and getting valid answers. The better the question, the better the results. Therefore it is important to consider the problems of the formulation of questions (type of questions, choice of words) as well as problems of the construction of a survey.

Types of Questions

Questions can be divided by type of information the answers will give, if they are open or closed and if they are direct or indirect.[172]

Categorisation by Type of Information

1. **Attitude or Opinion Questions:** The first question type refers to the evaluation or desirability of an issue. The respondent has to agree or disagree with the statement in the question. It can be answered by yes or no as well as by a rating scale
2. **Conviction Questions:** Conviction Questions have the goal to identify if the given statement is true/untrue or right/false in the view of the respondent. Such a question relates to facts, which could have really right or false answers, but also to those that can only be subjectively classified as right or wrong.
3. **Behaviour Questions**: The next question type is used to know the actual or intended behaviour of the respondent in the past, present or future. Behaviour questions can be answered with yes/no or by a rating scale.
4. **Characteristic Questions:** This type involves the characteristics of a person like age, sex, education, profession, confession and more. Characteristic questions are usually routinely collected, but are also often used to detect correlations between the characteristics and attitudes, convictions and behaviours.[173]

Open-ended and closed-ended Questions

Closed format questions are questions that include multiple choices but also yes or no and scale answers. In contrast open format questions give the audience an opportunity to express their opinions in their own words. Open-ended or free-response questions are not followed by any choices and the respondent must answer by supplying a response, usually by entering a number, a word, or a short text.

If the line of thought should not be fixed open questions are used, but open-ended questions have certain disadvantages. A big problem is that open questions only can be coded after the survey has been conducted and are thus time-consuming. Also open question often yields unusable information due to the fact that the respondent does not understand the question.[174]

Closed-ended questions are more advantageous than open ones. The respondent is restricted to a finite set of responses, so they are easy and quick to answer. They have response categories that are easy to code. The format enables the respondent to answer more questions in the same time required to answer fewer open-ended questions. Also the acquisition and analysis phase is easier to handle with closed-ended questions. The main disadvantage with closed questions are that they can introduce bias, doesn't allow creativity or to develop ideas for the respondent. It is recommendable to combine them with an open question to

[172]see Stier (1999), p. 172 et seqq.
[173]see Stier (1999), p. 173 et seqq.
[174]see Eiselen/Uys (2005), p. 6

give the opportunity to express answers in own words as well as a pre-test can be very helpful to ensure understanding.[175]

Direct and indirect questions

A direct question addresses the proband personally. "What do you think about..." is a way to get to know the personal opinion. An indirect question addresses the proband with a detour, for instance by a short story, in which different opinions were asked to one problem and the proband has to choose the best opinion in his view. Indirect questions are used because they are more likely to be answered and also the range of opinions is higher. The disadvantage is that they do not guarantee an answer expressing the personal thoughts.[176]

Data and Scale Level of Answers

Stanley Smith Stevens proposed that measurements can be classified into four different types of scales: nominal, ordinal, interval and ratio, unifying both qualitative and quantitative.

Nominal Scale

The nominal scale is only able to compare different objects without offering the possibility to rank them. The answer values to these questions are only "true" or "false", further interpretations are not possible.[177]

Example: Which coffee do you know? ○ Tchibo ○ Jacobs ○ Dallmayr

Ordinal Scale

With the ordinal scale it is possible to rank the values. It puts the data on an ordinal scale, but is not classified as metrically because the relative size or degree of difference between the items cannot be measured. The most common example are school notes. A 5 is worse than a 4, a 4 is worse than a 3 and so on.[178]

Another example: Are you drinking coffee gladly or reluctantly?

○ very gladly ○ gladly ○ nor ○ reluctantly ○ very reluctantly

Interval Scale

Additionally to the ordinal scale the values can be considered as metric by the use of an interval scale. The advantage is the applicability of nearly all statistical methods in the analysis. On the other hand the equidistant values have no natural zero, which restricts the range of calculations.[179]

Example: How gladly are you drinking coffee?

very reluctantly very gladly

○ 1--- --- ○ 2 --- --- ○ 3 --- --- ○ 4 --- --- ○ 5

[175] see Stier (1999), p. 175 et seqq.
[176] see Stier (1999), p. 177 et seqq.
[177] see Kamenz (1997), p. 167
[178] see Kamenz (1997), p. 167
[179] see Kamenz (1997), p. 168

Ratio Scale

A ratio scale is an interval scale with a true zero point. Length and size indication are typical examples.[180]

Example: How old are you? ____ Years

Guidelines for writing questions

One of the most decisive factors for the success of the survey is the wording and sentence construction of a question. Some rules for an attractive questionnaire are followed below:

- Keep the vocabulary simple ("keep it as simple as possible")
- Keep the question short (Generally, it is recommended to hold questions to 25 words or less)
- Avoid double-barrelled questions (questions that ask for two things and therefore require two answers)
- Avoid hypothetical questions (Hypothetical questions such as "Would you use this resource in your class if it is available?" are not good for the prediction of behaviour)
- Don't overtax the respondent's memory (it is risky to ask the respondent to recall past behaviour over a long retrospective period)
- Avoid double negatives
- Avoid overlapping response categories
- Beware of leading questions (questions phrased in such a way that it seems to the respondent that a particular answer is expected)[181]

Summarized this chapter explains the survey methodology, it gives a brief introduction into the phases of a survey, the data acquisition methods, the different types of questions, the scale level answers and the guidelines for attractive questions. Based on this theory the survey plan is developed and realized as described in the following chapters.

[180]se Kamenz (1997), p. 168

[181]see Siniscalco/Auriat (2005), p. 35 et seqq.

2.5 UTILITY ANALYSIS

To make decisions gets more and more difficult and complex. The number to come into consideration of future opportunities, products, methods, etc. is becoming increasingly diverse. Evaluations are getting an increasing scope and need to be made at ever shorter intervals, whereas following trends in technology, science and business are observed:

- the speed of technological development is on the increase
- in addition to technical or business aspects also more and more sociological and often psychological areas must be considered
- for a decision evermore options are available

Because of these trends the decision-making process in the industrial sector is also becoming increasingly difficult. As the practice shows, there are usually several criteria's, often a whole bunch of very heterogeneous facts like e.g. economy, development time, development cost, quality, reliability, technical feasibility, etc., which has to be observed, analysed and must be assessed, in order to allow to select one of the alternative.

Sometimes decisions are made simply intuitive, despite the obvious disadvantages. The negative impact of such a decision can be largely eliminated with the help of formal methods. One of these methods is the so called use value analysis.[182]

The utility analysis is a non-monetary valuation method from the field of accounting. With their help, non-monetary subgoals are made comparable in order to make such a choice between several alternatives.

2.5.1 PROCEDURE

The utility analysis can be used as a guide for all multi-objective decisions. It is performed according to one flowchart:

- determine upper and lower goals and organize them into a hierarchy of objectives
- derive criteria's that emerge from these objectives
- define the desired criteria's
- weighting of the desired criteria's (How important is this criterion to achieve the overall objective?)
- score evaluation (e.g. 1 is bad, 10 is very good) of the alternatives for the respective criteria
- relative weighting of the criteria multiplied by the point evaluation of the alternatives
- the sum of all multiplications of alternatives give the final result
- the alternative with the most points is the best solution

For an even clearer explanation a simple example is illustrated on the next page.

[182] see Rinza/Schmitz (1977) p. 1

2.5.2 EXAMPLE

A simple example for a utility analysis is shown in the table below. Here is the overall goal buying a passenger vehicle, broken down into five categories that describes this overall goal as completely as possible and covers the wishes and demands of the purchaser:

- a good driving property,
- much comfort,
- a high degree of safety,
- good equipment and
- low maintenance and repair costs.

These goals are listed in the rows of the table. The weight of the column A of the table expresses the importance of the objective of the overall goal for the buyer. All cars (car 1, 2 or 3) which are taken into account meet the individual goals more or less. Depending on how good or bad the goals are met by the alternative, the higher or lower the degree of fulfilment (DOF, column B in the table). The products of weight and level of fulfilment gives the shares of the possibility of this decision (hereinafter referred to as alternative) on the total value of use/benefit (column C in the table).[183] The first car in this example shows the highest value of benefit (utility) with 3,81 and would be therefore the favourite vehicle to buy.

			Car 1		Car 2		Car 3	
		A	B	C	B	C	B	C
	goals	**weight**	**DOF**	**benefit**	**DOF**	**benefit**	**DOF**	**benefit**
buying a car	driving property	27	3,7	0,99	3,15	0,85	4,11	1,11
	comfort	20	3,95	0,79	3,65	0,73	3,60	0,72
	safety	33	4,42	1,46	2,58	0,85	3,27	1,08
	equipment	7	1,71	0,12	1,71	0,12	3,29	0,23
	maintenance	13	3,46	0,45	3,62	0,47	1,92	0,25
	value of benefit	100 %		3,81		3,02		3,39

Table 6 Simple example of a utility analysis[184]

[183] see Rinza/Schmitz (1977), p. 1 et seqq.

[184] see Rinza/Schmitz (1977), p. 2

3 REALISATION OF SURVEY

3.1 STRUCTURING OF PROBLEM

The task of the study is to compare the Carbon Capture and Utilization technologies for the use in an Austrian industry sector. To achieve the task, a survey was planned and conducted.

Based on the literature research, especially of the CCU methods, a survey was constructed. The main goals of the survey or questions to answer are:

- to get information how the Austrian industry handles the emission trading act
- which risks and opportunities they see in this act
- how many CO_2 emissions they have in the company
- what are they doing with the CO_2 emissions
- what level of knowledge they have in terms of CCU technologies
- are they interested and would they invest in CCU technologies
- what general conditions can they offer for a possible realization of such a method

It is attempted to get reasonable results from the survey, because they are in turn the input data for a utility analysis and with this systematic process the most suitable CCU technology for an Austrian industry sector should be detected.

The questionnaire is conducted in German language because the survey is limited to Austria and also many smaller companies are among the respondents.

The main target is an excellent flyback rate, which is only realizable by previous promotion and persistent reminding activities.

3.1.1 REQUIRED DEFINITIONS

The questionnaire is in principle anonymous. The choice is left to the participants to give their personal data, but to get as an end result a utility analysis that shows the most suitable CCU technology for an Austrian industry, one question must be answered of the participants. It is obligatory to know in which industry sector the participant works.

3.1.2 STRUCTURE OF THE CONTENTS

The questionnaire is divided in three main parts:

- general information,
- emission trading scheme,
- and CO_2 emissions.

The general information part should gain some facts about the company. It's interesting to know their environment policy. Participants also can fill their personal data if they want to get the results of the questionnaire back. The only obligatory question of the questionnaire is also included in this part of the survey. For the construction of the utility analysis it is crucial to know the industry sector of the respondents.

The emission trading scheme sector should investigate their feeling about the emission trading act. The effects of the law should be detected, which maybe indicate a need for action.

The section CO_2 emissions should capture CO_2 data in their company. It is good to know how many emissions they have and what are they doing with the carbon dioxide. This part should also find out if they are interested in capturing carbon dioxide or maybe they have already a CO_2 capture. Questions in this chapter about the carbon capture utilization technologies should complete the data acquisition. It is the most important part for the survey. The utility analysis later is based on the answers of this section. The target is to get the evaluation criterion on such CCU methods from the industrial side. What is a crucial factor for the industry on such technologies and what is not so important is the question that has to be answered.

3.1.3 HYPOTHESIS

In Austria there are a few very large CO_2 polluters and many small companies with small amounts of CO_2 emissions. Therefore CO_2 capture and utilization is not as interesting for small companies as for big ones. They also have not the financial possibilities and conditions for investing in a CCU method.

In Austria there is no handful of companies which already do CO_2 capturing and in general the experience about this theme is at the beginning.

3.2 SURVEY METHODOLOGY

3.2.1 APPLIED DATA ACQUISITION METHODS

For the data collection of this study an online questionnaire was made and the link was send via email. The criterion was the simplicity, time and costs. To offer the participants the possibility to answer the questions in a written form a PDF file of the questionnaire was also attached to the email. So they had the choice to print the questionnaire and send it back via fax, email or postal.

The online questionnaire was made with the software EFS Survey from Unipark. Unipark is the university program of QuestBack, which develops since 1999 software for online surveys and online researches. The use of the program was not for free. After a learning period of the program and a stepwise construction phase the survey could be answered online in the internet. Therefore the link to the created homepage was integrated in the cover letter/email: http://ww2.unipark.de/uc/theodoridou_MUL/2454 A simple click on the link opens the welcome page of the survey. To read the full survey it is attached in the appendix (D).

Since the questionnaire is rather extensive and asks partially confidential data, the survey is at risk to fail due a very small numbers of answers, which would not allow meaningful interpretations. So it is decided to remind the target persons, to increase the flyback rate.

3.3 QUESTIONNAIRE DESIGN

The questionnaire and the cover letter are developed with great care since they are essential for the success of the study. Both are attached in the appendix (see appendix C and D).

3.3.1 COVER LETTER

The cover letter was send via email. Every contact person was addressed personally in the cover letter. It involves a short preface about the topic with the link to the questionnaire, because not all of the companies were previously contacted by phone.

To ensure the credibility of the study, the email was send from the account of the academic advisor DI Vassiliki Theodoridou.

3.3.2 QUESTIONNAIRE

The questionnaire was discussed several times and developed step by step. Due to the significance of the questionnaire, the formulations are revised several times and scientific staffs from the department were asked for their support.

The questionnaire starts with an introduction side for people which are previously not reached by phone. This side should perform the task to introduce the questioner, to explain the objectives and the procedure of the study, to create motivation and credibility, to offer incentives and to ensure confidentially.

Basically the question method used is mainly closed-ended to keep the duration to fill the questionnaire as short as possible. Because of the uncertainty of the level of knowledge from the people about CCU technologies, thus should facilitates the filling.

There are also some open-ended questions included, but they are only to give the respondent the possibility to comment some special questions.

3.3.3 PRE-TEST

The pre-test should check various conditions for a reasonable questionnaire, which may not be considered by the developer. For this purpose about 5 scientific staffs from the department of economic and business management of Leoben were asked to make a pre-test. They should look for special things like:

- How long does it take to answer the questionnaire?
- Do you understand the words, terms or concept?
- Is the sentence structure too complex?
- Is there more than one possibility to interpret the questions?
- Do your response categories correspond to the offered ones?
- Are the questions attractive for you?
- Does the questionnaire have a logical flow?
- Are some questions redundant?
- Are some questions missing?
- Are the instructions correct and to a suitable extent?

All test persons improved the quality of the questionnaire significantly. The modification based on the comments of the tester concern layout as well content and results in a far more attractive questionnaire.

3.4 FIELD PHASE

Every facility which falls under the definition of the directive 2003/87/EG from the European parliament needs a permission to emit greenhouse gases and receives an allocation of emissions permit.[185] The allocation for the period 2005 to 2007 was done by the first national allocation plan. Based on the second national allocation plan for the trading period 2008 till 2012 all relevant facilities for this study were detected (see Appendix A). The associated operators of the facilities were determined and for the corresponding contact person was searched. In larger companies more than one person was contacted for the survey.

The table below shows the national allocated CO_2 emissions in tonnes per year according to the industries for the year 2012 in Austria. (a more detailed list can be found in the appendix B including all plants in the allocation plan compared to all plants which received the survey) For the results it was necessary to achieve high return rates of the survey in the electricity-, steel-, cement-, paper- and chemical industry. These are the major polluters in Austria. Unfortunately this has not been achieved in the petroleum industry, which still has a large share of CO_2 emissions in Austria. Also it can be seen that the other industries have only a small share on the carbon dioxide emissions. So the lumber- and engineering and automotive industry was completely ignored for the survey because the small amount of emissions doesn't make a sense for a CCU method.

I. Energy	10.977.430	36,38%
electricity industry	8.209.127	27,21%
petroleum industry	2.768.303	9,17%
II. Industy	19.196.320	63,62%
steel industry	10.611.386	35,17%
cement industry	2.774.025	9,19%
paper industry	2.267.430	7,51%
chemical industry	852.432	2,83%
chalk industry	892.741	2,96%
refractory industry	509.576	1,69%
brick making industry	369.495	1,22%
food industry	385.849	1,28%
glass industry	211.580	0,70%
lumber industry	234.184	0,78%
engineering- and automotive industry	87.622	0,29%
Sum	30.173.750	100,00%

Table 7 National allocated CO_2 emissions according to the industries[186]

[185] Federal Ministry of Agriculture and Forestry, Environment and Water (2007), p. 7

[186] Ministry of Life (2007)

The table above illustrated in a diagram below.

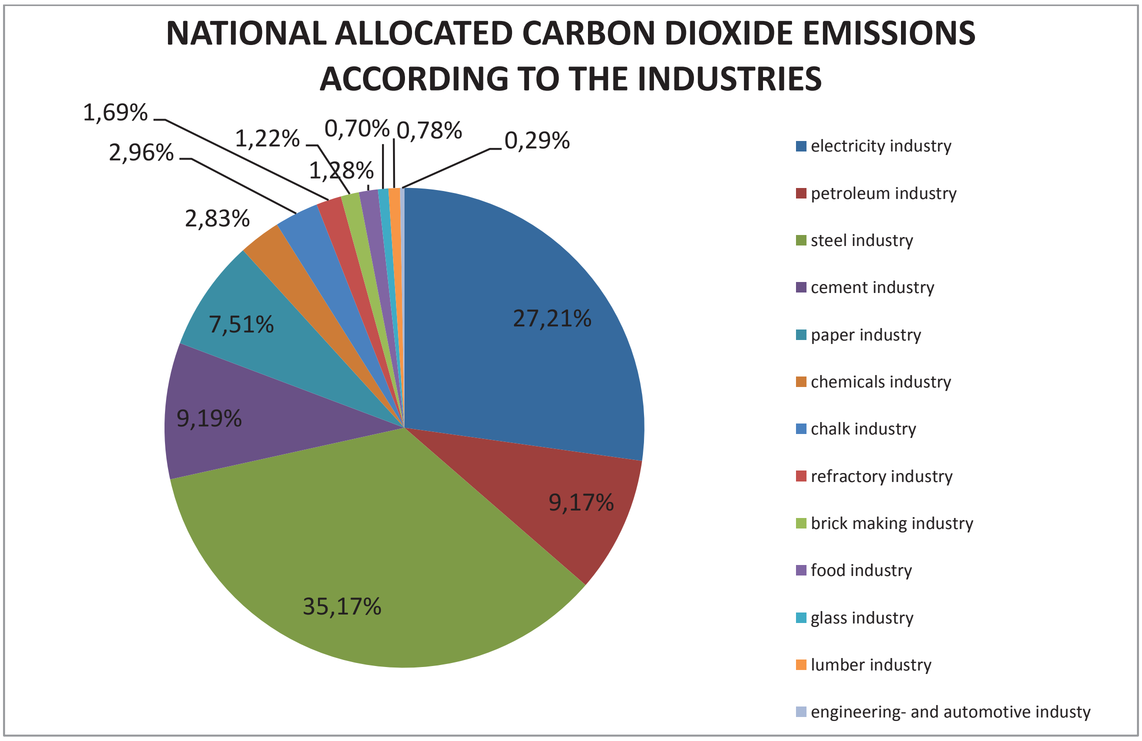


Figure 32 National allocated CO_2 emissions according to the industries

Finally 49 companies and 59 persons were contacted. These 49 companies cover 92 % of the total allocated certificates of Austria in the year 2012 (about 30 Mio. t CO_2) which makes a reasonable study possible. A list of the persons or companies, which were contacted or participated the survey, can't be found in this thesis, because the survey was declared as anonymous.

The response rate of the first two weeks was respectable. After stagnancy was recognisable, a recollection email was sent to all companies that have not responded. Also some recalls were made. Finally 23 replies were counted.

3.5 ANALYSIS PHASE

All, with the exception of one participant, filled out the survey online. The exception sent the answered survey back via email. To have all data digital, the only one was digitized by myself. The EFS survey software allowed an export of all collected data to Microsoft Excel, so the analysis and evaluation was made with Excel. To be able interpreting the results meaningfully, certain supplementary methods are applied.

Most of the survey questions have been created in a way to show and interpret the results of the individual questions simple with diagrams. For the analysis it is crucial to know in which industry sector the respondent works, because for every industry sector a utility analysis have to be made. This is the only question that needs to be filled of the questionnaire, all others are voluntarily.

The main target of the whole survey is to detect the evaluation criteria's on CCU technologies from the industrial side. So the last section of the questionnaire includes general questions about CCU methods and also questions about possible evaluation criteria's based on the literature. To get the priority of the evaluation criteria's for CCU technologies the last question of the questionnaire is a table where the respondents have to decide their priority of different criteria's. Based on the results of the table a utility analysis was constructed for each industry sector.

4 INTERPRETATION OF RESULTS

In the following chapters a summary of the results of the survey is presented, analysed and interpreted.

4.1 MATHEMATICAL FUNDAMENTALS

For evaluation of the collected data from the survey some mathematical calculations were required. The used calculations are demonstrated by their formulas.

Arithmetic Mean

The arithmetic mean is the central tendency of a collection of numbers taken as the sum of the numbers divided by the size of the collection.[187]

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$\bar{x}$ arithmetic mean

n number of values

i index of value

x value

Standard Deviation

The standard deviation is a measure of the dispersion of a set of data from its mean. The more spread apart the data, the higher the deviation.

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

σ standard deviation

$\bar{x}$ arithmetic mean

n number of values

i index of value

x value

[187] see http://en.wikipedia.org/wiki/Arithmetic_mean

4.2 STATISTICS

The statistics covers the chapter response rate, duration of answering and then it is composed in the sequence of the questionnaire: General Information, Emissions Trading Scheme and CO_2 Emissions with the focus on CCU Technologies. For the evaluation of flyback rate, duration of answering and the first two sections of the survey all answered questionnaires were used, because the chapters detect only general data. A separate evaluation for all industry sectors was made for the last sequence CO_2 emissions with the focus on CCU Technologies.

4.2.1 RESPONSE RATE

The survey was limited to the Austrian Industry. 49 companies were contacted for the study, which covers 92 % of the total allocated certificates from Austria in the year 2012. Because of the desired anonymity from the companies, the names of them are not listed. But the diagram below shows the number of replies for each industry sector. So totally 49 companies received the questionnaire and 23 filled out the form which corresponds to a flyback rate of 47 %, which is quite respectable. It is seen that for some industries no reply was received. Therefore, for these industries no evaluation was made. Compared to the table 7 (chapter field phase) it can be seen that the poor response rate is only at the "small industries" (industries with a small share of the total emissions in Austria). The poor flyback rates of these less important industries in terms of emissions are therefore to bear. All major polluters, except the petroleum industry, achieved a quite good response rate.

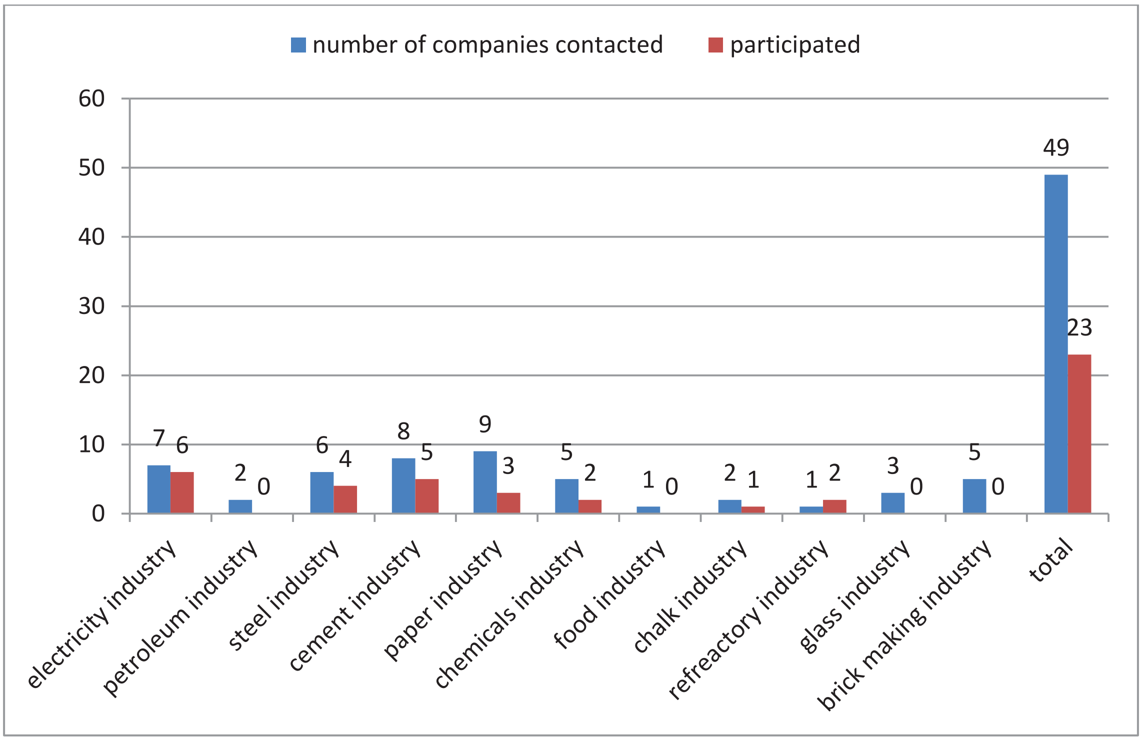


Figure 33 Flyback distribution

4.2.2 DURATION OF ANSWERING

The EFS Survey software, which is a program to construct online surveys, also detects the duration of answering from the participants. One respondent did not make the questionnaire online, so he is not considered in this evaluation. The slowest person needed more than 47 minutes to answer the survey, the fastest needed only about 7 minutes. The average took a little bit more than 19 minutes to fill out the form, which is 4 minutes longer than foretold.

Maximum	47,32	min
Minimum	6,50	min
Mean value	19,21	min
Standard Deviation	11,51	min

Table 8 Duration of answering

4.2.3 GENERAL INFORMATION

General information is called the first section of the questionnaire. It includes the question in which industry the interviewee works. The results of this question have already been shown in the chapter response rate. An addition result of the questions in this sequence is that each of the 23 respondents wants to get the results of the questionnaire back. So every person filled out his email address and personal data. Also every participant evaluates the environmental policy of his company as proactively.

4.2.4 EMISSIONS TRADING SCHEME

This chapter discusses the results of the next section of the survey, the emissions trading scheme. The following table includes specific questions to the emissions trading act. It is clearly apparent that the outlook into the future to achieve the EU targets for 2020 and 2050 is rather negative. Since the introduction of the emission trading scheme most companies have done some arrangements to reduce their emissions. Only one company has done nothing.

<table>
<tr><td colspan="4">Do you believe that your industry can achieve the EU climate protection goals 2020?</td></tr>
<tr><td>Choice</td><td colspan="2">YES</td><td>NO</td></tr>
<tr><td>Scale</td><td colspan="2">1</td><td>2</td></tr>
<tr><td>Mean</td><td>1,65</td><td>Standard Deviation</td><td>0,48</td></tr>
<tr><td colspan="4">As it appears today, do you believe that the long term EU climate protection goals 2050 are realistic for your industry?</td></tr>
<tr><td>Choice</td><td colspan="2">YES</td><td>NO</td></tr>
<tr><td>Scale</td><td colspan="2">1</td><td>2</td></tr>
<tr><td>Mean</td><td>1,78</td><td>Standard Deviation</td><td>0,41</td></tr>
<tr><td colspan="4">Do you have done arrangements for reduction in emissions since the introduction of emissions trading act?</td></tr>
<tr><td>Choice</td><td colspan="2">YES</td><td>NO</td></tr>
<tr><td>Scale</td><td colspan="2"></td><td>2</td></tr>
<tr><td>Mean</td><td>1,04</td><td>Standard Deviation</td><td>0,20</td></tr>
</table>

Table 9 Questions about EU climate protection goals

Next question asks about the effort of emissions in terms of recording, monitoring and reporting. Table 10 shows a very clear result. Most of the respondents tend to a high effort. For small companies this could be an existential problem. They don't have the money, time and staff for recording all emissions data in their companies.

How would you rate the effort for recording, monitoring and reporting the emissions?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	4,17		Standard Deviation	0,76	

Table 10 Question about the effort of the emissions

Table below demonstrates the results about the topic CO_2 management. Most of the participants think that CO_2 management is important. The introduction of the emissions trading act had for each firm an impact, and this consequence is evaluated rather high.

How important do you think is CO_2 management for your industry?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	4,43		Standard Deviation	0,77	
Did the introduction of the emissions trading act have an actual impact on the CO_2 management of your industry/company?					
Choice	YES		NO		
Scale	1		2		
Mean	1,00		Standard Deviation	0,00	
How would you rate the impact?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	3,74		Standard Deviation	0,90	

Table 11 Questions about CO_2 management

A very important question is how good the future certificate prices can be estimated. In circumstances this causes very large financial impacts for the companies and it seems from the results that it is not so easy to estimate the future price of a carbon dioxide certificate.

How good can be the future certificate prices estimated in your opinion?					
Choice	very difficult	difficult	moderate	easy	very easy
Scale	1	2	3	4	5
Mean	1,70		Standard Deviation	0,75	

Table 12 Question about the future certificate price

The legal framework conditions and promotions for CO_2 utilization are for most of the respondents poor or lacking. Table 13 compares the mean values of the answers.

Are the legal frameworks sufficient for CO_2 utilization?			
Choice	YES	NO	
Scale	1	2	
Mean	1,65	Standard Deviation	0,56

How would you rate the related promotion activities for CO_2 utilization?					
Choice	very bad	bad	moderate	well	very well
Scale	1	2	3	4	5
Mean	1,91	Standard Deviation	1,10		

Table 13 Questions about CO_2 utilization

4.2.5 CO_2 EMISSIONS

The third and last part of the survey, called CO_2 emissions, begins with specific questions about the plants of the companies itself. This data were detected just out of curiosity and have actually no relevance for the thesis target. Therefore in this chapter not all results of the third part are discussed.

The questions of the survey were designed so that no answer was also possible. For whatever reason not everyone has answered all questions. The following results have been accordingly adjusted to that.

From the 23 answered questionnaires 5 companies have already a CO_2 capture. The other eighteen companies have no one and also do not plan a carbon dioxide capture. Companies, who are already using a CO_2 capture, are already satisfied with their CO_2 capture, except one company made bad experiences. The resulting mean values of these questions are illustrated in the following table.

Does your company use a CO_2 capture?			
Choice	YES		NO
Scale	1		2
Mean	1,78	Standard Deviation	0,41

Do you plan a CO_2 capture?			
Choice	YES		NO
Scale	1		
Mean	2,00	Standard Deviation	0,00

How would you describe the experience with your CO_2 capture facility?					
Choice	very bad	bad	moderate	good	very good
Scale	1	2	3	4	5
Mean	3,80		Standard Deviation	0,98	

Table 14 Questions about CO_2 Capture

Most of the respondents know that also carbon dioxide utilization is possible without CO_2 capture, seen on the next results in the table. Also interesting is that the industry is interested in CO_2 capture and utilization though no company plans in the near future a CO_2 capture.

Do you know that CO_2 utilization is possible without CO_2 capture?			
Choice	YES		NO
Scale	1		2
Mean	1,26	Standard Deviation	0,44

Are you only interested in CO_2 capture, or do you also consider CO_2 utilization?			
Choice	CAPTURE	CAPTURE AND UTILIZATION	UTILIZATION
Scale	1	2	3
Mean	2,27	Standard Deviation	0,54

Table 15 Questions about Capture and Utilization

For companies that eventually plan a CCU method someday, the next result could be of great importance. Thirteen answered the following question with yes, nine with no, and one respondent selected the possible answer “not applicable”.

Would you deliver your captured CO_2 another company which recycles the CO_2 for free?			
Choice	YES		NO
Scale	1		2
Mean	1,41	Standard Deviation	0,49

Table 16 Question about delivering CO_2 for free

With few exceptions the most companies in Austria are satisfied with a cost covering CCU method. In contrast the willing for investing could be better. As it is seen below, it tends between low and moderate.

Which monetary expectations does your company have in terms of CO_2 utilization?					
Choice	INDIFFERENT		ECONOMICALLY VIABLE		GENERATE PROFIT
Scale	1		2		3
Mean	2,18		Standard Deviation		0,49
How high would be the willingness of investing to compensate the CO_2 costs?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	2,55		Standard Deviation		0,89

Table 17 Questions about the monetary expectations and willingness of investing

Very interesting is the result of the following question. About 60 percent of the respondents do not have a problem to manufacture new products from other industries with a carbon capture and utilization method.

Are you willing to manufacture products from other industries with a CO_2 utilization method?			
Choice	YES		NO
Scale	1		2
Mean	1,38	Standard Deviation	0,49

Table 18 Question about willingness to manufacture products from other industries

In the survey also questions about the importance of the stage of development from new methods are integrated. It is important to know the view from the industrial side in terms of new technologies. Are they interested, would they invest in new technologies and how important is the state of art of new methods for the companies are questions that are answered below. Most clearly visible is the high influence of the stage of development of a technology in finding an investment decision.

Is your company in principle interested in technologies which are in the stage of development?					
Choice		YES		NO	
Scale		1		2	
Mean	1,14		Standard Deviation		0,34
Is your company willing to invest in such technologies?					
Choice		YES		NO	
Scale		1		2	
Mean	1,40		Standard Deviation		0,49
How heavily influences the state of art of a technology your investment decision?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	4,22		Standard Deviation		0,72

Table 19 Questions about stage of development

For some CCU methods the availability of enough space is crucial (e.g. a biological conversion method requires a lot of area). Unfortunately the most companies have only limited space, which limits the possible methods significantly. Eight of the twenty-three answered that they have enough space, whereby thirteen said they have only limited space available and two companies have no area for a possible carbon dioxide utilization method. By asking this question it was assumed that the interviewee has a basic imagination of the required space of such CCU methods.

Would there be enough space at your location for additional production/CO_2 utilization?					
Choice	YES		LIMITED		NO
Scale	1		2		3
Mean	1,74		Standard Deviation		0,61
How important is the required area for a CO_2 method in your decision?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	3,30		Standard Deviation		0,91

Table 20 Questions about available space for CCU facilities

The last questions of the survey are handling about the significance of certain criteria's for carbon dioxide methods.

For methanation it is crucial to have access to renewable energy sources. The result of this question is well balanced. A little more than half could permit power supply by renewable energy sources.

How would the operating costs influence your decision?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3		5
Mean	3,96		Standard Deviation	0,91	
How would the energy consumption influence your decision?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3		5
Mean	4,00		Standard Deviation	0,83	
Is an energy supply of the CO_2 utilization method possible with renewable energy?					
Choice		YES		NO	
Scale		1		2	
Mean	1,55		Standard Deviation	0,50	
Would be recycling of industrial wastes, such as ash, slag, construction and mining wastes, interesting for your company?					
Choice		YES		NO	
Scale		1		2	
Mean	1,41		Standard Deviation	0,49	
How does the long term availability of the input materials for CO_2 methods influences your technology decision?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	3,43		Standard Deviation	1,26	
How important is the fixation duration of CO_2 in the end product for you?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	3,62		Standard Deviation	1,25	
How important is for you the transfer ratio of CO_2 to other input materials?					
Choice	very low	low	moderate	high	very high
Scale	1	2	3	4	5
Mean	3,05		Standard Deviation	1,10	

Table 21 Questions about the significance of certain factors

4.3 RESULTS OF EACH INDUSTRY SECTOR

The last question of the survey is a so called priority table, shown below. The respondent has to rank twelve evaluation criteria's for carbon capture and utilization methods according to his priority (1 is not important, 12 is very important). The evaluation criteria's were determined based on the literature review and were discussed sufficient in several meetings.

	1	2	3	4	5	6	7	8	9	10	11	12
Investment spending	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Area required	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Energy consumption	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Operating costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Availability of secondary raw materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing market for the end product	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
End product in the same industry sector	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CO_2 fixation duration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Transfer ratio CO_2 and secondary raw materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
State of art	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
direct CO_2 utilization without capture	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Utilization of existing waste as input material	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Table 22 Priority table of the evaluation criteria for CCU methods

The goal of the master thesis is to find the best CCU method for each industry sector. To achieve this target, this priority ranking is used to calculate the weighting of the criteria's for a utility analysis. The point rating of the different CCU methods for the respective criteria's are defined from 1 to 5, with 1 being poor and 5 being excellent. For each industry sector the results of the priority table are evaluated and a separate utility analysis was created. Finally the separate results of the different utility analysis were summarized in one table, showing the best CCU method for each industry.

On the next pages the results of the general part of the questionnaire and the priority table for each industry sector are discussed, followed by the constructed utility analysis. In the last part of this chapter the final results of the utility analysis were shown in a table and some diagrams.

4.3.1 ELECTRICITY INDUSTRY

Seven companies were selected for the survey. So from the whole 7.666.158 tonnes of carbon dioxide allocated to the electricity sector in the year 2012, 96 % or 7.349.041 tonnes of CO_2 were thus collected with the survey. More information according to the covered facilities of the companies is listed in the appendix A and B.

Six companies from the electricity industry have participated the survey. Every energy supplier in Austria evaluates the environmental policy of his company as proactively. The outlook into the future to achieve the EU targets is actually very positive in the electricity industry. Five of six companies believe that their industry sector can achieve the EU climate protection targets 2020. At least three believe that the 2050 goals are also feasible. 83,3% of the six firms have done some arrangements for emissions reduction since the introduction of emissions trading act, that means that one company has done nothing. This is the only company that has done nothing in terms of emissions reduction. Also the companies in the other industries did something to curb their emissions. Seen on the next diagram the effort of recording, monitoring and reporting of emissions since the introduction of the emissions trading scheme is seemed to be high. This also suggests that CO_2 management is considered to be very important in the electricity industry and the introduction of the emissions trading act did have a high impact in their management.

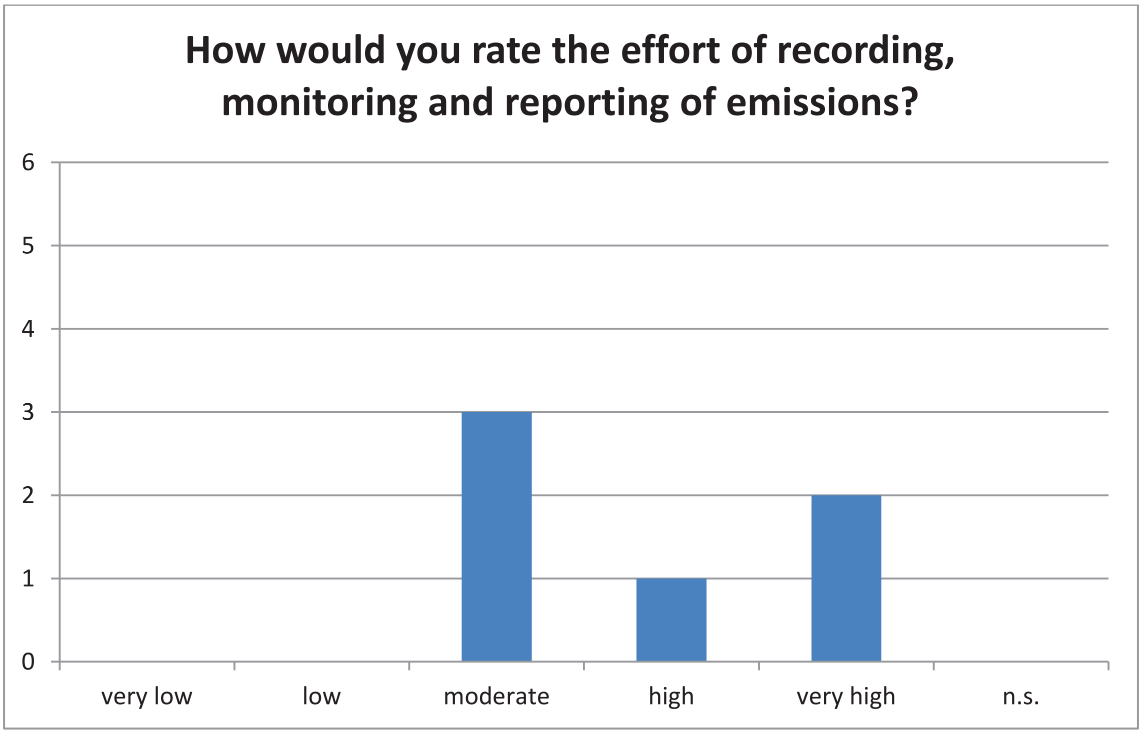


Figure 34 Effort of emissions for the electricity industry

The legal framework conditions and promotions for CO_2 utilization are for most of the respondents in the electricity industry poor or lacking. Four answered that the legal frameworks are not sufficient for carbon dioxide utilization (figure 35).

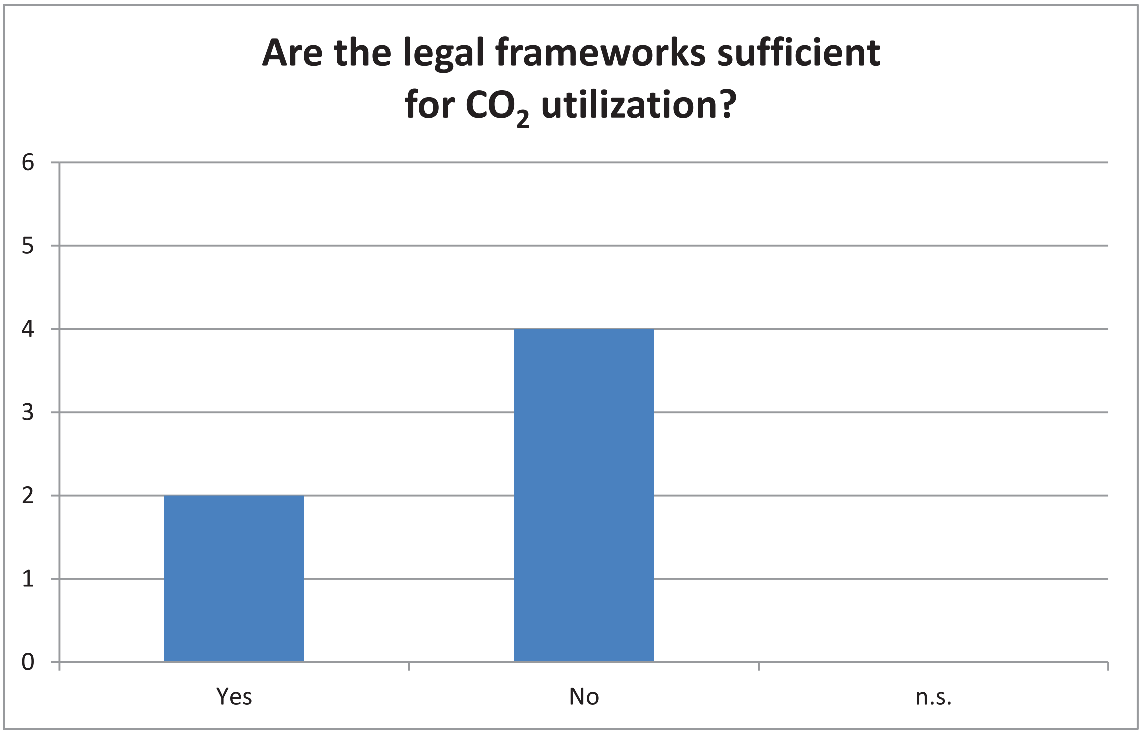


Figure 35 Adequate legal framework for CCU methods in the electricity industry

With the next figure it can be seen that there is some need for action in terms of promotion activities for carbon dioxide utilization methods in Austria.

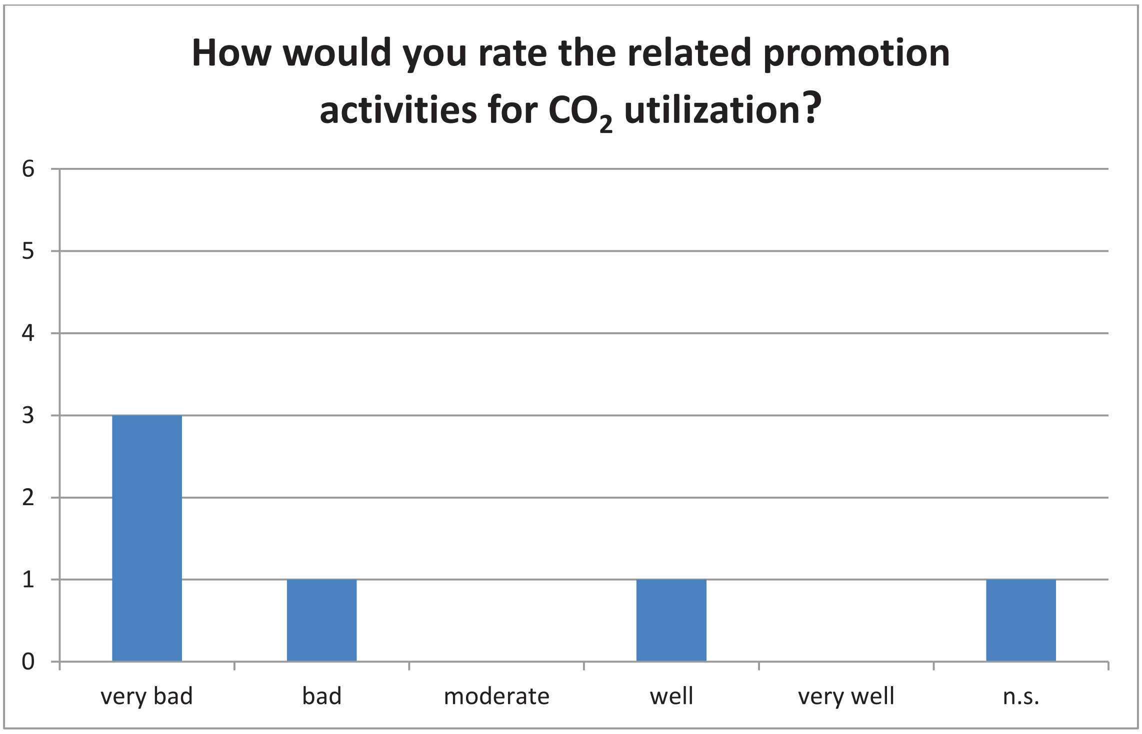


Figure 36 Adequate related promotion activities for CCU methods in the electricity industry

Further it was evident from the answered questionnaires that all six companies from the electricity industry have facilities with high amount of emissions (more than 500.000 tonnes CO_2 per year). The concentration of carbon dioxide in the flue gas varies between 5 to 13 %. They also answered that they have SO_2, NO_x, CO and dust in their flue gas. One participated company has already a carbon dioxide capture facility. It's a test facility and the past experience was classified as good from the respondent. Unfortunately, the other companies don't have plans to invest in a capture facility in the near future. Regarding the question if they are interested only in CO_2 capture, or also in CO_2 utilization, three answered that they are only interested in utilization and the other three are interested in capture and utilization.

Also very interesting is that four of the six companies would be willing to give their captured carbon dioxide company which uses carbon dioxide for free. Except one, all others are satisfied with a cost covered carbon dioxide use. The exception wants to generate a profit by the use of CO_2. Another interesting fact is that 66,7 % from the respondents of the electricity industry are willing to manufacture products from other industries with a carbon dioxide utilization method.

The next two diagrams are showing that companies from the electricity industry are in principle interested in technologies which are in the stage of development. But the willingness to invest in such technologies is less seen on the next page.

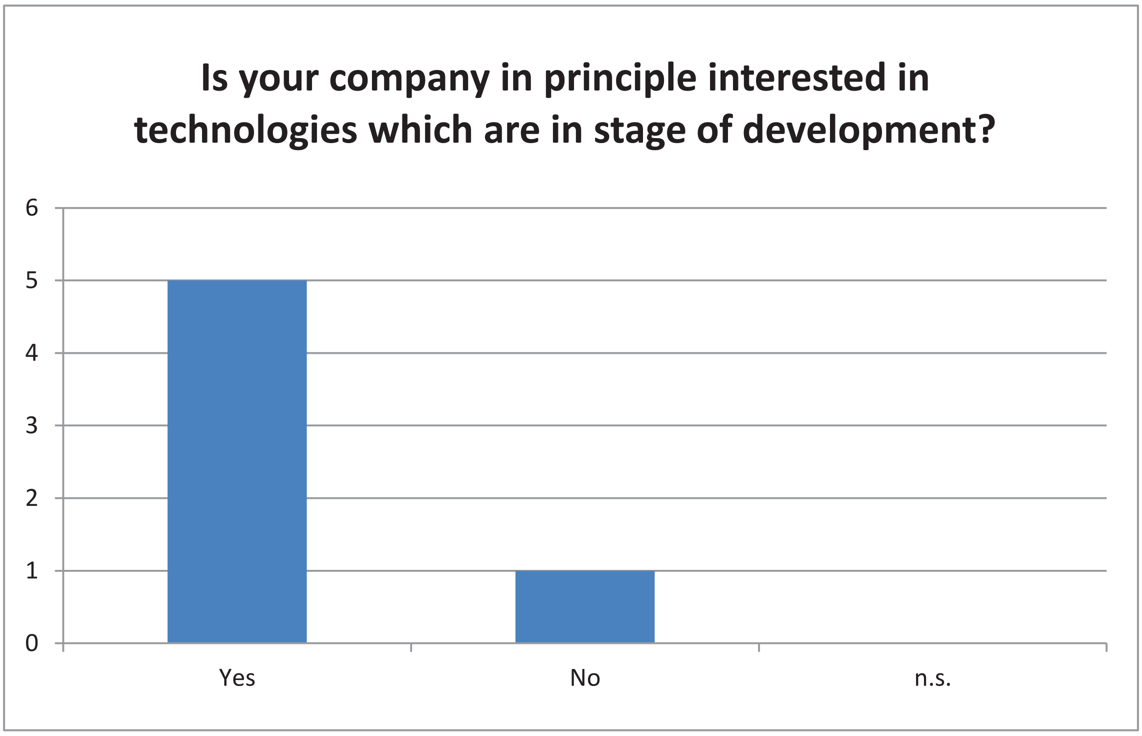


Figure 37 Interests of the electricity industry in technologies which are in stage of development

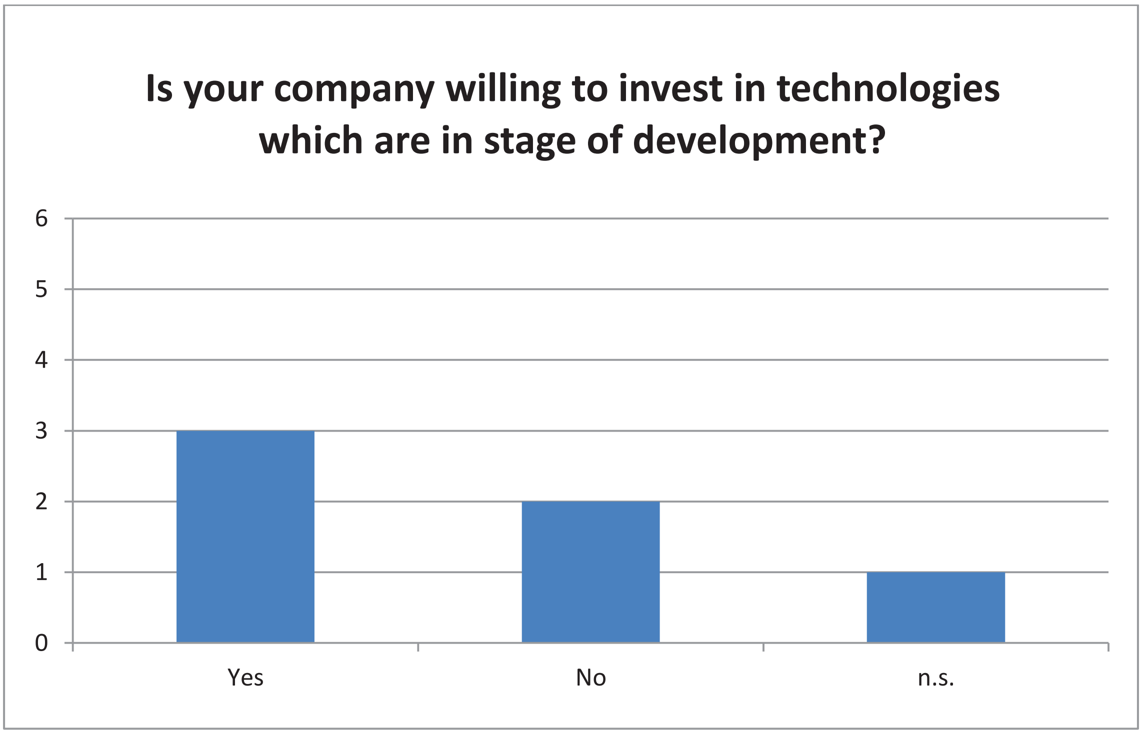


Figure 38 The willingness of the electricity industry to invest in technologies which are in stage of development

The stage of development of a carbon utilization method is for respondents from the electricity industry a very important factor for investment decisions. Figure 39 illustrates the answers of the six energy suppliers.

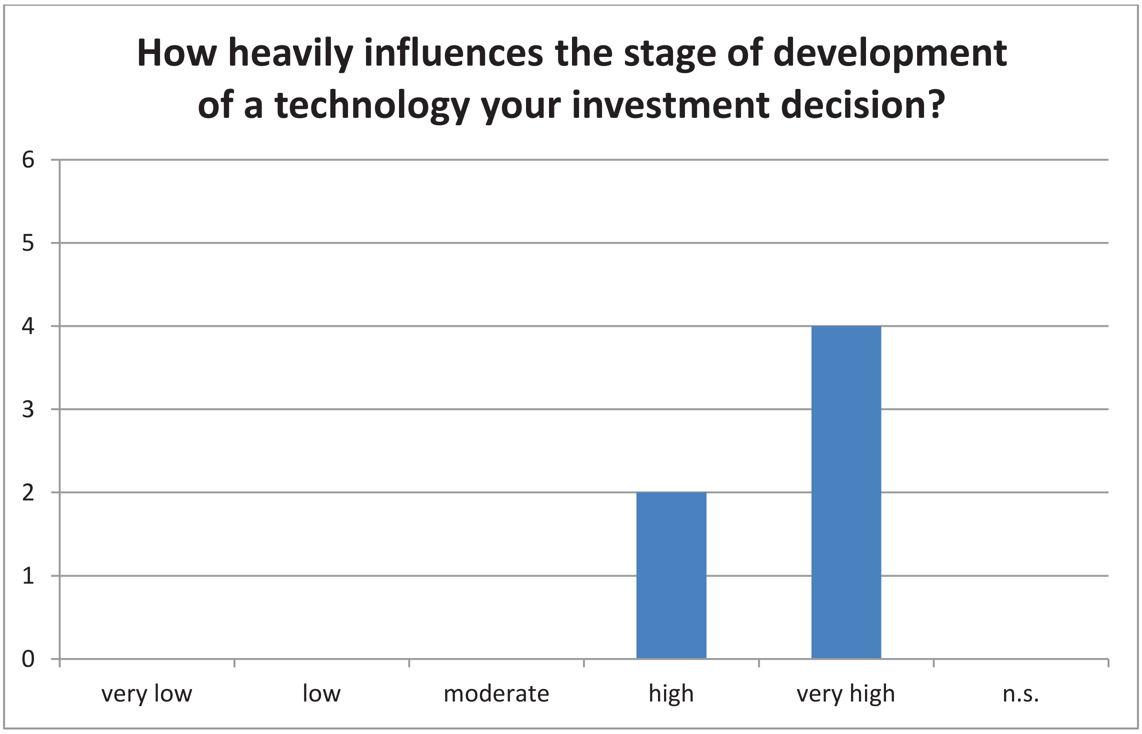


Figure 39 The influence of the state of art in an investment decision for the electricity industry

Further, three companies declared that they have enough space for a carbon dioxide utilization method, two have limited space, and one has no space for such new facility. The influence of costs and the energy demand of a facility for a new investment are relatively high. For some carbon utilization methods the energy supply from renewable sources is necessary. Four companies have access to such renewable energy.

Regarding to the question if recycling of industrial wastes, such as ash, slag, construction and mining wastes are interesting for your company, three answered it with yes and three with no. One respondent published more details regarding to this question. The quantity of waste in his company is as follows: 100.000 t/a fly ash, 15.000 t/a coarse ash, 20.000 t/a gypsum and 5.000 t/a lime sludge.

A very important criterion for carbon dioxide utilisation options is the fixation duration of CO_2 in the end product. For the participated companies from the electricity industry in Austria it seems that it is also a very important factor.

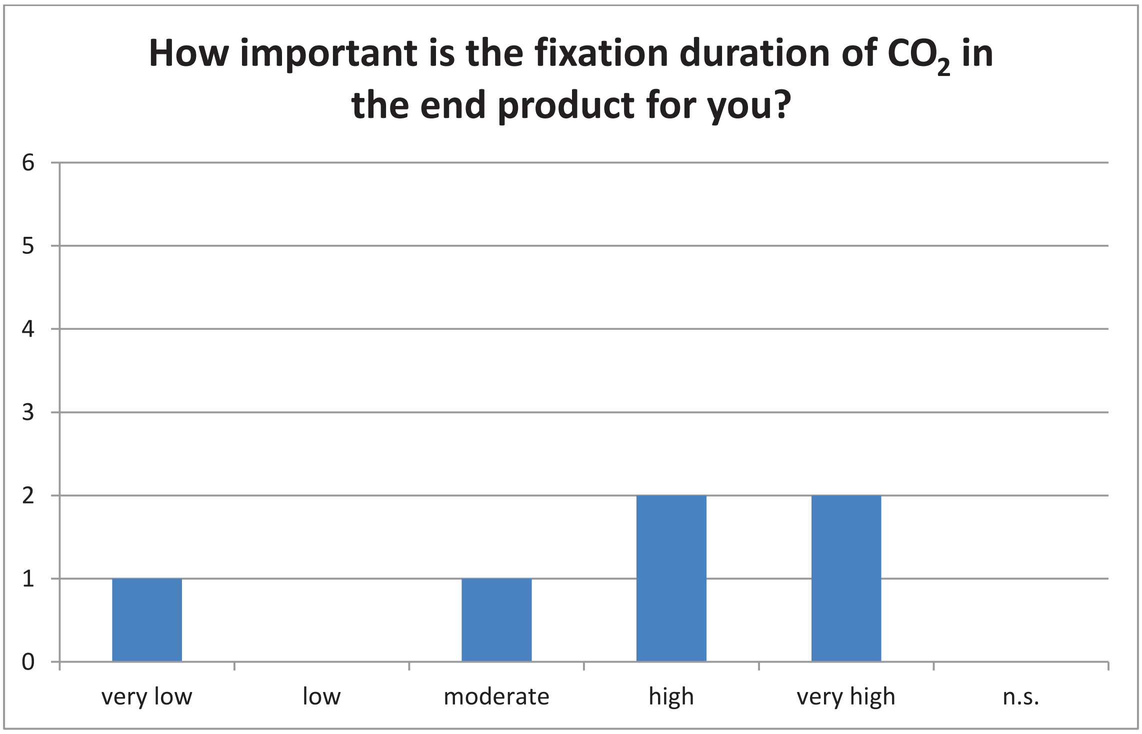


Figure 40 The Importance of the fixation duration for the electricity industry

That were the results from the general part of the questionnaire for the electricity industry, the results of the priority ranking for the evaluation criteria and the utility analysis is followed on the next pages.

Because six persons answered the survey, a maximum achievable amount of points of 72 for an evaluation criterion can be reached. The minimum of points is 6. The resulted priority ranking is shown in the diagram below. According to the results of the survey the costs represents the crucial factor for a decision to use a CCU technology in the electricity industry. For instances investment spending reached 53 points, which represents a relatively high proportion of the total awarding points. State of art, energy consumption and an existing market for the resulted products of a carbon capture method are also very important factors for our energy suppliers in Austria. In contrast it should be noted that the finally product doesn't have to be in the same market/industry.

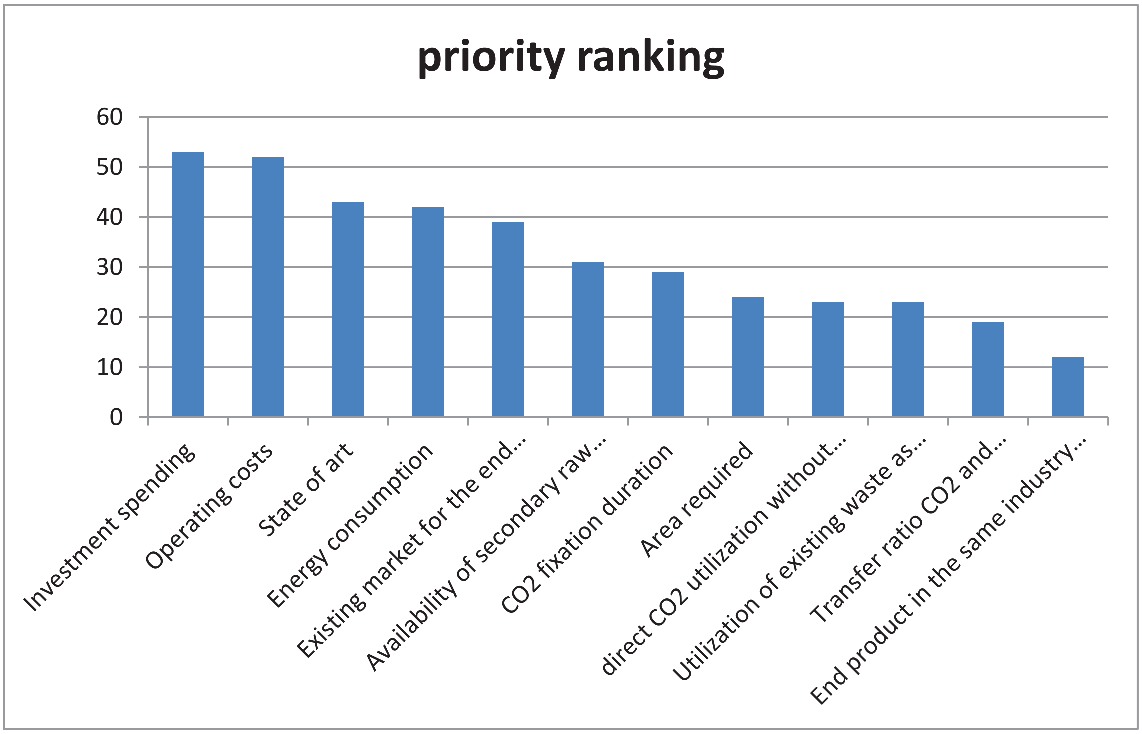


Figure 41 Priority ranking of the evaluation criteria of the electricity industry

These priority ranking is used for the utility analysis. The weighting of the twelve criteria is calculated by the amount of points from each criteria divided by the total amount of points. For example investment spending has 53 points, divided by 390 (is the total amount of points in the priority ranking table of the electricity industry) it leads to a weighting of 13,59 %. The results of all weightings can be seen in the utility analysis in the next table. As mentioned before the point rating of the different CCU methods for the respective criteria's are defined from 1 to 5, with 1 being poor and 5 being excellent. For example algae get one point in terms of investment spending, because bioreactors are very expensive to realise. Or as another example EOR is the only method which has 5 points in terms of maturity of technology. The reason is the large scale realisation worldwide with many years of experience. The point ratings were set by me on the basis of the literature and was discussed several times and checked by my adviser.

evaluation criteria	priority table		algae		methanation		fuels		chemical feedstock		mineral carbonation		EOR	
	points	weighting %												
Investment spending	53	13,59	1	13,6	3	40,8	3	40,8	3	40,8	2	27,2	4	54,4
Operating costs	52	13,33	3	40,0	3	40,0	3	40,0	3	40,0	4	53,3	5	66,7
State of art	43	11,03	2	22,1	5	55,1	3	33,1	4	44,1	3	33,1	5	55,1
Energy consumption	42	10,77	3	32,3	2	21,5	2	21,5	2	21,5	5	53,8	4	43,1
Existing market for the end product	39	10,00	3	30,0	5	50,0	4	40,0	5	50,0	3	30,0	3	30,0
Availability of secondary raw materials	31	7,95	5	39,7	2	15,9	2	15,9	2	15,9	3	23,8	5	39,7
CO2 fixation duration	29	7,44	3	22,3	3	22,3	1	7,4	4	29,7	5	37,2	2	14,9
Area required	24	6,15	1	6,2	4	24,6	4	24,6	4	24,6	1	6,2	4	24,6
direct CO2 utilization without capture	23	5,90	4	23,6	1	5,9	1	5,9	1	5,9	5	29,5	4	23,6
Utilization of existing waste as input material	23	5,90	1	5,9	1	5,9	1	5,9	1	5,9	5	29,5	1	5,9
Transfer ratio CO_2 and secondary raw materials	19	4,87	5	24,4	3	14,6	2	9,7	2	9,7	1	4,9	5	24,4
End product in the same industry sector	12	3,08	3	9,2	4	12,3	4	12,3	1	3,1	1	3,1	1	3,1
Sum	**390**	**100,00**		**269,2**		**309,0**		**257,2**		**291,3**		**331,5**		**385,4**

Table 23 The utility analysis of the electricity industry

The point rating for the carbon capture methods is almost identical for each industry. There are only a few criteria which are differing between the individual industries. This is the criteria end product in the same industry sector, utilization of existing waste as input material and availability of secondary raw materials.

So the final result of the utility analysis for the electricity is shown in the last row of the table. The resulted sequence is: EOR as the most suitable CCU method for the electricity industry with a resulted number of 385,4 points, followed by mineral carbonation with 331,5 points, methanation, chemical feedstock, algae and as last fuels. The last row of the table is used in the final table to summarize the results of all utility analysis of each industry (see chapter 4.4 final result of the utility analysis).

4.3.2 STEEL INDUSTRY

35% of the total national allocated CO_2 emissions in Austria (30.173.750 tonnes) are apportioned to the steel industry in the year 2012. The steel industry in Austria is dominated by one big company. This company is divided into several subsidiaries, which are counted as a single company in this chapter. So six companies in the steel industry were contacted, which got 99% of the allocated emissions for the steel sector. Four firms participated the survey.

All companies from the steel industry have a proactively environmental policy. In contrast to the electricity industry the outlook into the future to achieve the EU climate protection goals is not as positive. Four don't believe that the steel industry can meet the 2020 targets, same too for the 2050 except on respondent.

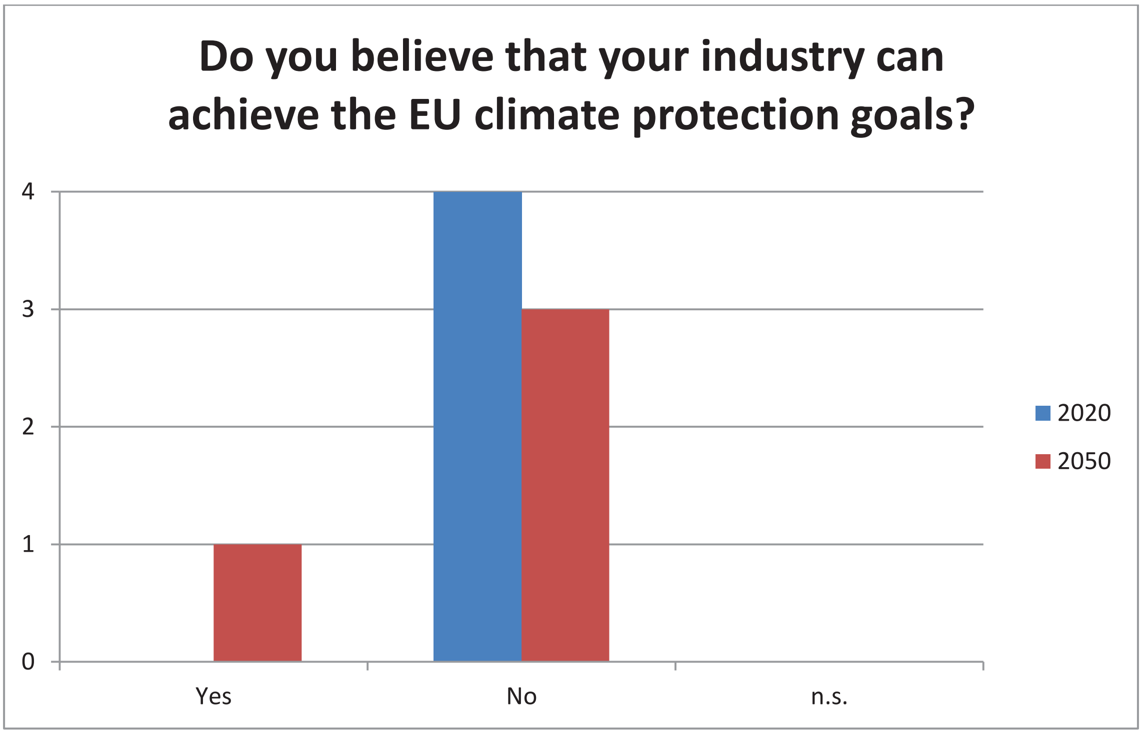


Figure 42 Reachability of the EU climate protection goals according to the steel industry

Since the introduction of the emissions trading act every company has done some arrangements to reduce their carbon dioxide emissions. Tendencially the effort of carbon dioxide recording, monitoring and reporting seems to be too much. This also suggests that CO_2 management is considered to be very important for the steel industry and the introduction of the emissions trading scheme already had a significant impact in terms of their carbon dioxide management. In general the respondents from the steel industry think that the future certificate price is difficult to estimate.

The results of the questions "Are the legal frameworks sufficient and how would you rate the related promotion activities for CO_2 utilization?" looks almost identical as for the electricity industry. Three answered that the legal frameworks are not sufficient for carbon dioxide utilization in contrast to one answer that the legal frameworks are sufficient. The diagram 43 shows that promotion activities are lacking for the respondents from the steel industry.

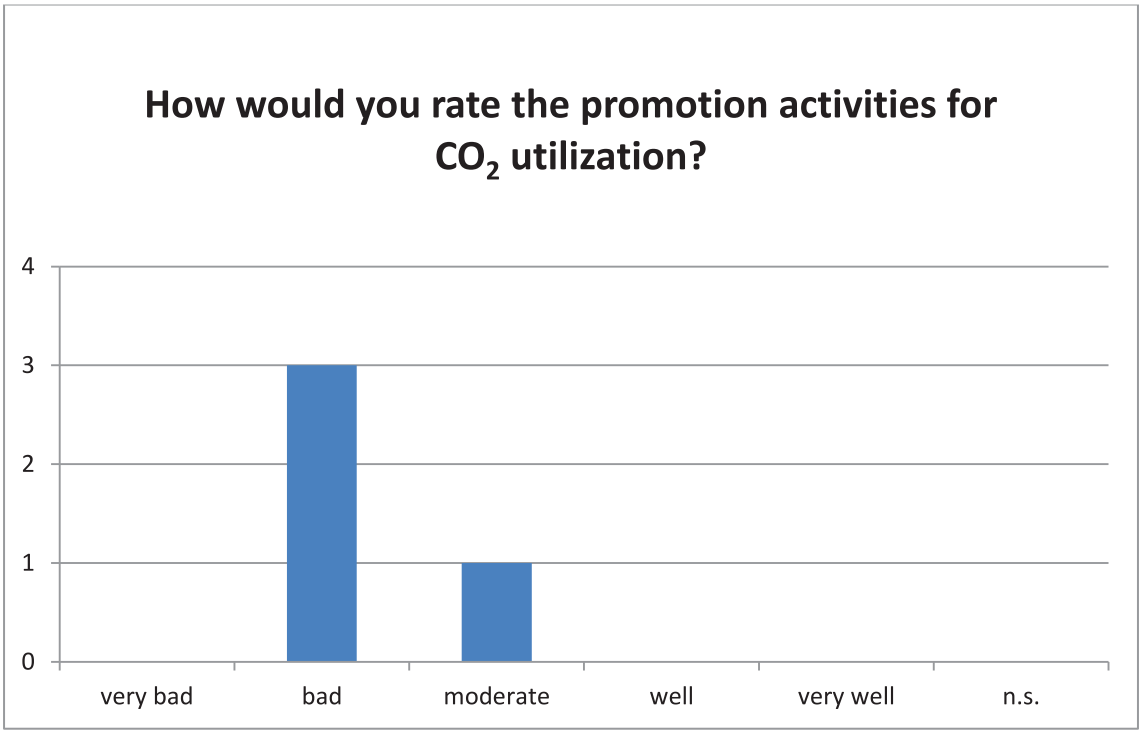


Figure 43 The opinion of the steel industry about the promotion activities for CCU options

It was also evident from the answers of the specific questions about the facilities that the steel industry emits a lot of carbon dioxide (it operates facilities with more than 500.000 tonnes CO_2 emissions per year). Regarding to the answers the concentration of carbon dioxide in the flue gas is between 6 and 9 %. Till today the steel industry doesn't capture carbon dioxide and it is also not planned in the short term future. Nevertheless three of four are in general interested in carbon capture and utilization. Except one which is only interested in carbon capture. Exactly those three would be willing to give their captured carbon dioxide a company, which utilize carbon dioxide, for free and are satisfied with a cost covered carbon dioxide use. Quite different as for the electricity industry, the steel industry is not interested to manufacture products from other industries with a CO_2 utilization method. 75% of the four are interested in technologies which are in the stage of development, and 50% of all four would also invest in such technologies. Regarding to a possible area for a new facility it looks bad in the Austrian steel industry. There is also no possible access to renewable energy sources.

The very important criterion fixation duration for carbon dioxide utilisation options is for the steel industry not as important as factors like the costs, energy demand or the possibility to use wastes as input materials. Regarding to wastes, two respondents published more details to this question. They accumulate slags about 40.000 tons and 90.000 tons per year.

The important priority ranking for the utility analysis is seen below. Four persons participated the survey, but one did not prioritize the evaluation criteria. That's the reason why 36 is the maximum achievable amount of points. The minimum of points is 3.

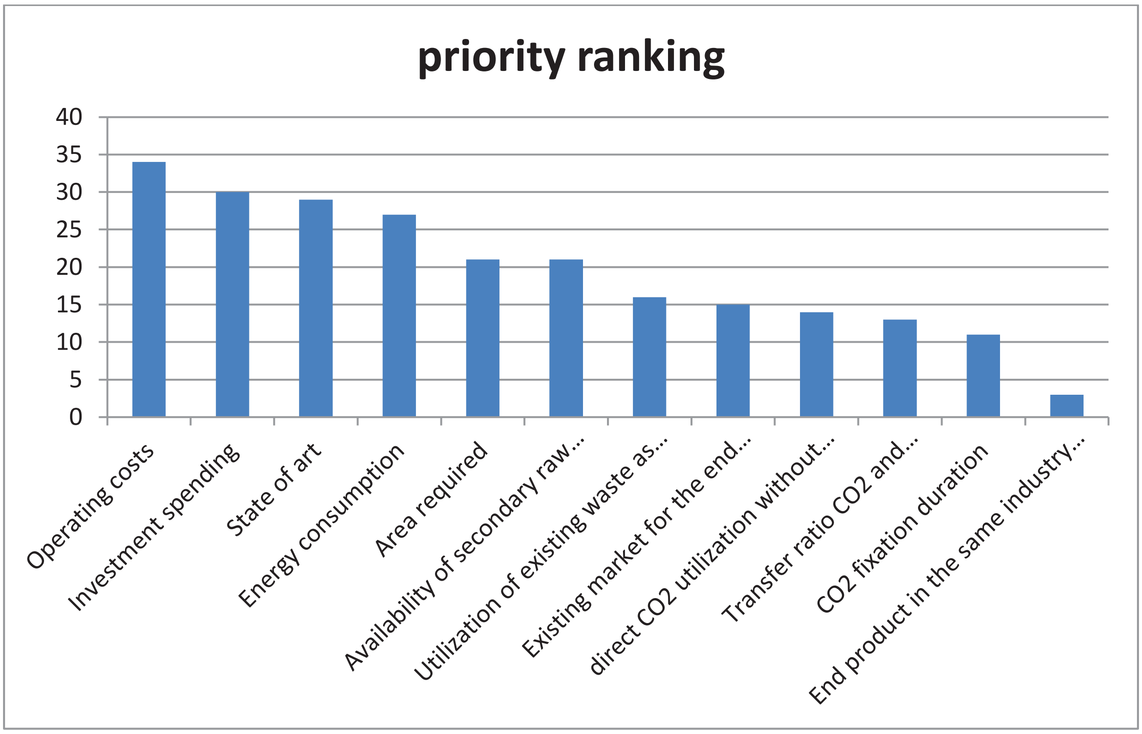


Figure 44 Priority ranking of the evaluation criteria of the steel industry

Similar to the electricity industry costs (operating and investment), state of art and energy consumption are the major factors which are playing a crucial role. One difference to the electricity industry is the importance of the area requirement. This criterion has a higher priority in the steel industry . As before it is unimportant to produce a product in the same industry (3 points for end product in the same industry). This was not expected in such a degree.

evaluation criteria	priority table points	priority table weighting %	algae		methanation		fuels		chemical feedstock		mineral carbonation		EOR	
Operating costs	34	14,53	3	43,6	3	43,6	3	43,6	3	43,6	4	58,1	5	72,6
Investment spending	30	12,82	1	12,8	3	38,5	3	38,5	3	38,5	2	25,6	4	51,3
State of art	29	12,39	2	24,8	5	62,0	3	37,2	4	49,6	3	37,2	5	62,0
Energy consumption	27	11,54	3	34,6	2	23,1	2	23,1	2	23,1	5	57,7	4	46,2
Area required	21	8,97	1	9,0	4	35,9	4	35,9	4	35,9	1	9,0	4	35,9
Availability of secondary raw materials	21	8,97	5	44,9	2	17,9	2	17,9	2	17,9	3	26,9	5	44,9
Utilization of existing waste as input material	16	6,84	1	6,8	1	6,8	1	6,8	1	6,8	5	34,2	1	6,8
Existing market for the end product	15	6,41	3	19,2	5	32,1	4	25,6	5	32,1	3	19,2	3	19,2
direct CO2 utilization without capture	14	5,98	4	23,9	1	6,0	1	6,0	1	6,0	5	29,9	4	23,9
Transfer ratio CO2 and secondary raw materials	13	5,56	5	27,8	3	16,7	2	11,1	2	11,1	1	5,6	5	27,8
CO2 fixation duration	11	4,70	3	14,1	3	14,1	1	4,7	4	18,8	5	23,5	2	9,4
End product in the same industry sector	3	1,28	1	1,3	1	1,3	1	1,3	1	1,3	1	1,3	1	1,3
Sum	**234**	**100,00**		**262,8**		**297,9**		**251,7**		**284,6**		**328,2**		**401,3**

Table 24 The utility analysis of the steel industry

As discussed before some point ratings of special criteria differs compared to the other industries. For the steel industry this meets to the criteria end product in the same industry sector. Every CCU method gets only one point in terms of this criterion because the products of the utilization of carbon dioxide methods are not belong to the steel industry. Electricity in contrast got a 3 for algae (biofuels) and a four for methanation and fuels.

The best carbon capture and utilization method using in the steel industry is again enhanced oil recovery, followed by mineral carbonation, methanation, chemical feedstock, algae and fuels. It is exactly the same sequence as for the electricity industry.

4.3.3 CEMENT AND CHALK INDUSTRY

Twelve percent of the total national allocated CO_2 emissions are apportioned to the cement and chalk industry in the year 2012. Most companies in the cement industries are also operating in the chalk industry. Therefore, these two industries have been combined. 5 from the cement and chalk industry answered the online questionnaire.

Every cement and chalk company in Austria has a proactively environmental policy. The outlook into the future to achieve the EU targets is very negative in this industry branch. Four of five companies believe that their industry sector cannot achieve the EU climate protection targets 2020 and all are of the same opinion that the 2050 goals are also unrealistic. In the electricity industry there is the only company that has done nothing in terms of emissions reduction since the introduction of emissions trading act. So every company in the cement and chalk industry has already done something to curb their emissions. The effort of recording, monitoring and reporting of emissions since the introduction of the emissions trading scheme is seemed to be very high, but nevertheless for one person carbon dioxide management is not as important as for the others. The figure below shows the importance of CO_2 management in the cement and chalk industry.

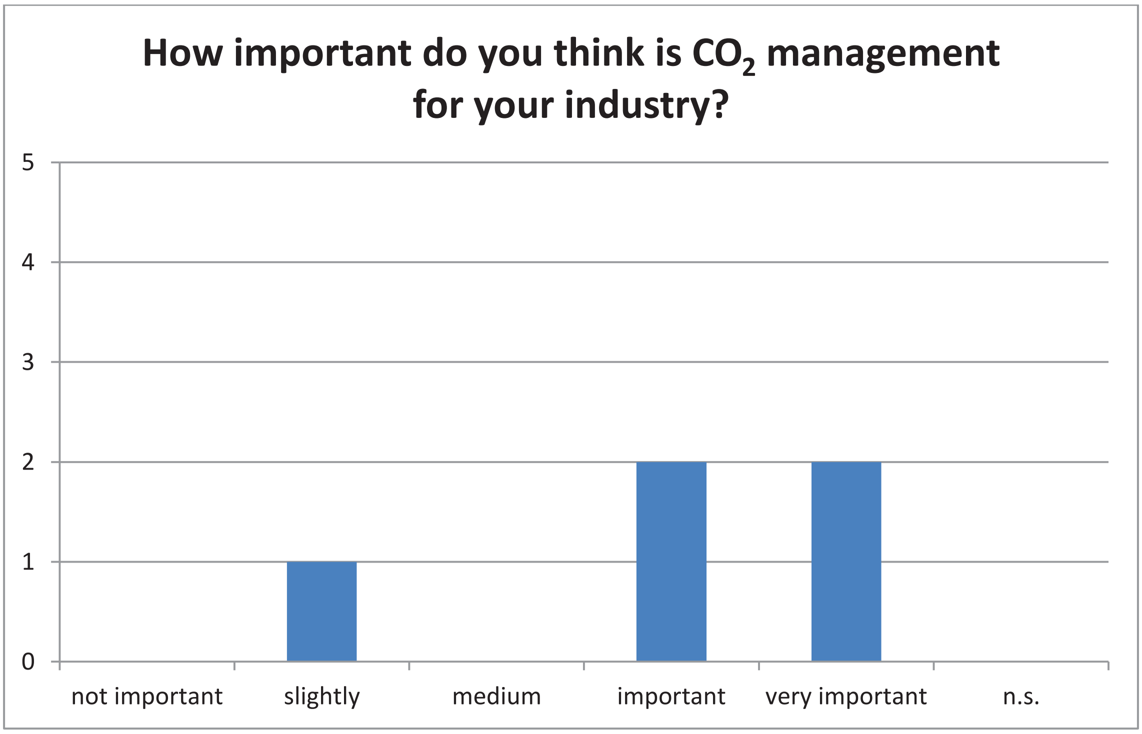


Figure 45 Importance of CO_2 Management in the Cement and Chalk Industry

One person answered the question if the legal frameworks are sufficient for CO_2 utilization in Austria with yes, four persons with no. Promotion activities are perceived from good to bad.

CO_2 emitting plants in the cement and chalk industry are large (more than 500.000 tons CO_2 equivalent per year) to small (less than 50.000 t/a). The concentration of carbon dioxide in the waste gas is about 20%. Other impurities in the flue gases are dust, heavy metals, SO_2, HF, NO_x and HCL. One company already operates a post-combustion capture facility and has so far made very good experiences with it. A capture facility is not planned by the others in the short term future.

Also very interesting is that 60% of the five companies would be willing to give their captured carbon dioxide, if they would have a capture facility, to a company which uses carbon dioxide for free. Except one, all others are satisfied with a cost covered carbon dioxide use. The exception wants to generate a profit by the use of CO_2. Producing products from other industries with a CCU technology is for 3 respondents no problem. In general the cement and chalk industry is interested in technologies which are in the stage of development, but except one would not invest in such a technology. Space for a new CCU facility is limited in the cement and chalk industry, but two companies has access to renewable energy sources. The influence of costs, fixation duration and the energy demand of a facility for a new investment are relatively high.

The cement and chalk industry claim for themselves that they are already recycling their wastes such as ash, slag or construction debris. Further one person asserts that a use by capturing makes no sense for his company. The reason for that has not been specified.

5 surveys were answered, but one priority ranking table was not filled out. So the results of four were presented below:

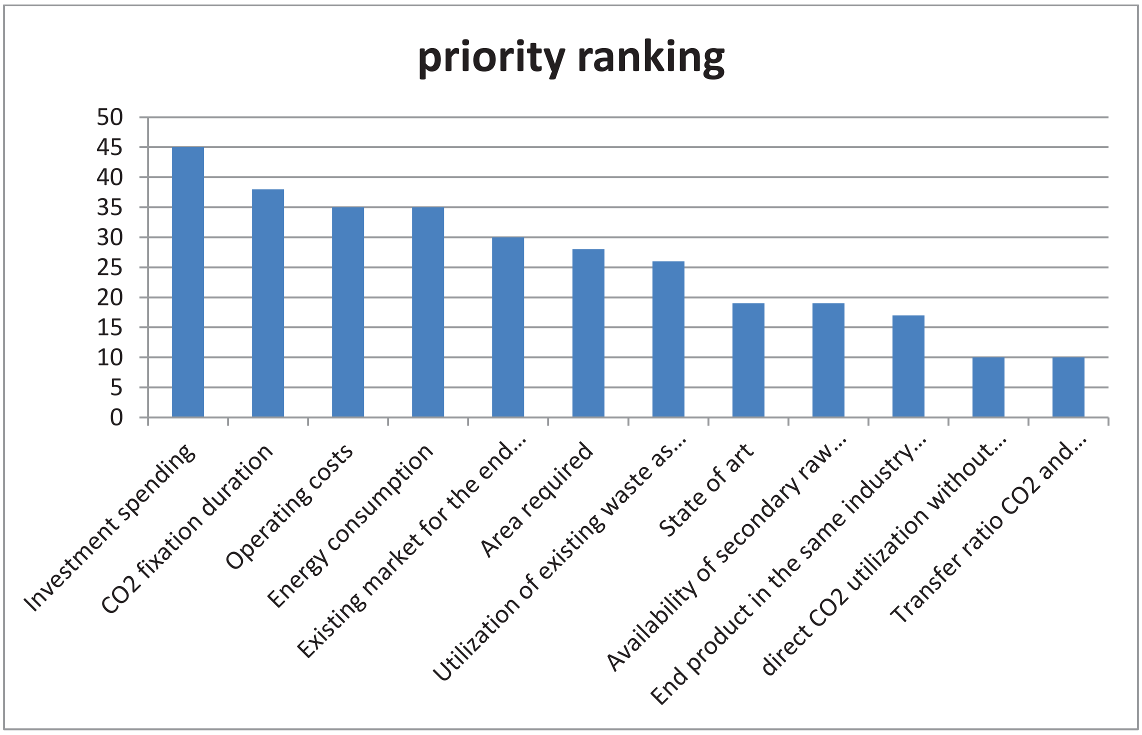


Figure 46 Priority ranking of the evaluation criteria of the cement and chalk industry

For a better understanding of the importance 48 is the maximum number of points that can be achieved by an evaluation criterion. Notable of these results from the priority ranking is that the fixation duration is on the second place. The other results are mostly the same like in the other industries before.

evaluation criteria	priority table		algae		methanation		fuels		chemical feedstock		mineral carbonation		EOR	
	points	weighting %												
Investment spending	45	14,42	1	14,4	3	43,3	3	43,3	3	43,3	2	28,8	4	57,7
CO2 fixation duration	38	12,18	3	36,5	3	36,5	1	12,2	4	48,7	5	60,9	2	24,4
Operating costs	35	11,22	3	33,7	3	33,7	3	33,7	3	33,7	4	44,9	5	56,1
Energy consumption	35	11,22	3	33,7	2	22,4	2	22,4	2	22,4	5	56,1	4	44,9
Existing market for the end product	30	9,62	3	28,8	5	48,1	4	38,5	5	48,1	3	28,8	3	28,8
Area required	28	8,97	1	9,0	4	35,9	4	35,9	4	35,9	1	9,0	4	35,9
Utilization of existing waste as input materi-al	26	8,33	1	8,3	1	8,3	1	8,3	1	8,3	5	41,7	1	8,3
State of art	19	6,09	2	12,2	5	30,4	3	18,3	4	24,4	3	18,3	5	30,4
Availability of sec-ondary raw materials	19	6,09	5	30,4	2	12,2	2	12,2	2	12,2	3	18,3	5	30,4
End product in the same industry sector	17	5,45	3	16,3	1	5,4	1	5,4	1	5,4	1	5,4	1	5,4
direct CO2 utilization without capture	10	3,21	4	12,8	1	3,2	1	3,2	1	3,2	5	16,0	4	12,8
Transfer ratio CO2 and secondary raw materials	10	3,21	5	16,0	3	9,6	2	6,4	2	6,4	1	3,2	5	16,0
Sum	312	100,00		252,2		289,1		239,7		292,0		331,4		351,3

Table 25 The utility analysis of the cement and chalk industry

The point ratings for the criterion end product in the same industry sector looks like: algae got 3 points and all other CCU technologies got 1 point. The reason for the 3 points for biogenic processes is due to the possibility to produce also building materials by using algae as an option.

EOR is again the favourite carbon capture and utilization method. Second is mineral car-bonation. Then the first exception occurs in the sequence in contrast to the previous two results. After mineral carbonation the production of chemical feedstock is followed. Next is methanation, and then the lasts are again algae and fuels.

4.3.4 PAPER INDUSTRY

Nine companies were contacted, but only three persons filled out the survey. This leads to a flyback rate of 33,3% at the paper industry. However, from the whole 2.267.430 tonnes of carbon dioxide allocated to the paper industry in the year 2012, 85 % or 1.920.347 tonnes of CO_2 were collected. The reason of this high share is that there are many small carbon dioxide polluters in Austria, but the focus of the survey was to get answers from the big players in the paper industry, which was achieved. The paper industry got 8 % of the total national allocated CO_2 certificates in Austria.

All three companies from the paper industry have a proactively environmental policy. Only one person of this industry thinks that the EU climate protection target 2020 is achievable, another person thinks that the 2050 goals are realistic. Arrangements to reduce carbon dioxide emissions were done already in the paper industry since the introduction of the emissions trading act.

The effort of recording, monitoring and reporting of emissions is seemed to be high for two companies; one guy believes it is appropriate. Management in terms of carbon dioxide is considered very important.

The introduction of the emissions trading act did have an impact in their management, but the impact is also considered appropriate. This result was found only in this industry.

Future certificate price is difficult to estimate for the paper industry. Legal frameworks and the related promotion activities for CCU technologies in Austria are sufficient for two persons in Austria. This is also a result which cannot be found in the other industries. The other person gives reasons why he believes that the legal promotion measures are not enough: "One opinion is that he thinks the system is too complicated and expensive. An energy intensive industry is already highly motivated to save energy (carbon dioxide are energy costs) and does not require additional legal challenge to do so with very costly additional inspections. Savings are there anyway only a few available. The system is an additional punishment for already taken measures (they were not count and usually received no funding). On the other hand, industries with higher total CO_2 emissions (transport, households) are not subjected to forced savings because of political reasons. This force internationally operating European companies to migrate due to financial reasons. Decoupling between production and consumption is only slightly possible. Absolute forced saving prevents further economic growth."

Unfortunately no exact details have been announced in respect to the carbon dioxide emitting facilities in their companies.

Two are satisfied with a cost covered carbon dioxide utilization method but are not willing to give their captured carbon dioxide, if they would have a capture facility, to a company which uses carbon dioxide for free.

Two companies from the paper industry have no problem to manufacture products from other industries.

The next figures are showing the result of the interests of the paper industry in technologies which are in stage of development and how they are willing to invest in such an option.

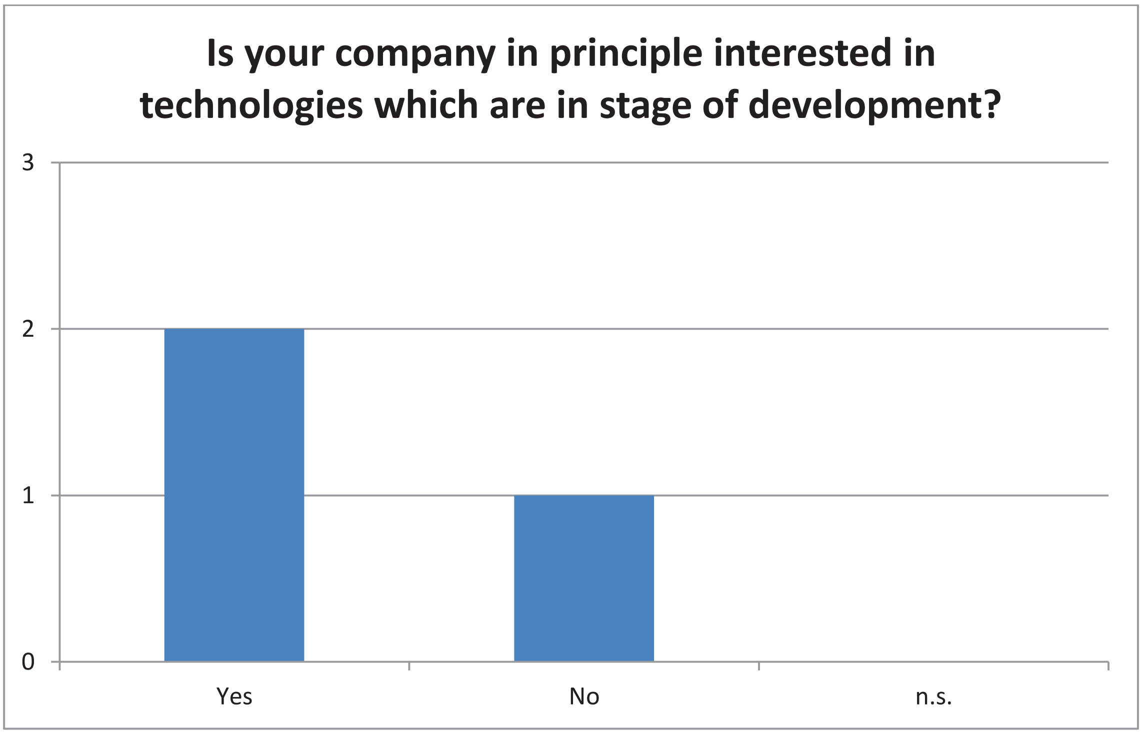


Figure 47 Interests of the paper industry in technologies which are in stage of development

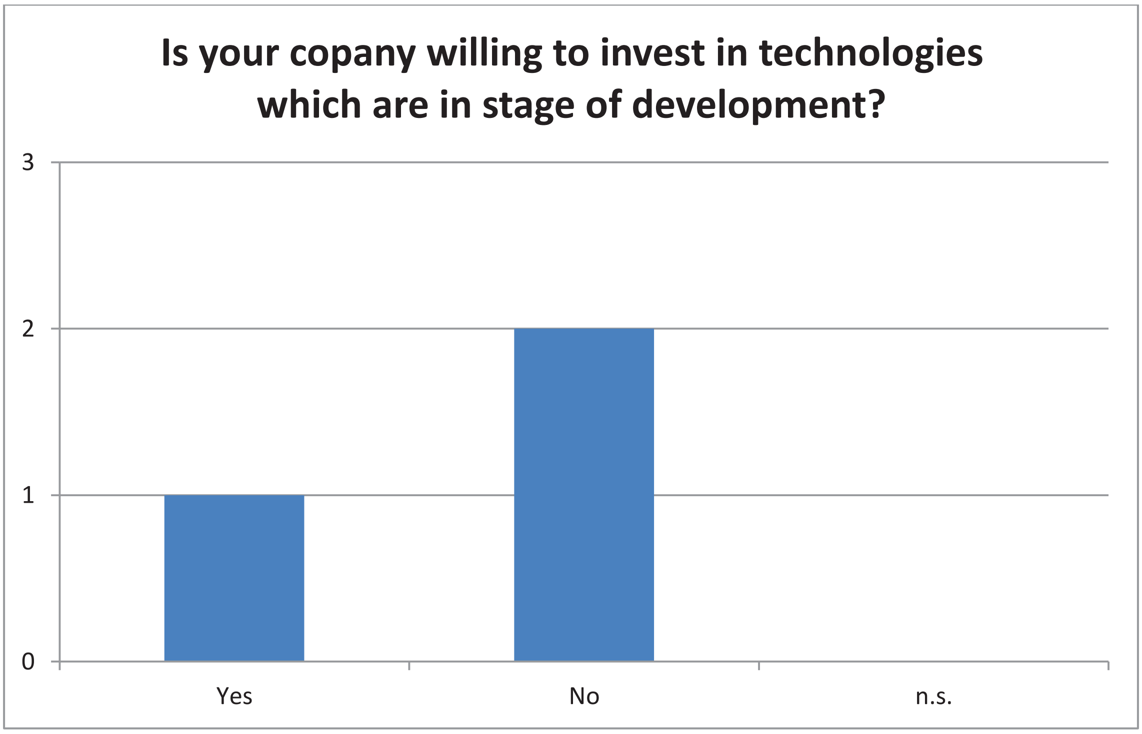


Figure 48 The willingness of the paper industry to invest in technologies which are in stage of development

Further, two companies from the paper industry declared that they have enough space for a carbon dioxide utilization method; the other has only limited space for such a new facility. The influence of costs and the energy demand of a facility for a new investment are very high. However, the fixation duration of carbon dioxide in the endproduct of a CCU method is not so important. Also two have already access to renewable energy sources.

Unfortunately, one of the three online surveys was not fully completed. The person quit for whatever reason the survey before the important question about the priority ranking of the evaluation criteria's. So only results of two surveys can be seen in the next figure. 24 points is the maximum, 2 is the minimum of points that can be achieved.

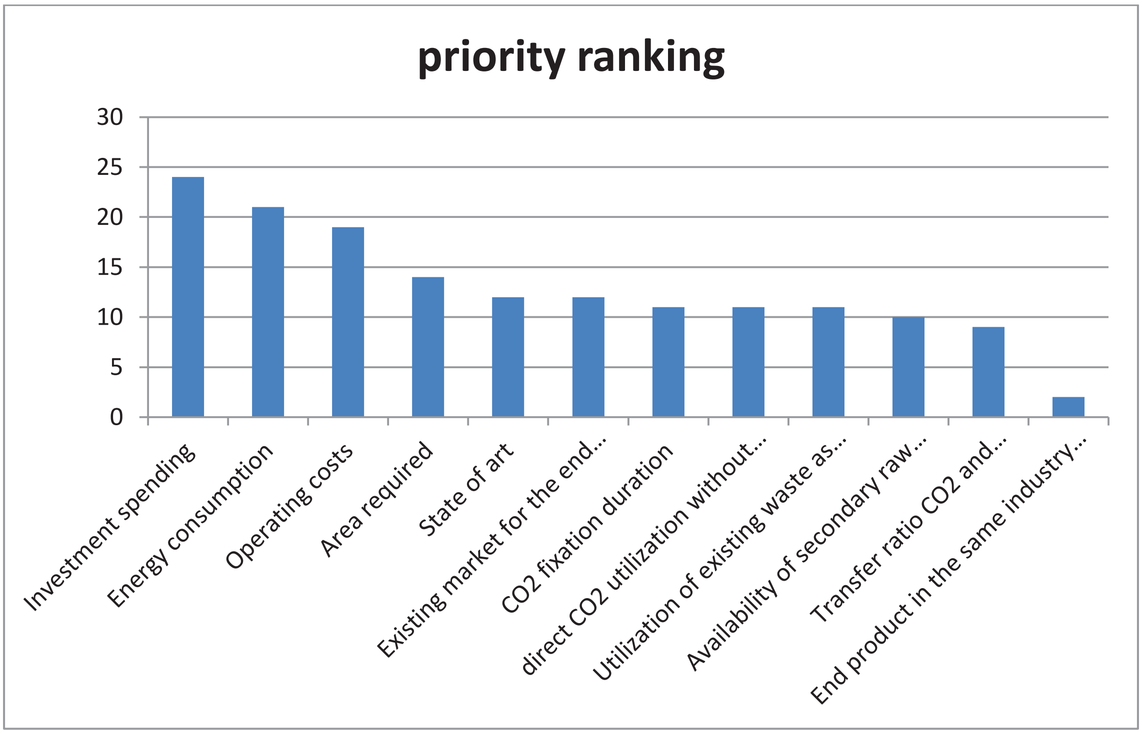


Figure 49 Priority ranking of the evaluation criteria of the paper industry

Again costs and energy consumption is very important for people working in the paper industry. To be mentioned would be that the criterion area required is on the fourth place. In no other industry this criterion is so far forward.

evaluation criteria	priority table points	priority table weighting %	algae		methanation		fuels		chemical feedstock		mineral carbonation		EOR	
Investment spending	24	15,38	1	15,4	3	46,2	3	46,2	3	46,2	2	30,8	4	61,5
Energy consumption	21	13,46	3	40,4	2	26,9	2	26,9	2	26,9	5	67,3	4	53,8
Operating costs	19	12,18	3	36,5	3	36,5	3	36,5	3	36,5	4	48,7	5	60,9
Area required	14	8,97	1	9,0	4	35,9	4	35,9	4	35,9	1	9,0	4	35,9
State of art	12	7,69	2	15,4	5	38,5	3	23,1	4	30,8	3	23,1	5	38,5
Existing market for the end product	12	7,69	3	23,1	5	38,5	4	30,8	5	38,5	3	23,1	3	23,1
CO2 fixation duration	11	7,05	3	21,2	3	21,2	1	7,1	4	28,2	5	35,3	2	14,1
direct CO2 utilization without capture	11	7,05	4	28,2	1	7,1	1	7,1	1	7,1	5	35,3	4	28,2
Utilization of existing waste as input material	11	7,05	1	7,1	1	7,1	1	7,1	1	7,1	1	7,1	1	7,1
Availability of secondary raw materials	10	6,41	5	32,1	2	12,8	2	12,8	2	12,8	3	19,2	5	32,1
Transfer ratio CO2 and secondary raw materials	9	5,77	5	28,8	3	17,3	2	11,5	2	11,5	1	5,8	5	28,8
End product in the same industry sector	2	1,28	1	1,3	1	1,3	1	1,3	1	1,3	1	1,3	1	1,3
Sum	**156**	**100,00**		**258,3**		**289,1**		**246,2**		**282,7**		**305,8**		**385,3**

Table 26 The utility analysis of the paper industry

Products from all CCU technologies are not comparable to the products in the paper industry, that's why all methods got only one point in respect to the criterion end product in the same industry. It is here to mention that this criterion has actually only little influence on the final result due to his almost always last place in the ranking.

The resulting sequence of different methods for a use in the paper industry is exactly the same as for the electricity and steel industry. The sequence looks like: EOR before mineral carbonation, methanation, chemical feedstock, algae and fuels.

4.3.5 CHEMICAL INDUSTRY

Two persons participated the survey, which leads to a response rate of 25% because four companies were selected for the online survey. 852.432t CO_2 emissions were allocated to the chemical industry; this is a share of about 3 % of the total allocated emissions in Austria. With the four selected companies 349.894t allocated carbon dioxide emissions have been achieved. The problem in the chemical industry was that there are many small companies, where it was not possible to find out the responsible persons for such an online survey.

The two companies from the chemical industry have a proactively environmental policy. They think that the EU climate protection targets 2020 and 2050 are not achievable. Arrangements to reduce carbon dioxide emissions were done already since the introduction of the emissions trading act. The effort of recording, monitoring and reporting of emissions is seemed to be high for both companies. This also suggests that CO_2 management is considered to be very important in the business today. The introduction of the emissions trading act also did have a high impact in their management. The respondents from the chemical industry are in the opinion that the future certificate price is difficult to estimate. Legal frameworks for CCU technologies and the related promotion activities are not sufficient in Austria.

There are only small facilities operated in the chemical industry in Austria which are emitting carbon dioxide. This means that they have plants emitting less than 50.000 tons carbon dioxide equivalent per year. The concentration of carbon dioxide is about 10 % in the flue gas. Unfortunately the two have no carbon capture facility and also don't plan such capture plant in the short future.

No one from the chemical industry is willing to give their captured carbon dioxide, if they would have a capture facility, to a company which uses carbon dioxide for free. But they would be satisfied with a cost covered carbon dioxide use. Manufacturing products from other industries with a CCU technology is no problem for both companies. They are interested in technologies which are in the stage of development and also would invest in such a technology. The chemical industry has also a beneficial; they have enough space to build a new facility such for a CCU method. One company can deliver renewable electricity for a carbon capture and utilization technology. Same as for other industries the influence of costs, fixation duration and the energy demand of a facility for a new investment are relatively high.

The results of the priority ranking are seen below.

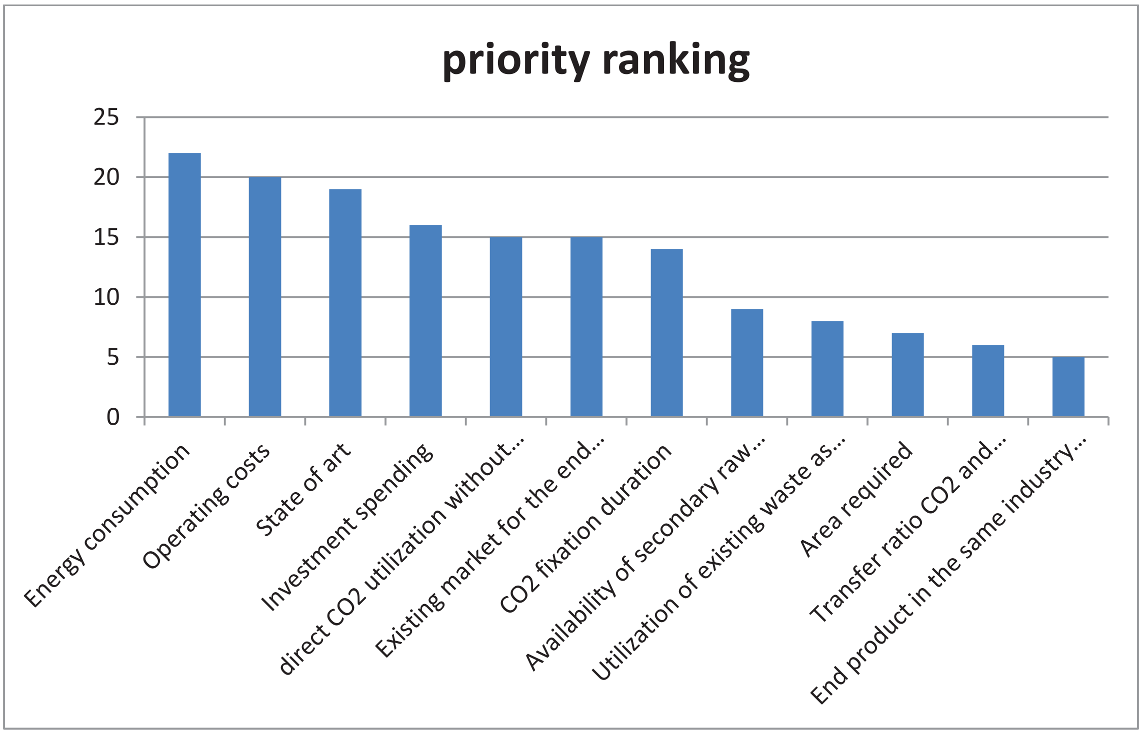


Figure 50 Priority ranking of the evaluation criteria of the chemical industry

A significant difference to the other industries is here that the required area of a carbon capture and utilization method is relatively unimportant. Other criteria like costs or stage of development are as usual in the front part of the ranking. The sequence of the most important is just different. Interesting is also that for chemists the direct CO_2 utilization without capture is important.

evaluation criteria	priority table		algae		methanation		fuels		chemical feedstock		mineral carbonation		EOR	
	points	weighting %												
Energy consumption	22	14,10	3	42,3	2	28,2	2	28,2	2	28,2	5	70,5	4	56,4
Operating costs	20	12,82	3	38,5	3	38,5	3	38,5	3	38,5	4	51,3	5	64,1
State of art	19	12,18	2	24,4	5	60,9	3	36,5	4	48,7	3	36,5	5	60,9
Investment spending	16	10,26	1	10,3	3	30,8	3	30,8	3	30,8	2	20,5	4	41,0
direct CO2 utilization without capture	15	9,62	4	38,5	1	9,6	1	9,6	1	9,6	5	48,1	4	38,5
Existing market for the end product	15	9,62	3	28,8	5	48,1	4	38,5	5	48,1	3	28,8	3	28,8
CO2 fixation duration	14	8,97	3	26,9	3	26,9	1	9,0	4	35,9	5	44,9	2	17,9
Availability of secondary raw materials	9	5,77	5	28,8	2	11,5	2	11,5	2	11,5	3	17,3	5	28,8
Utilization of existing waste as input material	8	5,13	1	5,1	1	5,1	1	5,1	1	5,1	1	5,1	1	5,1
Area required	7	4,49	1	4,5	4	17,9	4	17,9	4	17,9	1	4,5	4	17,9
Transfer ratio CO2 and secondary raw materials	6	3,85	5	19,2	3	11,5	2	7,7	2	7,7	1	3,8	5	19,2
End product in the same industry sector	5	3,21	3	9,6	4	12,8	1	3,2	5	16,0	1	3,2	1	3,2
Sum	**156**	**100,00**		**276,9**		**301,9**		**236,5**		**298,1**		**334,6**		**382,1**

Table 27 The utility analysis of the chemical industry

Again the results of the utility analysis for the chemical industry are exactly the same as for the electricity, steel and paper industry. EOR is the winner, followed by mineral carbonation, methanation, production of chemical feedstock and algae and fuels are again the last ones.

4.3.6 REFRACTORY INDUSTRY

In some industries several people from one company were contacted for the survey. An example of this is the refractory industry. One company was selected and two persons in the same company were asked to answer the survey. Both participated. Thus were 500.469 t of CO_2 selected of the total allocated 509.576 t emissions for this industry sector. The 509.576 t emissions of the greenhouse gas are less than two percent of the total allocated emissions in Austria (30.173.750 tonnes).

The answers of the two received online questionnaires from the refractory industry are for almost all questions identical. Both predicate that their company has a proactively environmental policy. Further they don't think that the EU climate protection targets 2020 and 2050 are realistic for the refractory industry in Austria. Measures to curb their emissions were done since the introduction of emissions trading act. Definitely the effort for CO_2 recording, monitoring and reporting is too high for both respondents, so carbon dioxide management is considered very important. The introduction of the emissions trading scheme did have a high impact in their management.

The two surveyed from the refractory industry think that it is very difficult to estimate the future certificate price. Besides, both agree that the legal frameworks are not sufficient for CCU methods in Austria and the related promotion activities are also very bad.

The company operates 5 facilities which are emitting carbon dioxide. The biggest emits between 125.000 and 250.000 tons carbon dioxide per year. The others are all smaller plants (less than 125.000 t/a). Wastes in their flue gas are SO_2, NO_x, CO and dust. They also have no carbon capture facility and also don't plan such capture plant in the short future.

The first different answer of the two questionnaires is that one respondent would supply another company with CO_2 for free, while the other won't do that. One wants to generate profit, while the other one is satisfied with a cost covered CO_2 use. There is no willingness to produce products which are not in the same branch. In general the refractory industry is interested in technologies which are in the development stage, but they are not interested to invest in such technologies. Unfortunately there is only limited space available for a new facility, for instance a CCU plant, and there is also no access to get the energy from a renewable energy source.

Unfortunately, a completed priority ranking table could not be evaluated, because one respondent assigned the priorities to the series, which makes no sense and leads to the conclusion that the condition to fill out this table was not understood or the person wanted to finish the survey as quickly as possible because of time pressure. Figure below shows the results of one person and is therefore regarded with caution. Only one respondent leads to a maximum achievable number of points of 12.

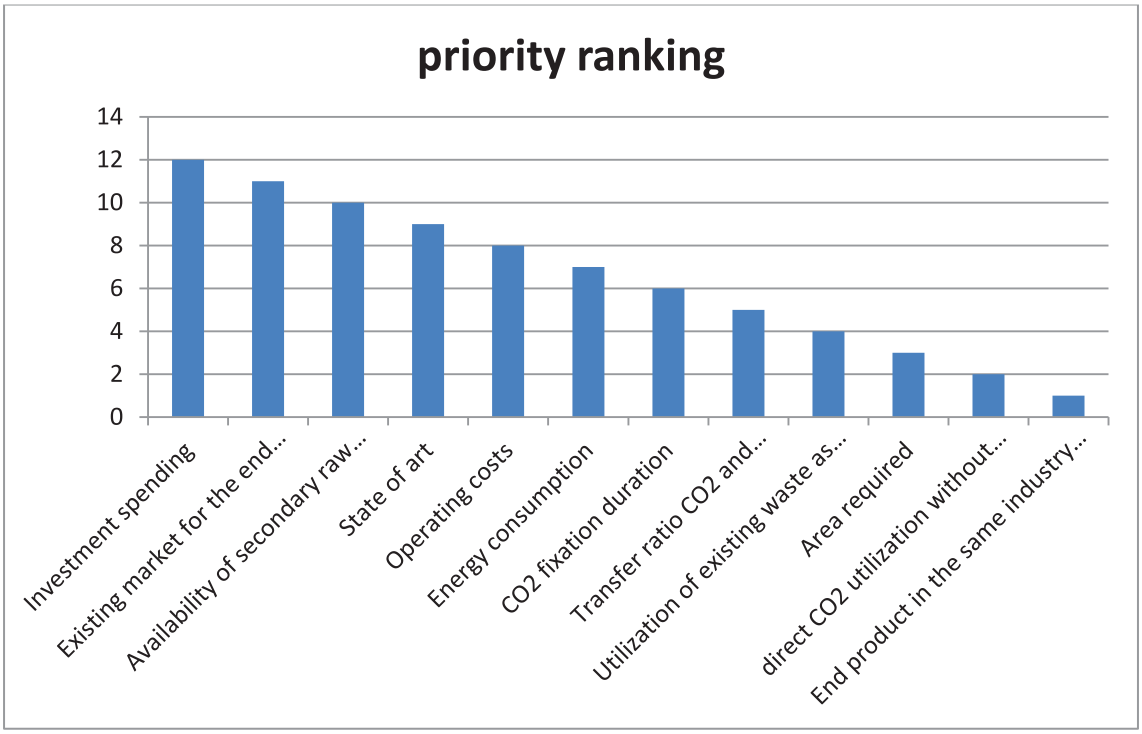


Figure 51 Priority ranking of the evaluation criteria of the refractory industry

Besides the investment spending also very important for the refractory industry is the existing market of such a CCU method and the availability of secondary raw materials. Similar to the chemical industry the criterion area required is in the ranking antepenultimate. The end of the ranking is the same as in all other industries, except in the cement and chalk industry, the criterion that the end product should be in the same industry.

evaluation criteria	priority table: points	priority table: weighting %	algae		methanation		fuels		chemical feedstock		mineral carbonation		EOR	
Investment spending	12	15,38	1	15,4	3	46,2	3	46,2	3	46,2	2	30,8	4	61,5
Existing market for the end product	11	14,10	3	42,3	5	70,5	4	56,4	5	70,5	3	42,3	3	42,3
Availability of secondary raw materials	10	12,82	5	64,1	2	25,6	2	25,6	2	25,6	3	38,5	5	64,1
State of art	9	11,54	2	23,1	5	57,7	3	34,6	4	46,2	3	34,6	5	57,7
Operating costs	8	10,26	3	30,8	3	30,8	3	30,8	3	30,8	4	41,0	5	51,3
Energy consumption	7	8,97	3	26,9	2	17,9	2	17,9	2	17,9	5	44,9	4	35,9
CO2 fixation duration	6	7,69	3	23,1	3	23,1	1	7,7	4	30,8	5	38,5	2	15,4
Transfer ratio CO2 and secondary raw materials	5	6,41	5	32,1	3	19,2	2	12,8	2	12,8	1	6,4	5	32,1
Utilization of existing waste as input material	4	5,13	1	5,1	1	5,1	1	5,1	1	5,1	1	5,1	1	5,1
Area required	3	3,85	1	3,8	4	15,4	4	15,4	4	15,4	1	3,8	4	15,4
direct CO2 utilization without capture	2	2,56	4	10,3	1	2,6	1	2,6	1	2,6	5	12,8	4	10,3
End product in the same industry sector	1	1,28	1	1,3	2	2,6	3	3,8	1	1,3	1	1,3	1	1,3
Sum	**78**	**100,00**		**278,2**		**316,7**		**259,0**		**305,1**		**300,0**		**392,3**

Table 28 The utility analysis of the refractory industry

The point ratings for the criteria end product in the same industry sector are similar to the electricity industry. Methanation got 2 points and fuels got 3 points in terms of this criterion. Also no wastes can be used to bind carbon dioxide for instance with mineral carbonation, so every CCU method got one point in the utilization of existing waste as input material criterion.

The best carbon capture method for a use in the refractory industry to utilize carbon dioxide is again enhanced oil recovery, followed by methanation, chemical feedstock, mineral carbonation, algae and fuels. It differs to the results of the other utility analysis.

4.4 FINAL RESULT OF THE UTILITY ANALYSIS

The final results from the utility analysis of each industry sector are summarized to one table illustrated below. This table should reflect the ranking of the different carbon dioxide utilization methods for the respective industry.

It is quite evident that the use of industrially captured carbon dioxide for tertiary oil production would be an excellent alternative for each of the industry sector. Further prioritization is given by mineral carbonation, methanation and chemical feedstock with two exceptions. The first exception is the cement and chalk industry. Here is the mineral carbonation before the production of chemical feedstock and methanation. The second exception could be found in the refractory industry, where methanation is on the second place, followed by the production of chemical raw materials and mineral carbonation. The use of carbon dioxide by microalgae and the production of fuels have occupied without exceptions the last places.

Industry sector	Carbon Capture and Utilization methods					
	algae	methanation	fuels	chemical feedstock	mineral carbonation	EOR
electricity industry	269	309	257	291	332	385
steel industry	263	298	252	285	328	401
cement & chalk industry	252	289	240	292	331	351
paper industry	258	289	246	283	306	385
chemical industry	277	302	237	298	335	382
refractory industry	278	317	259	305	300	392

Table 29 Final results

These results should support the industries in their CO_2 decision making management and furthermore visualize in which technologies research and development efforts should be intensified.

On the next page two charts are showing the results for a better illustration. The second chart shows only the results methanation, chemical feedstock and mineral carbonation.

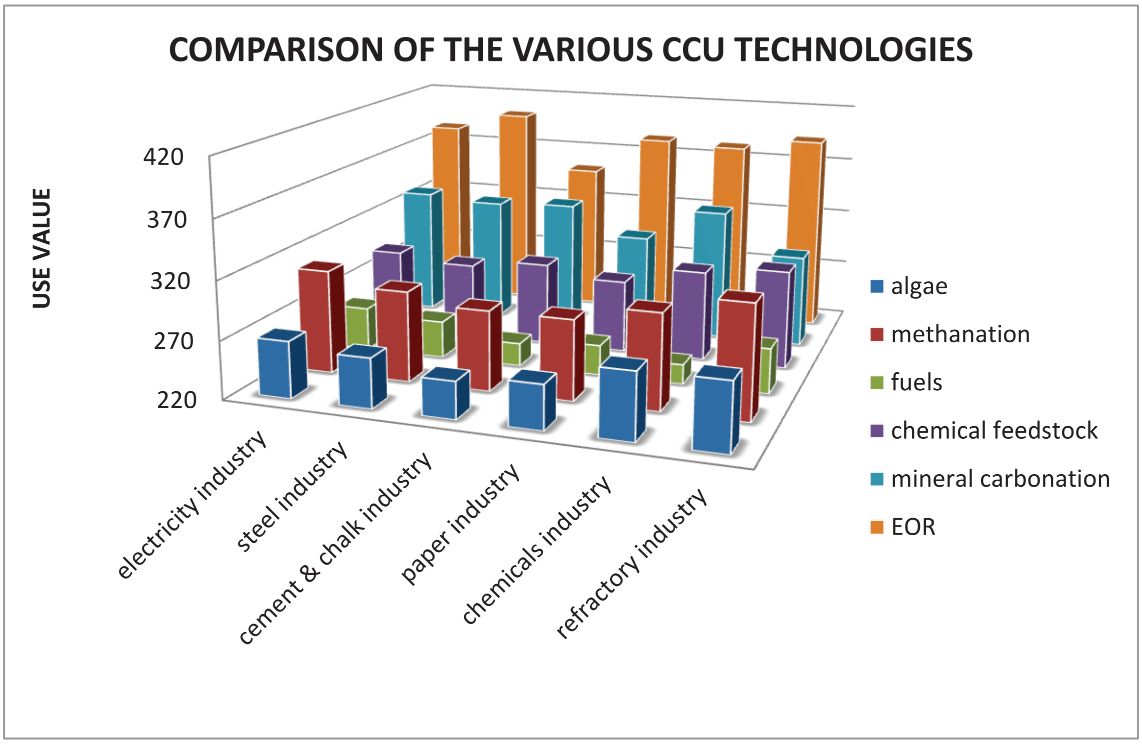


Figure 52 Comparison of the various CCU technologies

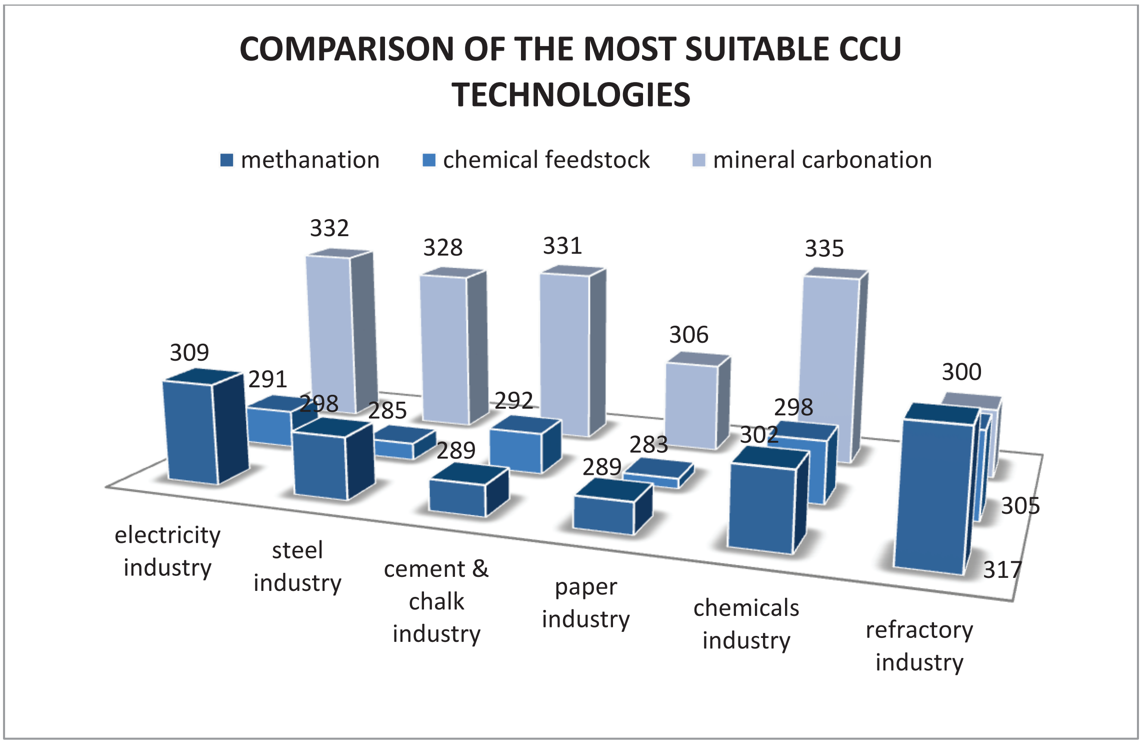


Figure 53 Comparison of the most suitable CCU technologies

5 CONCLUSION

5.1 INDIVIDUAL FINDINGS

Carbon dioxide is considered to be the major cause of the climate change, because of its greenhouse properties and continuous accumulation in the atmosphere. The result of this accumulation of emissions is seen in a continuous rising of the global average temperature. Without action to restrict emissions, there is a very high risk of global warming reaching well beyond 2°C relative to pre-industrial times. In the past 150 years an increase in average annual temperature of 1.8°C was recorded in Austria. Such global warming would increase the risk of accelerated or irreversible changes in the climate system.

2010 was the third year of the five-year Kyoto period and greenhouse gas emissions in Austria amounted to 84.6 million tons of carbon dioxide equivalents. Emissions in 2010 were thus 15.8 million tons above the annual mean value of the Kyoto target defined for 2008 – 2012. That's the reason why measures for avoiding carbon dioxide emissions and improving energy efficiency, as well as developing new energy sources and the partial conversion of the energy system from fossil fuels to renewable sources are discussed intense in recent times. However, different scenarios for the development of the atmospheric CO_2 concentration are showing that strategies for avoiding carbon dioxide emissions alone are insufficient to stop the climate change. In addition to these measures the use of the industrially separated carbon dioxide can make its contribution to the CO_2 management. The material use of CO_2 is based on his application as a carbon source for chemical, biochemical reactions or its direct use as an industrial gas to achieve a value added.

By identifying the best carbon capture and utilization method for a use in the Austrian industry, all industries in terms of emissions were recorded. Carbon dioxide emissions are mainly polluted in the sectors transport, industry, energy supply and lower consumer through the combustion of fossil fuels like natural gas, oil and coal. The sectors of interest for CCU technologies are the energy sector and industry sector. The main polluters in these sectors are the electricity industry, steel industry, petroleum industry, cement and chalk industry, paper industry as well as the chemical industry. These industries and in addition also other industry were interviewed using an online survey. 49 companies were contacted for the study, which covers 92 % of the total allocated certificates from Austria in the year 2012. Questionaires were answered from the electricity industry, steel industry, cement and chalk industry, paper industry, chemical industry and refractory industry. 23 filled out the form which corresponds to a flyback rate of 47 %, which is quite respectable.

On the whole the answers of the online questionaires indicate a direction and are pretty the same. A negative outlook was in relation to the achievement of emission targets for 2020, which turned out even more clearly for the targets for the year 2050. In addition, the overall effort of recording, monitoring and reporting of emissions from the view of the industry is considered as too high. While there is a general interest in new technologies, however, the willingness to invest is limited due to the low incentive. This results from an urgent need for action in terms of encouragement for CCU methods.

Regarding to the emission trading act I would like to quote a comment from a respondent, which reflects the overall picture very well. "The system is too complicated and expensive. An energy intensive industry is already highly motivated to save energy (carbon dioxide are energy costs) and does not require additional legal challenge to do so with very costly additional inspections. Savings are there anyway only a few available. The system is an additional punishment for already taken measures (they were not count and usually received no funding). On the other hand, industries with higher total CO_2 emissions (transport, households) are not subjected to forced savings because of political reasons. This force internationally operating European companies to migrate due to financial reasons. Decoupling between production and consumption is only slightly possible. Absolute forced saving prevents further economic growth."

Despite the use of carbon dioxide by a carbon capture and utilisation option, companies are subjected to the emission trading scheme. At present the amount of carbon dioxide used by a CCU method is not calculated against to the allotted emissions. This should be changed in the future.

In general the industry is interested in CO_2 capture and utilization, but is not planning to invest in a capture and utilization technologie in the near future. Unfortunately, there are only a handful companies in Austria which already capture carbon dioxide. Some of these companies already operate a CCU test facility or have plans in this direction. To achieve great progress in Austria in terms of CCU technologies the number of firms which are really acting is still too low.

The plurality of the respondents would be satisfied with a cost-covering CCU method and are ready to produce products that are not in their line of industry. Another result of the survey was that the space requirement of some CCU methods is a limiting factor.

Overall the obtained information of the survey was used to determine the best CCU technology for each industry by using a utility analysis, which distinguishes between five CCU alternatives: microalgae, chemical materials, fuels, mineral carbonation and enhanced oil recovery. The result of the analysis was quite evident that the use of industrially captured carbon dioxide for tertiary oil production would be an excellent alternative for each of the industry sector, but the market doesn't exist in Austria for EOR. Further prioritization was given by mineral carbonation, methanation and chemical feedstocks with two exceptions. The first exception is the cement and chalk industry. Here is the mineral carbonation before the production of chemical feedstocks and methanation. The second exception could be found in the refractory industry, where methanation is on the second place, followed by the production of chemical raw materials and mineral carbonation. The use of carbon dioxide by microalgae and the production of fuels have occupied without exceptions the last places.

5.2 GENERAL CONCLUSION

Current climate change scenarios of the IEA indicate a great potential of CCS as an option for reducing CO_2 emissions. Therefor CO_2 utilization is being increasingly recognized and would be in more sufficient quantities available for new and innovative applications. The use of CO_2 as C1 building block therefore has the potential to make a contribution to economic and environmentally friendly use of carbon dioxide, thus contributing to climate protection. Innovation potential can be found mainly in improved products and new processes, resulting in a higher value, which in turn is a primary economic driver. A positive feedback results in the climate policy by marketing.

Contamination of CO_2 determines the applications of the products. The applications may be sensitive to certain contaminants (e.g. urea regarding heavy metals used as fertilizer).

Another important criterion is the potential of CO_2 fixation. Amount of fixation and duration of fixation vary greatly depending on product and application. In the manufacture of fuels large amounts of CO_2 can be fixed, but the fixing time is low. Producing fine chemicals only needs small amounts of CO_2, but can sometimes have long fixation duration. In both cases, the relevance of climate change is rather low. Polymers or mineral carbonation can potentially save a lot carbon dioxide during manufacturing and also fix it very long. The potential for climate here is rather high. An estimate of the CO_2 fixation potential requires consideration of both aspects.

For the issue of climate relevance, not only the chemical fixation alone is crucial, as all conversions require energy which may correlate with CO_2 emissions. CO_2 savings can also result from the total energy balance and not only from the consumption of CO_2.

The generation of energy and CO_2 balances for the individual options of CO_2 use was not included in this study. But it is a fundamental requirement for the detailed assessment of CO_2 utilization methods and products, and should therefore be made in the context of future research activities. Furthermore, the value added is a critical element of the assessment and has to be expected in utilization strategies.

5.3 RECOMMENDATIONS

Considerable research is being conducted in many directions to further the economic viability of processes that utilize CO_2, but federal subsidies and therefore research activities are always subjected to strong fluctuations. To promote research and innovation in Austria and to close the gap between basic research and industrial application, it is important to link stronger public research and industry through appropriate associations. Demonstration plants are needed to test the feasibility of an industrial scale. They should be more aided in the future. Measures to support the use of carbon dioxide should be focused on the free assessment criteria: amount of fixation, duration of fixation and in particular the resulting value added.

To ensure the industrial location Europe, especially Austria, it is necessary to change the legal framework conditions and increase promotions in terms of CCU options. Currently energy intensive firms are only punished, which leads these companies maybe to change the location. They are forced to reduce their emissions, but they will not be rewarded to do so. To create an incentive the amount of carbon dioxide used by a carbon dioxide and utilisation method has to be calculated against to the CO_2 emissions. To promote the development of carbon capture and utilisation methods in Austria the promotions by the state or country has to be increased. Currently only few companies in Austria are developing and researching in CCU methods and they would only share their know-how very expensive. This must be prevented to do really something for the environment and against the climate change.

There should be more research carried out to consider the feasibility and economic benefits of CCU to the Austrian economy. It is particularly important to consider the role that synthetic liquid fuel production from chemical catalytic and algal technologies can play in reducing the Austria's dependence on oil rich nations for the maintenance of energy supply.

A number of innovative technologies are on the verge of implementation. Biomass conversion to fuels is perhaps the most intensively pursued route, not only to mitigate CO_2 emissions, but also to secure alternative fuel supply. Conversion of biomass into alcohols and algae into biodiesel or other hydrocarbon fuel is predicted to become extensively adopted in the coming decades. Lifecycle assessments of these fuel sources demonstrate considerable reductions in CO_2 emissions compared with petroleum fuels. However, their present economic viability is dependent on government subsidies.

Several companies are pursuing chemical conversion of CO_2 into chemical feedstock or polymers. Research and development are currently focused towards reducing the temperature of conversion, increasing catalyst life, and decreasing the use of consumables. Conversion of CO_2 into minerals has advanced significantly. Carbon policies that impose a significant increase in carbon prices are necessary to sustain these efforts until they can become economically viable.

Since hydrogen is currently produced almost entirely from fossil fuels, a reduction of carbon dioxide emissions would only be feasible when using hydrogen from CO_2 free sources. Almost all infrastructure facilities required for establishment of the fuel, such as the hydrogen production, transport and distribution are not available in Austria.

The electro-and especially photocatalytic reduction of CO_2 would be the most elegant form of carbon dioxide utilization, because it imitates the synthesis power of nature in photosynthesis. Both heterogeneous (mainly based on TiO_2 as a photosensitizer) and homogeneous (mainly based on ruthenium and rhenium- bipyridine complexes) catalysts have been and are being intensely investigated. Existing systems, however, require significant improvements before a technically acceptable efficiency can be reached.

Carbon Capture and Utilization offers the opportunity for investors to profit from the production of consumer chemicals by treating CO_2 as a commodity rather than as a waste product. The positive contributions that CCU can make to the economy needs to be emphasised through strategic publications.

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LIST OF APPENDICES

CONTENT

APPENDIX A

CONTENT:

LIST OF FACTORIES

PLANT	OPERATOR	ACTIVITY
AGRANA Aschach	AGRANA Stärke GmbH	Feuerungsanlagen > 20 MW
Bioethanolanlage Pischelsdorf	AGRANA Bioethanol GmbH	Feuerungsanlagen > 20 MW
AGRANA Gmünd	AGRANA Stärke GmbH	Feuerungsanlagen > 20 MW
AGRANA Leopoldsdorf	AGRANA Zucker GmbH	Feuerungsanlagen > 20 MW
AGRANA Tulln	AGRANA Zucker GmbH	Feuerungsanlagen > 20 MW
AMAG Service Ranshofen	AMAG Service GmbH	Feuerungsanlagen > 20 MW
AMI Agrolinz Melamine International Linz	Borealis Agrolinz Melamine GmbH	Feuerungsanlagen > 20 MW
Baumit Baustoffe Bad Ischl	"BAUMIT" Baustoffe Gesellschaft m.b.H.	Zementklinker- oder Kalkproduktion
Bernegger Molln Ofen 1	Bernegger GmbH	Zementklinker- oder Kalkproduktion
Bernegger Molln Ofen 2	Bernegger GmbH	Zementklinker- oder Kalkproduktion
Bernegger Molln Ofen 3	Bernegger GmbH	Zementklinker- oder Kalkproduktion
CMST Thondorf Graz BHKW	Steirische Gas-Wärme GmbH	Feuerungsanlagen > 20 MW
BMW Motoren Steyr	BMW Motoren GmbH	Feuerungsanlagen > 20 MW
Borealis Agrolinz Melamine Salpetersäu-reanlage	Borealis Agrolinz Melamine GmbH	Sonstige Aktivitäten
Borealis Schwechat	Borealis Polyolefine GmbH	Feuerungsanlagen > 20 MW
Brau Union Göss Leoben	Brau Union Österreich Aktiengesell-schaft	Feuerungsanlagen > 20 MW
Brau Union Puntigam Graz	Brau Union Österreich Aktiengesell-schaft	Feuerungsanlagen > 20 MW
Breitenfelder Edelstahl Mitterdorf	Breitenfeld Edelstahl AG	Roheisen- oder Stahlerzeugung
Brigl & Bergmeister Niklasdorf	Brigl & Bergmeister GmbH	Zellstoff- oder Papierproduktion
CMOÖ GuD Anlage Laakirchen	Cogeneration-Kraftwerke Management Oberösterreich GmbH	Feuerungsanlagen > 20 MW
Comelli Ziegel Kirchbach Maxendorf	Comelli-Ziegel Gesellschaft m.b.H.	Ziegel- oder sonstige Keramikproduktion
TEICH AG Weinburg	Constantia Teich GmbH	Feuerungsanlagen > 20 MW
DKW Voitsberg	A-Tec Beteiligungs GmbH	Feuerungsanlagen > 20 MW
DSM Fine Chemicals Austria Linz	DSM Fine Chemicals Austria Nfg GmbH & CoKG	Feuerungsanlagen > 20 MW
Dynea Krems	Dynea Austria GmbH	Feuerungsanlagen > 20 MW
KW Timelkam IV	Gas- und Dampfkraftwerk Timelkam GmbH	Feuerungsanlagen > 20 MW
Energie- und Medienzentrale Heiligen-kreuz	Lenzing Fibers GmbH	Feuerungsanlagen > 20 MW
Energie-Contracting Steyr	Energie-Contracting Steyr GmbH	Feuerungsanlagen > 20 MW
Energiepark Donawitz	voestalpine Stahl Donawitz GmbH & Co KG	Feuerungsanlagen > 20 MW
Ernstbrunner Kalktechnik Ernstbrunn	Ernstbrunner Kalktechnik GmbH	Zementklinker- oder Kalkproduktion
EVN Baxter Krems	Baxter AG	Feuerungsanlagen > 20 MW
EVN BHKW Krankenhaus Mistelbach	EVN Wärme GmbH	Feuerungsanlagen > 20 MW
EVN COGEN Agrana Tulln	EVN Wärme GmbH	Feuerungsanlagen > 20 MW
EVN Cogen Salzer St. Pölten	EVN Wärme GmbH	Feuerungsanlagen > 20 MW
EVN FHKW Mödling	EVN Wärme GmbH	Feuerungsanlagen > 20 MW
EVN FHKW Wr. Neustadt	EVN Wärme GmbH	Feuerungsanlagen > 20 MW
EVN FHW Baden	EVN Wärme GmbH	Feuerungsanlagen > 20 MW
EVN FHW Palmers Wr. Neudorf	EVN Wärme GmbH	Feuerungsanlagen > 20 MW
EVN KW Dürnrohr Zwentendorf	EVN AG	Feuerungsanlagen > 20 MW

EVN KW Kornneuburg	EVN AG	Feuerungsanlagen > 20 MW
EVN KW Theiß Gedersdorf	EVN AG	Feuerungsanlagen > 20 MW
F.M. Hämmerle Dornbirn	F.M. Hämmerle Textil Produktion und Vertrieb GmbH	Feuerungsanlagen > 20 MW
Feinpapier Feurstein Traun	Dr. Franz Feurstein Gesellschaft m.b.H.	Zellstoff- oder Papierproduktion
Fernheizwerk Grillgasse Wien	ÖBB-Infrastruktur Aktiengesellschaft	Feuerungsanlagen > 20 MW
FHKW Arsenal Fernwärme Wien	Fernwärme Wien GmbH	Feuerungsanlagen > 20 MW
FHKW Dornach Linz AG Linz	LINZ STROM GmbH	Feuerungsanlagen > 20 MW
FHKW Kagran Fernwärme Wien	Fernwärme Wien GmbH	Feuerungsanlagen > 20 MW
FHKW Klagenfurt Stadtwerke Klagenfurt	Stadtwerke Klagenfurt AG	Feuerungsanlagen > 20 MW
LS FHKW Mitte Linz Linie 1b	LINZ STROM GmbH	Feuerungsanlagen > 20 MW
FHKW Nord StW St. Pölten	Fernwärme St. Pölten GmbH	Feuerungsanlagen > 20 MW
FHKW Spittelau Fernwärne Wien	Fernwärme Wien GmbH	Feuerungsanlagen > 20 MW
FHKW Steirische Gas-Wärme Graz	Steirische Gas-Wärme GmbH	Feuerungsanlagen > 20 MW
FHKW Süd Inzersdorf	Fernwärme Wien GmbH	Feuerungsanlagen > 20 MW
FHKW Süd StW St. Pölten	Fernwärme St. Pölten GmbH	Feuerungsanlagen > 20 MW
KW CMST Thondorf Graz	Steirische Gas-Wärme GmbH	Feuerungsanlagen > 20 MW
FHKW WelsStrom Wels	Wels Strom GmbH	Feuerungsanlagen > 20 MW
Frantschach St. Gertraud	Mondi Frantschach GmbH	Zellstoff- oder Papierproduktion
Fritz Egger St. Johann Tirol	Fritz Egger GmbH. & Co. OG	Feuerungsanlagen > 20 MW
Fritz Egger Unterradlberg	Fritz Egger GmbH. & Co. OG	Feuerungsanlagen > 20 MW
Fritz Egger Wörgl	Fritz Egger GmbH. & Co. OG	Feuerungsanlagen > 20 MW
Funder Neudörfl	FunderMax GmbH	Feuerungsanlagen > 20 MW
Funder Werk 1 St. Veit/Glan	FunderMax GmbH	Feuerungsanlagen > 20 MW
FW Kirchdorf	Energie AG Oberösterreich Wärme GmbH	Feuerungsanlagen > 20 MW
FW Leopoldau Fernwärme Wien	Fernwärme Wien GmbH	Feuerungsanlagen > 20 MW
FW Voitsberg Bärnbach	Steirische Gas-Wärme GmbH	Feuerungsanlagen > 20 MW
Glanzstoff St. Pölten	Glanzstoff Austria GmbH	Feuerungsanlagen > 20 MW
Gmundner Zement Gmunden	Zementwerk Hatschek GmbH	Zementklinker- oder Kalkproduktion
Herbert Pexider GmbH Teufenbach	Herbert Pexider Gesellschaft m.b.H.	Ziegel- oder sonstige Keramikproduktion
Hilti Mettauer Götzis	Ziegelei Hilti, Mettauer GmbH	Ziegel- oder sonstige Keramikproduktion
Isomax Dekorative Laminate Wiener Neudorf	FunderMax GmbH	Feuerungsanlagen > 20 MW
Jungbunzlauer Rohstoffanlage Pernh-ofen	Jungbunzlauer Austria AG	Sonstige Aktivitäten
Jungbunzlauer Wulzeshofen	Jungbunzlauer Austria AG	Feuerungsanlagen > 20 MW
Kaindl Holzindustrie Wals	M. Kaindl KG	Feuerungsanlagen > 20 MW
Kalkwerk Tagger (Leube) Golling	Zementwerk Leube Gesellschaft m.b.H.	Zementklinker- oder Kalkproduktion
Kelag Wärme Badgastein	Kelag Wärme GmbH	Feuerungsanlagen > 20 MW
Kelag Wärme Lactoprot Hartberg	Kelag Wärme GmbH	Feuerungsanlagen > 20 MW
Kelag Wärme Linz Bindermichl	Kelag Wärme GmbH	Feuerungsanlagen > 20 MW
Kelag Wärme Pinkafeld	Kelag Wärme GmbH	Feuerungsanlagen > 20 MW
Kelag Wärme Scheydgasse Wien	Kelag Wärme GmbH	Feuerungsanlagen > 20 MW
Kelag Wärme St. Magdalen	Kelag Wärme GmbH	Feuerungsanlagen > 20 MW
Kunert Rankweil	GasserKunert GmbH	Feuerungsanlagen > 20 MW
KW Riedersbach	Energie AG Oberösterreich	Feuerungsanlagen > 20 MW

KW Timelkam II	Energie AG Oberösterreich	Feuerungsanlagen > 20 MW
KW Timelkam III	Energie AG Oberösterreich	Feuerungsanlagen > 20 MW
Lafarge Perlmooser Mannersdorf	Lafarge Zementwerke GmbH	Zementklinker- oder Kalkproduktion
Lafarge Perlmooser Retznei	Lafarge Zementwerke GmbH	Zementklinker- oder Kalkproduktion
Leitl Spannton Eferding	Leitl Spannton Gesellschaft m.b.H.	Ziegel- oder sonstige Keramikproduktion
Lenzing AG Faser+Energie 1, Zellstoff, Papier	Lenzing AG	Zellstoff- oder Papierproduktion
Lias Fehring	Lias Österreich GesmbH	Ziegel- oder sonstige Keramikproduktion
LS FHKW Mitte Linz Linie 1a	LINZ STROM GmbH	Feuerungsanlagen > 20 MW
LS FHKW Süd Linz	LINZ STROM GmbH	Feuerungsanlagen > 20 MW
Magna Steyr Werk 1 Graz	MAGNA STEYR Fahrzeugtechnik AG & Co KG	Feuerungsanlagen > 20 MW
Magna Steyr Werk 2 Graz	MAGNA STEYR Fahrzeugtechnik AG & Co KG	Feuerungsanlagen > 20 MW
Mayr Melnhof Karton Frohnleiten	Mayr-Melnhof Karton Gesellschaft m.b.H.	Zellstoff- oder Papierproduktion
Mayr Melnhof Karton Frohnleiten Antrieb KM2	Mayr-Melnhof Karton Gesellschaft m.b.H.	Feuerungsanlagen > 20 MW
Mayr Melnhof Karton Frohnleiten Antrieb KM3	Mayr-Melnhof Karton Gesellschaft m.b.H.	Feuerungsanlagen > 20 MW
Mayr Melnhof Karton Hirschwang	Mayr-Melnhof Karton Gesellschaft m.b.H.	Zellstoff- oder Papierproduktion
MDF (Binder) Hallein	Mitteldichte Faserplatten Hallein GmbH & Co KG	Feuerungsanlagen > 20 MW
Merckens Schwertberg	Merckens Karton- und Pappenfabrik GmbH	Zellstoff- oder Papierproduktion
Mondi Packaging Frohnleiten	W. Hamburger GmbH	Zellstoff- oder Papierproduktion
M-real Hallein	Schweighofer Fiber GmbH	Zellstoff- oder Papierproduktion
Nettingsdorfer Ansfelden	Nettingsdorfer Papierfabrik AG & Co KG	Zellstoff- oder Papierproduktion
Neusiedler Hausmening	Mondi Neusiedler GmbH	Zellstoff- oder Papierproduktion
Neusiedler Kematen	Mondi Neusiedler GmbH	Zellstoff- oder Papierproduktion
Neusiedler Zellstoff Kematen	Ybbstaler Zellstoff GmbH	Zellstoff- oder Papierproduktion
Norske Skog Bruck GmbH	Norske Skog Bruck GmbH	Zellstoff- oder Papierproduktion
Novopan-Holzind Nachf. (Egger) Leoben	Österreichische Novopan Holzindustrie OG	Feuerungsanlagen > 20 MW
ÖBB TS Werk Floridsdorf Wien	ÖBB-Infrastruktur Aktiengesellschaft	Feuerungsanlagen > 20 MW
Ölmühle Bunge Bruck a.d. Leitha	Bunge Austria GmbH	Feuerungsanlagen > 20 MW
OMV Biturox-Anlage	OMV Refining & Marketing GmbH	Mineralölraffinerien
OMV Ethylenanlage AC 2 Erweiterung	OMV Refining & Marketing GmbH	Mineralölraffinerien
OMV Gasstation Aderklaa I	OMV Austria Exploration & Production GmbH	Feuerungsanlagen > 20 MW
OMV Gasstation Aderklaa II	OMV Austria Exploration & Production GmbH	Feuerungsanlagen > 20 MW
OMV SNOx-Anlage	OMV Refining & Marketing GmbH	Mineralölraffinerien
OÖ Tierkörperverwertung Regau	AVE Tierkörperverwertungs GmbH	Feuerungsanlagen > 20 MW
Papierfabrik Hamburger Pitten	W. Hamburger GmbH	Zellstoff- oder Papierproduktion
Papierfabrik Wattens	Papierfabrik Wattens GmbH & Co KG	Feuerungsanlagen > 20 MW
Paul Hartmann GmbH Grimmenstein	Paul Hartmann Gesellschaft mbH	Zellstoff- oder Papierproduktion
Raffinerie Schwechat	OMV Refining & Marketing GmbH	Mineralölraffinerien
Rath GmbH Krummnußbaum	Chamottewaren- und Thonöfenfabrik Aug. Rath jun. GmbH	Ziegel- oder sonstige Keramikproduktion
Rauch Nüziders	RAUCH Fruchtsäfte GmbH & Co OG	Feuerungsanlagen > 20 MW
Rondo Ganahl Frastanz	Ganahl Aktiengesellschaft	Zellstoff- oder Papierproduktion
Saint-Gobain Isover Austria	Saint-Gobain Isover Austria GmbH	Glas- oder Glasfaserproduktion

Salzburg AG FHKW Mitte Salzburg	Salzburg AG für Energie, Verkehr und Telekommunikation	Feuerungsanlagen > 20 MW
Salzburg AG FHKW Nord Salzburg	Salzburg AG für Energie, Verkehr und Telekommunikation	Feuerungsanlagen > 20 MW
Salzburg AG HW Süd Salzburg	Salzburg AG für Energie, Verkehr und Telekommunikation	Feuerungsanlagen > 20 MW
Salzburg AG LKH Salzburg	Salzburg AG für Energie, Verkehr und Telekommunikation	Feuerungsanlagen > 20 MW
Salzburger Ziegelwerk Oberndorf	Salzburger Ziegelwerk Gesellschaft m.b.H. & Co	Zementklinker- oder Kalkproduktion
Sandoz Werk Kundl	SANDOZ GmbH	Feuerungsanlagen > 20 MW
Sappi Gratkorn	Sappi Austria Produktions-GmbH & Co. KG	Zellstoff- oder Papierproduktion
Sappi Gratkorn Neuanlage	Sappi Austria Produktions-GmbH & Co. KG	Zellstoff- oder Papierproduktion
SCA Laakirchen	SCA Graphic Laakirchen AG	Feuerungsanlagen > 20 MW
SCA Ortmann	SCA Hygiene Products GmbH	Zellstoff- oder Papierproduktion
Schretter & Cie (Kalk) Vils	Schretter & Cie GmbH & Co KG	Zementklinker- oder Kalkproduktion
Schretter & Cie (Zement) Vils	Schretter & Cie GmbH & Co KG	Zementklinker- oder Kalkproduktion
Semperit Technische Produkte Wimpassing	Semperit Technische Produkte Gesellschaft m.b.H.	Feuerungsanlagen > 20 MW
Sinteranl., Hochöfen, Stahlwerk Donawitz	voestalpine Stahl Donawitz GmbH & Co KG	Röst- oder Sinteranlagen
Solvay Ebensee	Solvay Österreich GmbH	Feuerungsanlagen > 20 MW
Stadtwärme Lienz	Stadtwärme Lienz Produktions- und Vertriebs-GmbH	Feuerungsanlagen > 20 MW
Stadtwerke Kufstein	Bioenergie Kufstein GmbH	Feuerungsanlagen > 20 MW
Stahlproduktion Böhler Edelstahl Kapfenberg	Böhler Edelstahl GmbH & Co KG	Roheisen- oder Stahlerzeugung
Stahlwerk Marienhütte GmbH	Stahl- und Walzwerk Marienhütte Gesellschaft m.b.H.	Roheisen- oder Stahlerzeugung
Steyrermühl AG Steyrermühl	UPM-Kymmene Austria GmbH	Zellstoff- oder Papierproduktion
Stölzle-Oberglas Köflach	Stölzle-Oberglas GmbH	Glas- oder Glasfeserproduktion
Stw Heizwerk Süd Klagenfurt	Energie Klagenfurt GmbH	Feuerungsanlagen > 20 MW
Swarovski Wattens	D. Swarovski KG	Glas- oder Glasfeserproduktion
Swarovski Wattens Neuanlage	D. Swarovski KG	Glas- oder Glasfeserproduktion
Technoglas Voitsberg	Technoglas Produktions-Gesellschaft m.b.H.	Glas- oder Glasfeserproduktion
Tondach Gleinstätten	Tondach Gleinstätten AG	Ziegel- oder sonstige Keramikproduktion
Tondach Pinkafeld	Tondach Gleinstätten AG	Ziegel- oder sonstige Keramikproduktion
Tondach Unterpremstätten	Tondach Gleinstätten AG	Ziegel- oder sonstige Keramikproduktion
Veitsch-Radex Breitenau	Veitsch-Radex GmbH & Co OG	Feuerungsanlagen > 20 MW
Veitsch-Radex Hochfilzen	Veitsch-Radex GmbH & Co OG	Feuerungsanlagen > 20 MW
Veitsch-Radex Radenthein	Veitsch-Radex GmbH & Co OG	Ziegel- oder sonstige Keramikproduktion
Veitsch-Radex Trieben	Veitsch-Radex GmbH & Co OG	Ziegel- oder sonstige Keramikproduktion
Veitsch-Radex Veitsch	Veitsch-Radex GmbH & Co OG	Ziegel- oder sonstige Keramikproduktion
Verbrennungsanlagen Böhler Edelstahl Kapfenberg	Böhler Edelstahl GmbH & Co KG	Feuerungsanlagen > 20 MW
Verbund FHKW Mellach	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW
Verbund FHKW Werndorf 1 Wildon	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW
Verbund FHKW Werndorf 2 Wildon	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW
Verbund GDK Mellach (Neuanlage § 11/7)	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW
Verbund KW Dürnrohr Zwentendorf	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW

Verbund KW Korneuburg	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW
Verbund KW St. Andrä	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW
Verbund KW Zeltweg	VERBUND Thermal Power GmbH & CO KG	Feuerungsanlagen > 20 MW
Vetropack Kremsmünster	Vetropack Austria GmbH	Glas- oder Glasfeserproduktion
Vetropack Pöchlarn	Vetropack Austria GmbH	Glas- oder Glasfeserproduktion
Voestalpine Donawitz Kohleeinblasung	voestalpine Stahl Donawitz GmbH & Co KG	Feuerungsanlagen > 20 MW
Voestalpine Donawitz sonstige Anlagen	voestalpine Stahl Donawitz GmbH & Co KG	Feuerungsanlagen > 20 MW
Voestalpine Kokerei Linz	voestalpine Stahl GmbH	Kokereien
Voestalpine Kraftwerk Linz	voestalpine Stahl GmbH	Feuerungsanlagen > 20 MW
Voestalpine L6 Erweiterung	voestalpine Stahl GmbH	Feuerungsanlagen > 20 MW
Voestalpine Stahl Linz	voestalpine Stahl GmbH	Röst- oder Sinteranlagen
VOEST-Alpine Stahl Linz (Kalk) Steyrling	voestalpine Stahl GmbH	Zementklinker- oder Kalkproduktion
Voestalpine Stahl Linz sonstige Anlagen	voestalpine Stahl GmbH	Feuerungsanlagen > 20 MW
W&P Kalkwerk Peggau Neuanlage	w&p Kalk GmbH	Feuerungsanlagen > 20 MW
W&P Zementwerk Wietersdorf Neuanlage	w&p Zement GmbH	Feuerungsanlagen > 20 MW
Inn Crystal Glass Braunau	Walther GmbH	Glas- oder Glasfeserproduktion
Wärmebetriebe FHW Innrain Innsbruck TILAK	TILAK-Tiroler Landeskrankensanstalten GmbH	Feuerungsanlagen > 20 MW
Wienerberger Fürstenfeld	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienerberger Göllersdorf	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienerberger Helpfau Uttendorf	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienerberger Hennersdorf	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienerberger Knittelfeld (Apfelberg)	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienerberger Krengelbach Haiding	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienerberger Laa Thaya	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienerberger Rotenturm	Wienerberger Ziegelindustrie GmbH	Ziegel- oder sonstige Keramikproduktion
Wienstrom KW Donaustadt Wien	WIEN ENERGIE GmbH	Feuerungsanlagen > 20 MW
Wienstrom KW Leopoldau Wien	WIEN ENERGIE GmbH	Feuerungsanlagen > 20 MW
Wienstrom KW Simmering Wien	WIEN ENERGIE GmbH	Feuerungsanlagen > 20 MW
Wienstrom Simmering Block 1+2 (Bestandsanlage)	WIEN ENERGIE GmbH	Feuerungsanlagen > 20 MW
Wienstrom Simmering Block 1+2	WIEN ENERGIE GmbH	Feuerungsanlagen > 20 MW
Wiesner-Hager Altheim	Wiesner-Hager Zentrale Dienste G.m.b.H.	Feuerungsanlagen > 20 MW
Wietersdorfer & Peggauer (Kalk) Peggau	w&p Kalk GmbH	Zementklinker- oder Kalkproduktion
Wietersdorfer & Peggauer Zement Peggau	w&p Zement GmbH	Zementklinker- oder Kalkproduktion
Wietersdorfer & Peggauer Zement Wietersdorf	w&p Zement GmbH	Zementklinker- oder Kalkproduktion
Wopfinger Baustoffindustrie Waldegg	Wopfinger Baustoffindustrie GmbH	Zementklinker- oder Kalkproduktion
Wopfinger Zement Waldegg	Wopfinger Baustoffindustrie GmbH	Zementklinker- oder Kalkproduktion
Wopfinger Zement Waldegg Neuanlage	Wopfinger Baustoffindustrie GmbH	Zementklinker- oder Kalkproduktion
Zellstoff Pöls	Zellstoff Pöls Aktiengesellschaft	Zellstoff- oder Papierproduktion
Zellstoff Pöls Neuanlage	Zellstoff Pöls Aktiengesellschaft	Zementklinker- oder Kalkproduktion
Zementwerk Hofmann Kirchdorf	Kirchdorfer Zementwerk Hofmann GmbH	Zementklinker- oder Kalkproduktion
Zementwerke Leube Gartenau	Zementwerk Leube Gesellschaft m.b.H.	Zementklinker- oder Kalkproduktion
Ziegelwerk Brenner Wirth St. Andrä	Ziegelwerk Brenner, F. Wirth Gesellschaft m.b.H.	Ziegel- oder sonstige Keramikproduktion

Ziegelwerk Danreiter Ried im Innkreis	Ziegelwerk Danreiter & Co KG	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Eberschwang	Ziegelwerk Eberschwang Gesellschaft m.b.H.	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Eder Peuerbach Bruck	Ziegelwerk Eder GmbH & Co.KG.	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Eder Weibern	Ziegelwerk Eder GmbH & Co.KG.	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Frixeder Senftenbach	SENFTENBACHER Ziegelwerk Flotzinger GmbH & Co KG	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Lizzi Erlach	Ziegelwerk Lizzi GmbH	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Martin Pichler Aschach	Martin Pichler Ziegelwerk GmbH.	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Nicoloso Pottenbrunn	Vittorio Nicoloso	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Obermair Neuhofen	Ziegelwerk Neuhofen K.F. u. DI H. Obermair GmbH & Co KG	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Pichler Wels	Ziegelwerk Pichler Wels Gesellschaft m.b.H.	Ziegel- oder sonstige Keramikproduktion
Ziegelwerk Rhomberg-Dornbirn	Ziegelei Rhomberg Gesellschaft m.b.H.	Zementklinker- oder Kalkproduktion

Table 30 List of the factories which getting CO_2 emission certificates[188]

[188]Ministry of Life (2007)

APPENDIX B

CONTENT:

NATIONAL ALLOCATION PLAN 2012

CODE	PLANT NAME	2012		Survey received		
	I. Energy	10.977.430	36,38%			
	Electricity Industry					
EEW001	Energie AG OÖ KW Riedersbach	437.140	1,45%	x	437.140	
EEW002	Energie AG OÖ KW Timelkam II	37.606	0,12%	x	37.606	
EEW004	EVN KW Dürnrohr	901.136	2,99%	x	901.136	
EEW007	Verbund KW Dürnrohr	1.139.438	3,78%	x	1.139.438	
EEW009	Verbund FHKW Mellach	734.102	2,43%	x	734.102	
EEW011	Verbund KW St. Andrä	0	0,00%	x	0	
EEW012	Verbund KW Voitsberg	0	0,00%	x	0	
EEW015	Verbund KW Zeltweg	0	0,00%	x	0	
EEW014	Verbund FHKW Werndorf 2	250.267	0,83%	x	250.267	
EEW025	Salzburg AG FHKW Nord	61.991	0,21%			
EEW003	Energie AG OÖ KW Timelkam III	6.268	0,02%	x	6.268	
EEW005	EVN KW Kornneuburg	102.267	0,34%	x	102.267	
EEW006	EVN KW Theiß	449.521	1,49%	x	449.521	
EEW008	Verbund KW Korneuburg	0	0,00%	x	0	
EEW013	Verbund FHKW Werndorf 1	0	0,00%	x	0	
EEW018	EVN BHKW Krankenhaus Mistelbach 8	3.206	0,01%	x	3.206	
EEW019	EVN FHKW Mödling	20.316	0,07%	x	20.316	
EEW020	EVN Cogen Salzer St. Pölten	42.675	0,14%	x	42.675	
EEW021	Linz Strom FHKW Mitte Linie 1a	272.540	0,90%	x	272.540	
EEW022	Linz Strom FHKW Mitte Linie 1b	238.941	0,79%	x	238.941	
EEW023	Linz Strom FHKW Süd	306.698	1,02%	x	306.698	
EEW024	Salzburg AG FHKW Mitte	181.423	0,60%			
EEW028	Wels Strom FHKW Wels	74.703	0,25%			
EEW029	Wienstrom KW Leopoldau	304.721	1,01%	x	304.721	
EEW030	Wienstrom KW Donaustadt	933.401	3,09%	x	933.401	
EEW031	Wienstrom KW Simmering Block 3	693.569	2,30%	x	693.569	
EEW230	Wienstrom Simmering Block 1+2 (Bestandsanlage)	475.229	1,57%	x	475.229	
EEW016	Energie AG GuD Kraftwerk Timelkam (Neuanlage § 11/7) 9			x	0	
EEW210	Verbund GDK Mellach (Neuanlage § 11/7) 9			x	0	
EEW209	Verbund GDK Klagenfurt (Neuanlage § 11/7) 9			x	0	
EEW231	Wienstrom Simmering Block 1+2 (Neuanlage § 11/7) 9			x	0	
		7.667.158	**25,41%**		**7.349.041**	**95,85%**

	District heating					
EFE017	Energie AG OÖ FW Kirchdorf	13.656	0,05%	x	13.656	
EFE027	Stw Klagenfurt FHKW Klagenfurt	151.140	0,50%			
EFE032	EVN FHW Baden	16.567	0,05%	x	16.567	
EFE033	EVN FHW Palmers Wr. Neudorf	7.119	0,02%	x	7.119	
EFE034	EVN FHKW Wr. Neustadt	5.940	0,02%	x	5.940	
EFE035	Salzburg AG HW Süd	411	0,00%			
EFE036	Linz Strom FHKW Dornach	142	0,00%	x	142	
EFE037	Steirische Gas-Wärme FHKW Graz	23.903	0,08%			
EFE038	CMST KW Thondorf Graz	89.789	0,30%			
EFE229	CMST Thondorf Graz BHKW (Neuanlage § 11/7)	11.724	0,04%			
EFE039	Kelag FHKW St. Magdalen	23.643	0,08%			
EFE040	StW St.Pölten FHKW Nord	52.901	0,18%			
EFE041	StW St.Pölten FHKW Süd	14.295	0,05%			
EFE042	Fernwärme Wien FHKW Spittelau	14.598	0,05%			
EFE043	Fernwärme Wien FHKW Süd Inzersdorf	6.952	0,02%			
EFE044	Fernwärme Wien FHKW Kagran	4.907	0,02%			
EFE045	Fernwärme Wien FW Leopoldau	3.435	0,01%			
EFE046	Fernwärme Wien FHKW Arsenal	4.997	0,02%			
EFE047	Bioenergie Kufstein	6.253	0,02%			
EFE048	STGW FW Voitsberg Bärnbach	20.716	0,07%			
EFE049	Salzburg AG LKH Salzburg	7.684	0,03%			
EFE050	Wärmebetriebe FHW Badgastein	8.794	0,03%			
EFE051	TILAK FHW Innrain Innsbruck	15.337	0,05%			
EFE052	Wärmebetriebe Lactoprot Hartberg	2.312	0,01%			
EFE053	ÖBB FHW Grillgasse Wien	6.370	0,02%			
EFE054	ÖFWG FHW Scheydgasse Wien	7.270	0,02%			
EFE055	ÖFWG FW Pinkafeld	11.573	0,04%			
EFE056	ÖFWG FW Linz Bindermichl	126	0,00%			
EFE057	Energie Klagenfurt GmbH Heizwerk Süd	719	0,00%			
EFE058	Stadtwärme Lienz Lienz	2.017	0,01%			
EFE206	ÖBB TS Werk Floridsdorf Wien	6.679	0,02%			
		541.969	**1,80%**		**43.424**	**8,01%**

	Petroleum Industry					
EMV059	OMV EPI Gasstation Aderklaa II	14.214	0,05%	x	14.214	
EMV060	OMV EPI Gasstation Aderklaa I	28.547	0,09%	x	28.547	
EMV061	OMV Raffinerie Schwechat	2.491.436	8,26%	x	2.491.436	
EMV232	OMV Biturox-Anlage (Neuanlage § 11/7)	5.949	0,02%	x	5.949	
EMV233	OMV Ethylenanlage AC 2 Erweiterung (Neuanlage § 11/7)	215.413	0,71%	x	215.413	
EMV234	OMV SNOx-Anlage (Neuanlage § 11/7)	12.744	0,04%	x	12.744	
		2.768.303	**9,17%**		**2.768.303**	**100,0%**

	II. Industry	**19.196.320**	**63,62%**			
	Steel industry					
IVA062	Voestalpine Stahl Linz	4.380.526	14,52%	x	4.380.526	
IVA063	Voestalpine Kokerei Linz	985.761	3,27%	x	985.761	
IVA064	Voestalpine Kraftwerk Linz	1.771.401	5,87%	x	1.771.401	
IVA235	Voestalpine L6 Erweiterung (Neuanlage § 11/7)	556.899	1,85%	x	556.899	
IVA224	Voestalpine Stahl Linz sonstige Anlagen (in NAP I nicht enthalten)	291.348	0,97%	x	291.348	
IVA065	Voestalpine Stahlwerk Donawitz	1.807.393	5,99%	x	1.807.393	
IVA066	Voestalpine Energiepark Donawitz	626.610	2,08%	x	626.610	
IVA236	Voestalpine Donawitz Kohleeinblasung (Neuanlage § 11/7)	77.813	0,26%	x	77.813	
IVA225	Voestalpine Donawitz sonstige Anlagen (in NAP I nicht enthalten)	22.706	0,08%	x	22.706	
IES067	Böhler Stahlproduktion Kapfenberg	33.337	0,11%	x	33.337	
IES068	Böhler Verbrennungsanlage Kapfenberg	13.131	0,04%	x	13.131	
IES069	Breitenfeld Edelstahl Mitterdorf	14.063	0,05%	x	14.063	
IES070	Marienhütte Stahlwerk	30.398	0,10%			
		10.611.386	**35,17%**		**10.580.988**	**99,71%**

	Cement Industry					
IZE071	Schretter&Cie Zementwerk Vils	177.390	0,59%			
IZE072	Lafarge Perlmooser Mannersdorf	536.364	1,78%	x	536.364	
IZE073	Lafarge Perlmooser Retznei	293.107	0,97%	x	293.107	
IZE074	Zementwerk Hofmann Kirchdorf	231.583	0,77%	x	231.583	
IZE075	W&P Zementwerk Peggau	179.028	0,59%	x	179.028	
IZE076	W&P Zementwerk Wietersdorf	350.337	1,16%	x	350.337	
IZE238	W&P Zementwerk Wietersdorf (Neuanlage § 11/7)	112.480	0,37%	x	112.480	
IZE077	Gmundner Zement	333.309	1,10%	x	333.309	
IZE078	Zementwerke Leube Gartenau	272.614	0,90%	x	272.614	
IZE246	Wopfinger Zement Waldegg_(Neuanlage § 11/7)	54.543	0,18%	x	54.543	
IZE202	Wopfinger Zement Waldegg	233.270	0,77%	x	233.270	
		2.774.025	**9,19%**		**2.596.635**	**93,61%**

	Papierindustrie					
IPA079	Trierenberg Papierfabrik Wattens	22.301	0,07%			
IPA080	SCA Ortmann	70.370	0,23%	x	70.370	
IPA081	Rondo Ganahl Frastanz	23.470	0,08%			
IPA082	Hamburger Papierfabrik Pitten	143.200	0,47%	x	143.200	
IPA083	Mondi Business Paper Hausmening	103.707	0,34%	x	103.707	
IPA084	Mondi Business Paper Kematen	38.946	0,13%	x	38.946	
IPA085	Ybbstaler Zellstoff Kematen	10.296	0,03%			
IPA086	Frantschach St. Gertraud	50.196	0,17%			

IPA087	Steyrermühl AG	235.856	0,78%	x	235.856	
IPA088	Sappi Gratkorn	383.459	1,27%	x	383.459	
IPA248	Sappi Gratkorn (Neuanlage § 11/7)	105.397	0,35%	x	105.397	
IPA089	M-real Hallein	107.796	0,36%	x	107.796	
IPA090	Nettingsdorfer Ansfelden	92.042	0,31%			
IPA239	Nettingsdorfer Ansfelden (Neuanlage § 11/7) 9					
IPA091	Norske Skog Bruck an der Mur	209.979	0,70%	x	209.979	
IPA092	Mayr-Melnhof Karton Frohnleiten	129.481	0,43%	x	129.481	
IPA250	Mayr-Melnhof Karton Frohnleiten Antrieb KM3 (Neuanlage § 11/7)			x		
IPA249	Mayr-Melnhof Karton Frohnleiten Antrieb KM2 (Neuanlage § 11/7)			x		
IPA093	Roman Bauernfeind Frohnleiten	43.569	0,14%			
IPA094	Brigl & Bergmeister Niklasdorf	2.967	0,01%			
IPA095	Mayr-Melnhof Karton Hirschwang	28.302	0,09%	x	28.302	
IPA096	Trierenberg Feurstein Traun	34.823	0,12%			
IPA097	Pappenfabrik Timmersdorf	0	0,00%			
IPA098	Merckens Schwertberg	4.258	0,01%			
IPA100	Paul Hartmann Grimmenstein	4.401	0,01%			
IPA101	SCA Laakirchen	4.827	0,02%	x	4.827	
IPA102	CMOÖ GuD Anlage Laakirchen	243.831	0,81%	x	243.831	
IPA240	CMOÖ GuD Laakirchen GT2 (Neuanlage § 11/7)	115.196	0,38%	x	115.196	
IPA251	Zellstoff Pöls (Neuanlage §11/7)	11.236	0,04%			
IPA103	Zellstoff Pöls	47.524	0,16%			
		2.267.430	**7,51%**		**1.920.347**	**84,69%**

	Chemische Industrie					
ICH104	Semperit Tech.Produkte Wimpassing	17.889	0,06%			
ICH105	Glanzstoff St. Pölten	60.346	0,20%			
ICH106	Sandoz Werk Kundl	74.886	0,25%	x	74.886	
ICH107	Jungbunzlauer Wulzeshofen	188.188	0,62%			
ICH241	Jungbunzlauer Wulzeshofen (Neuanlage § 11/7)	22.335	0,07%			
ICH108	Dynea Krems	1.408	0,00%			
ICH109	Borealis Schwechat	14.798	0,05%			
ICH110	Solvay Ebensee	64.521	0,21%	x	64.521	
ICH112	DSM Fine Chemicals Austria Linz	31.421	0,10%	x	31.421	
ICH113	Isomax Wiener Neudorf	27.343	0,09%			
ICH114	AMI Agrolinz Melamine Linz	85.080	0,28%			
ICH242	AMI Agrolinz GuD Kraftwerk (Neuanlage nach § 11/7) 9					
ICH115	EVN Baxter Krems	1.599	0,01%			
ICH116	Energie-und Medienzentrale Heiligenkreuz	62.900	0,21%			
ICH203	F.M. Hämmerle Dornbirn	9.981	0,03%			
ICH205	Kunert Rankweil	10.671	0,04%			
ICH117	Lenzing AG Zellstoff, Faser, Papier	179.066	0,59%	x	179.066	
		852.432	**2,83%**		**349.894**	**41,05%**

	Chalk Industry					
IKA118	Ernstbrunner Kalktechnik	33.635	0,11%	x	33.635	
IKA119	Baumit Baustoffe Bad Ischl	43.171	0,14%			
IKA120	Voestalpine Kalkwerk Steyrling	325.873	1,08%	x	325.873	
IKA121	Wopfinger Baustoffindustrie Kalk	137.792	0,46%	x	137.792	
IKA122	W&P Kalkwerk Peggau	66.253	0,22%	x	66.253	
IKA243	W&P Kalkwerk Peggau (Neuanlage § 11/7)	49.480	0,16%	x	49.480	
IKA123	Schretter&Cie Kalkwerk Vils	39.642	0,13%			
IKA208	Bernegger Molln Ofen 1 (Neuanlage § 11/7)	24.947	0,08%	x	24.947	
IKA244	Bernegger Molln Ofen 2 (Neuanlage § 11/7)	24.947	0,08%	x	24.947	
IKA245	Bernegger Molln Ofen 3 (Neuanlage § 11/7)	24.947	0,08%	x	24.947	
IKA124	Leube Kalkwerk Tagger Golling	122.054	0,40%	x	122.054	
		892.741	**2,96%**		**809.928**	**90,72%**

	Refractory Industry					
IFE125	Veitsch-Radex Radenthein	83.801	0,28%	x	83.801	
IFE126	Veitsch-Radex Hochfilzen	151.173	0,50%	x	151.173	
IFE127	Veitsch-Radex Trieben	23.651	0,08%	x	23.651	
IFE128	Veitsch-Radex Veitsch	15.986	0,05%	x	15.986	
IFE129	Rath Krummnußbaum	9.107	0,03%			
IFE130	Veitsch-Radex Breitenau	225.858	0,75%	x	225.858	
		509.576	**1,69%**		**500.469**	**98,21%**

	Brick Making Industry					
IZI131	Tondach Gleinstätten	25.492	0,08%	x	25.492	
IZI132	Wienerberger Hennersdorf	23.831	0,08%	x	23.831	
IZI133	Wienerberger Krengelbach Haiding	26.140	0,09%	x	26.140	
IZI134	Wienerberger Knittelfeld Apfelberg	8.894	0,03%	x	8.894	
IZI135	Tondach Unterpremstätten	8.351	0,03%	x	8.351	
IZI136	Wienerberger Fürstenfeld	10.189	0,03%	x	10.189	
IZI137	Herbert Pexider Teufenbach	11.693	0,04%			
IZI138	Wienerberger Göllersdorf	17.701	0,06%	x	17.701	
IZI139	Tondach Pinkafeld	16.283	0,05%	x	16.283	
IZI140	Wienerberger Helpfau Uttendorf	6.906	0,02%	x	6.906	
IZI141	Wienerberger Rotenturm	3.660	0,01%	x	3.660	
IZI142	Wienerberger Laa Thaya	17.313	0,06%	x	17.313	
IZI143	Ziegelwerk Eder Peuerbach Bruck	29.822	0,10%	x	29.822	
IZI144	Ziegelwerk Eder Weibern	21.858	0,07%	x	21.858	
IZI145	Ziegelwerk Pichler Wels	23.086	0,08%			
IZI147	Hilti Mettauer Götzis	4.621	0,02%			
IZI148	Salzburger Ziegelwerk Oberndorf	9.929	0,03%			
IZI149	Leitl Spannton Eferding	21.299	0,07%	x	21.299	
IZI150	Ziegelwerk Martin Pichler Aschach	13.646	0,05%			

IZI151	Ziegelwerk Brenner Wirth St. Andrä	9.673	0,03%			
IZI152	Ziegelwerk Lizzi Erlach	1.605	0,01%			
IZI153	Ziegelwerk Obermair Neuhofen	1.643	0,01%			
IZI154	Ziegelwerk Nicoloso Pottenbrunn	985	0,00%			
IZI155	Ziegelwerk Danreiter Ried Innkreis	5.927	0,02%			
IZI156	Ziegelwerk Frixeder Senftenbach	13.556	0,04%			
IZI157	Comelli Ziegel Kirchbach Maxendorf	13.486	0,04%			
IZI158	Ziegelwerk Eberschwang	3.876	0,01%			
IZI201	Lias Fehring	9.860	0,03%			
IZI159	Ziegelwerk Rhomberg Dornbirn	5.292	0,02%			
IZI160	Ziegelwerk Weindl Steyr	2.878	0,01%			
		369.495	**1,22%**		**237.739**	**64,34%**

	Food Industry					
ILE161	Agrana Tulln	87.081	0,29%	x	87.081	
ILE162	Agrana Hohenau	0	0,00%	x	0	
ILE163	Agrana Leopoldsdorf	77.133	0,26%	x	77.133	
ILE164	OÖ Tierkörperverwertung Regau	801	0,00%			
ILE165	Agrana Aschach	74.854	0,25%	x	74.854	
ILE166	Agrana Gmünd	33.837	0,11%	x	33.837	
ILE167	Rauch Nüziders	12.024	0,04%			
ILE168	EVN COGEN Agrana Tulln	27.610	0,09%			
ILE170	Brau Union Göss Leoben	2.529	0,01%			
ILE171	Brau Union Puntigam Graz	4.728	0,02%			
ILE211	Bioethanolanlage Pischelsdorf (Neuanlage § 11/7)	65.252	0,22%			
		385.849	**1,28%**		**272.905**	**70,73%**

	Glass Industry					
IGL172	Vetropack Kremsmünster	63.496	0,21%	x	63.496	
IGL173	Vetropack Pöchlarn	49.161	0,16%	x	49.161	
IGL174	Technoglas Voitsberg	6.489	0,02%			
IGL175	Inn Crystal Glass Braunau	3.171	0,01%			
IGL176	Stölzle-Oberglas Köflach	40.242	0,13%	x	40.242	
IGL179	Swarovski Wattens	32.166	0,11%	x	32.166	
IGL252	Swarovski Wattens (Neuanlage § 11/7)	6.961	0,02%	x	6.961	
IGL181	Saint-Gobain Isover Austria	9.894	0,03%			
		211.580	**0,70%**		**192.026**	**90,76%**

	Lumber Industry					
IH0182	Funder Werk 1 St. Veit Glan	43.015	0,14%			
IH0184	Fritz Egger St. Johann Tirol	23.983	0,08%			
IH0185	Fritz Egger Wörgl	20.024	0,07%			
IH0186	Fritz Egger Unterradlberg	13.785	0,05%			
IH0187	Fritz Egger Novopan Nachf. Leoben	13.237	0,04%			
IH0188	Umdasch Amstetten	3.381	0,01%			
IH0189	Funder Neudörfl	20.791	0,07%			
IH0190	Wiesner-Hager Altheim	696	0,00%			
IH0191	Binder MDF Hallein	4.520	0,01%			
IH0192	Kaindl Holzindustrie Wals	90.752	0,30%			
		234.184	**0,78%**			

	Engineering- and Automative Industry					
IMS193	AMAG Service Ranshofen	9.149	0,03%			
IMS196	BMW Motoren Steyr	17.632	0,06%			
IMS197	Magna Steyr Werk 1 Graz	13.826	0,05%			
IMS198	Magna Steyr Werk 2 Graz	12.096	0,04%			
IMS199	Teich AG Weinburg	10.868	0,04%			
IMS200	Energie-Contracting Steyr	24.051	0,08%			
		87.622	**0,29%**			
	SUM	**30.173.750**	**100,0%**		**27.621.699**	**91,54%**

Table 31 National Allocation Plan 2012 compared to factories which received the survey[189]

All factories which are marked with an (x) have received the survey through an email.

[189]Ministry of Life (2007)

APPENDIX C

CONTENT:

COVER LETTER

Kohlendioxidnutzungstechnologien am Beispiel der österreichischen Industrie

Sehr geehrter Herr ______________!

Im Zuge einer Masterarbeit an der Montanuniversität Leoben, welche sich mit der Anwendbarkeit der CO_2 Nutzungstechnologien auf österreichische Industriebetriebe beschäftigt, befinden wir uns aktuell in der Phase der empirischen Untersuchung. Hierfür haben wir einen Fragebogen erstellt, dessen Ergebnis die Basis für diese Masterarbeit darstellt.

Wir wären Ihnen sehr dankbar, wenn Sie uns dabei unterstützen und an der nachfolgenden Umfrage teilnehmen (Dauer: ca. 15 min):

http://ww2.unipark.de/uc/theodoridou_MUL/2454

Sie finden die Umfrage auch als PDF im Anhang.

Im Namen des Lehrstuhls für Wirtschafts- und Betriebswissenschaften bedanken sich für Ihre wertvolle Unterstützung

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APPENDIX D

CONTENT:

QUESTIONAIRE

Institut für Wirtschafts- und Betriebswissenschaften
Vorstand: o.Univ.Prof. Dr. Hubert Biedermann
Montanuniversität Leoben

Kohlendioxidnutzungstechnologien am Beispiel der österreichischen Industrie

I Untersuchungsgegenstand

Im Rahmen einer Diplomarbeit an der Montanuniversität Leoben im Bereich Wirtschafts- und Betriebswissenschaften werden Experteninterviews durchgeführt. Die Diplomarbeit behandelt den Vergleich der Kohlendioxidnutzungsverfahren am Beispiel der österreichischen Industrie und wird von Frau Dipl.-Ing. Vassiliki Theodoridou betreut. Ziel der Diplomarbeit ist es, sich mit den aktuellen Entwicklungsstand der sogenannten „Carbon Capture and Utilisation Technologien" auseinander zu setzen, die jeweiligen Vor- und Nachteile der Verfahren darzustellen und mittels einer Nutzwertanalyse die geeignetsten Technologien für österreichische Industriebetriebe aufzuzeigen. Für die Erstellung der Nutzwertanalyse ist Ihre Teilnahme wesentlich, um die notwendigen Bewertungskriterien für eine mögliche Anwendung eines der Verfahren in einem Industrieunternehmen festzustellen.

II Struktur des Fragebogens

Dieser Fragebogen gliedert sich in folgende thematische Abschnitte:

- Allgemeine Informationen
- Emissionshandel
- Kohlendioxid-Nutzungstechnologien

III Beantwortung des Fragebogens

Die Umfrage enthält ein Fragensample, das Sie innerhalb von 15 Minuten beantworten können. Für die Repräsentativität dieser Studie ist eine möglichst vollständige Beantwortung der Umfrage von großer Bedeutung. Sollten Sie vereinzelt Fragen vorliegen haben, bei denen Ihnen eine Beantwortung schwer fällt, so wird um Ihre Einschätzung gebeten.

Wir bedanken uns bereits jetzt für Ihre wertvolle Zeit bei der Unterstützung dieser Masterarbeit und werden Ihnen bei Interesse die Ergebnisse der Umfrage gerne zur Verfügung stellen.

Bei Rückfragen stehen wir Ihnen sehr gerne zu Verfügung.

Mit freundlichen Grüßen

Christoph Niederseer und Vassiliki Theodoridou

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Hinweis:
Dies ist eine anonyme Umfrage. Alle Angaben unterliegen dem Datenschutz und werden absolut vertraulich behandelt. Eine Verwendung erfolgt ausschließlich im Zusammenhang mit dieser Studie. Zur besseren Lesbarkeit dieser Umfrage wird ausschließlich die männliche Schreibform verwendet. Selbstverständlich schließen alle geschlechtsspezifischen Formen auch die weibliche Form mit ein.

1. Allgemeine Informationen

(freiwillige Angabe)
Firmenname: ______________________________

Titel/Name der befragten Person: ______________________________

Position der befragten Person: ______________________________

Telefonnummer: ______________________________

Mail: ______________________________

☐Ja, ich möchte die Ergebnisse der Studie erhalten (E-Mail Adresse erforderlich)

1.1 Branche des Unternehmens

☐Bergbau	☐Mineralölindustrie
☐Chemische Industrie	☐Papierindustrie
☐Elektrizitätswirtschaft	☐Stahlindustrie
☐Feuerfestindustrie	☐Zement-/Kalkindustrie
☐Glasindustrie	☐Ziegelindustrie
☐Lebensmittelindustrie	

1.2 Wie würden Sie die Umweltpolitik Ihres Unternehmens beschreiben?

Proaktiv	Reaktiv
☐	☐

2. Emissionshandel

2.1 Glauben Sie, dass Ihre Branche die EU Klimaschutzziele bis 2020 erreichen kann?

Ja	Nein
☐	☐

2.2 Glauben Sie aus heutiger Sicht, dass die langfristigen EU Klimaschutzziele bis 2050 für Ihre Branche realistisch sind?

Ja	Nein
☐	☐

2.3 Haben Sie seit der Einführung des Emissionshandels Maßnahmen zur Reduzierung der Emissionen durchgeführt?

Ja	Nein
☐	☐

2.4 Wie würden Sie den Aufwand zur Erfassung, Überwachung und Berichterstattung der Emissionen beurteilen?

sehr gering		angemessen		sehr hoch
☐	☐	☐	☐	☐

2.5 Wie wichtig schätzen Sie das CO_2 Management für Ihre Branche?

nicht wichtig		mittel		sehr wichtig
☐	☐	☐	☐	☐

2.6 Hatte die Einführung des Emissionshandels konkrete Auswirkungen auf das CO_2 Management Ihres Unternehmens?

Ja	Nein
☐	☐

2.7 Wie würden Sie das Ausmaß dieser Auswirkungen einstufen?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

2.8 Wie lassen sich Ihrer Meinung nach die zukünftigen CO_2 Zertifikatspreise abschätzen?

sehr schwierig		angemessen		sehr leicht
☐	☐	☐	☐	☐

2.9 Sind die gesetzlichen Rahmenbedingungen ausreichend für eine CO_2 Nutzung?

Ja	Nein
☐	☐

2.9.1 Freiwillige Kommentare zu den gesetzlichen Rahmenbedingungen:

____

____

2.10 Wie würden Sie die dazugehörigen Förderungsmaßnahmen beurteilen?

sehr schlecht		mittel		sehr gut
☐	☐	☐	☐	☐

2.10.1 Freiwillige Kommentare zu den Förderungsmaßnahmen:

____

____

3. CO_2 Emissionen

3.1 Wo wird das CO_2 bei Ihrem Unternehmen emittiert?

Zentral	Dezentral
☐	☐

3.2 Geben Sie die Anzahl der vom Emissionshandelsgesetz betroffenen Anlagen in Ihrem Unternehmen an.

1	2	3	4	>5
☐	☐	☐	☐	☐

3.3 Welche Emissionsmengen in Tonnen CO_2 pro Jahr fallen in Ihren Anlagen an?
(bei mehreren Anlagen bitte nur die 3 Emissionsintensivsten)

	Anlage 1	Anlage 2	Anlage 3
bis 50.000	☐	☐	☐
50.000 bis 125.00	☐	☐	☐
125.000 bis 250.00	☐	☐	☐
250.000 bis 500.000	☐	☐	☐
500.000 bis 1.000.000	☐	☐	☐
über 1.000.000	☐	☐	☐

3.4 Ist Ihnen die Zusammensetzung der aus dem Abgas gefilterten Stoffe bekannt?

Ja	Nein
☐	☐

3.4.1 Wenn ja, um welche Stoffe handelt es sich?

____

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3.5 Wie sieht die Zusammensetzung des Abgases aus?
(bei mehreren Anlagen bitte nur die 3 Emissionsintensivsten)

		Anlage 1	Anlage 2	Anlage 3
CO_2	[Vol. - %]			
N_2O	[Vol. - %]			
HFCs	[Vol. - %]			
PFCs	[Vol. - %]			
SF_6	[Vol. - %]			
andere	[Vol. - %]			

3.6 Ist in Ihrem Unternehmen eine CO_2 Abscheidung vorhanden? (Wenn nicht, gehen Sie bitte zu Punkt 3.7 über)

Ja	Nein
☐	☐

3.6.1 Falls vorhanden, welche CO_2 Abscheidung wird eingesetzt? (Verfahren/Wäsche)

____

3.6.2 Können Sie Angaben zur Abscheidungsrate machen?

____

3.6.3 Wie würden Sie Ihre bisherige Erfahrung mit der CO_2 Abscheidung beschreiben?

sehr schlecht		angemessen		sehr gut
☐	☐	☐	☐	☐

3.7 Falls Sie keine CO2 Abscheidung haben, ist künftig eine geplant?

Ja	Nein
☐	☐

3.8 Ist Ihnen bekannt dass eine CO_2 Nutzung auch ohne CO_2 Abscheidung möglich ist?

Ja	Nein
☐	☐

3.9 Sind Sie nur an einer CO_2 Abscheidung interessiert oder kommt für Sie die Nutzung des CO_2 auch in Betracht?

Abscheidung	Abscheidung und Nutzung	Nutzung
☐	☐	☐

3.10 Wären Sie bereit Ihr abgeschiedenes CO_2 einem anderen Unternehmen zur Verwertung kostenlos zu übergeben?

Ja	Nein
☐	☐

3.11 Welche monetären Erwartungen stellt Ihr Unternehmen an die CO_2 Nutzungstechnologie?

gleichgültig	Kostendeckend	Gewinn erwirtschaften
☐	☐	☐

3.12 Wie hoch wäre die Investitionsbereitschaft um die CO_2 Kosten zu kompensieren?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.13 Wären Sie bereit durch eine CO_2 Nutzung „branchenfremde Produkte“ zu erzeugen?

Ja	Nein
☐	☐

3.14 Ist Ihr Unternehmen grundsätzlich an Technologien, die erst in der Entwicklungsphase sind, interessiert?

Ja	Nein
☐	☐

3.15 Wäre Ihr Unternehmen auch bereit in solche zu Investieren?

Ja	Nein
☐	☐

3.16 Wie stark beeinflusst der Entwicklungsstand einer Technologie Ihre Investitionsentscheidungen?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.17 Gäbe es an Ihrem Standort ausreichend Fläche für eine zusätzliche Produktion / CO_2 Nutzungstechnologie?

ja	begrenzt	nein
☐	☐	☐

3.18 Welche Rolle würde der Flächenbedarf einer CO_2 Nutzungsanlage für Sie spielen?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.19 Wie würden die Betriebskosten einer CO_2 Nutzungsanlage Ihre Entscheidungen beeinflussen?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.20 Wie würde der Energieverbrauch einer CO_2 Nutzungstechnologie Ihre Entscheidung beeinflussen?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.21 Wäre eine Energieversorgung der CO_2 Nutzungstechnologie durch erneuerbare Energiequellen möglich?

Ja	Nein
☐	☐

3.22 Wäre eine Verwertung von industriellen Abfällen, wie Schlacken, Aschen, Baurestmassen und Bergbauabfälle für Ihr Unternehmen interessant?

Ja	Nein
☐	☐

3.22.1 Falls solche Abfälle in Ihrem Unternehmen vorhanden sind, benennen Sie bitte diese und geben Sie die jährlich anfallende Menge an.

____

____

3.23 Wie beeinflusst die längerfristige Verfügbarkeit der in CO_2 Nutzungstechnologien eingesetzten Inputstoffe Ihre Technologieauswahl?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.24 Wie wichtig wäre Ihnen die Bindungsdauer des CO_2 am Endprodukt?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.25 Wie wichtig ist für Sie das Umsetzungsverhältnis von CO_2 zu den restlichen Inputgrößen für die Technologieauswahl?

sehr gering		mittel		sehr hoch
☐	☐	☐	☐	☐

3.26 Reihen Sie die Kriterien für eine CO_2 Nutzungstechnologie nach Ihrer Wichtigkeit. (1 nicht wichtig, 12 sehr wichtig) Bitte beachten Sie, dass JEDEM Kriterium nur EINE UNTERSCHIEDLICHE Wertigkeit zugeteilt werden kann.

	1	2	3	4	5	6	7	8	9	10	11	12
Investitionsausgabe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Flächeninanspruchnahme	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Energieverbrauch	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Betriebskosten	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Verfügbarkeit der Sekundärstoffe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Vorhandener Markt für das Endprodukt	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Endprodukt im gleichen Industriezweig	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CO_2Bindungsdauer im Endprodukt	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Umsetzungsverhältnis CO_2 und Sekundärstoffe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Technologiereifegrad	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Direkte CO_2Nutzung ohne Abscheidung	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Verwertung vorhandener Abfälle als Inputstoffe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4. Sonstige Kommentare

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Vielen Dank für Ihre wertvolle Zeit!