Albert Stockhammer

Master Thesis

Energy Efficiency in Underground Gas Storage Facilities

ALMA MATER LEOBIENSIS

Supervised by:	Univ.-Prof. Dipl.–Ing. Dr.mont. Herbert Hofstätter; Technical Director Ing. Kurt Sonnleitner
Approval date:	December 16th, 2009

Freie Seite!!!

Affidavit

I hereby declare that the following Master Thesis "Energy Efficiency in Underground Gas Storage Facilities" has been written
only by the undersigned and without any assistance from third parties.

Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself.

Albert Stockhammer

Leoben, December 16th, 2009

Table of Contents

List of Figures

List of Tables

Acknowledgments

I wish to express my gratitude to my supervisor, Univ.-Prof. Dipl.–Ing. Dr.mont Herbert Hofstätter, whose expertise, understanding, and patience added considerably to my graduate experience and who has not only been a supporter through the time of developing this thesis, but throughout my whole time at the Mining University of Leoben.

I also want to thank my supervisor within RAG, Technical Director Ing. Kurt Sonnleitner for the assistance he provided and whose supervision provided many open doors. Being supervised by the management is a special honor and was a big motivation.

Special thanks goes to Dipl.-Ing. Dr. Markus Oberndorfer for integrating me in his team. Within this team I want to thank Dipl.-Ing. David Doppelreiter for sharing many ideas and for taking every such so strange seeming idea seriously.

I also want to acknowledge Ing. Franz Winter and Dipl.-Ing. Johannes Kinast, who supervised this thesis on location at the underground gas storage facilities in Haidach and Puchkirchen and who were open for every question, also after my time on site.

Especially I want to show my appreciation to the team of the Engineering and Technology Department of RAG, to Ing. Günther Gira, Ing. Oliver Friedlaender, Ing. Miroslav Zdihan, Ing. Harald Rada, Dipl.-Ing. Clemens Brachinger, Stefan Federling, Dipl.-Ing. Christoph Janka, Bernhard Kegelreiter, Ing. Michael Neuwirth, Ing. Stefan Pauzenberger, Karl Szydlowski, Ing. Herbert Fux, Monika Weiss and everyone else in the department for always being open for new ideas and expressing very own views and ideas on this subject and beside that for always having a good laugh together.

I also want to acknowledge Rudolf Loisel and the crew of the Underground Gas Storage Facility Haidach for giving me an inside view on operating an underground gas storage facility and helped me to get acquainted in the first steps.

I am thanking my family, my parents Regina and Josef, my sister Eva Maria and especially my grandparents Theresia and Albert Knoll, who were an inspiration how to live an honorable life and who supported me through all my life without losing their faith in me.

I want to thank my friends for the support they provided through my entire life.

In this connection I want to single out Monika Mörtl, who had been a companion through all the years at university and within the SPE Student Chapter Leoben, on various trips all over the world and who had always an open ear for problems and concerns on whatever subject.

I also want to thank the SPE Student Chapter Leoben and its officers, who had been great colleagues during my time as an officer and very good friends ever since.

In the end I want to thank all the people unmentioned in these acknowledgments, who have accompanied me through all my life and who made me to who I am.

Abstract

This Master Thesis deals with the topic “Energy Efficiency in Underground Gas Storage Facilities” in three ways:

- Finding facilities or processes where energy is not used in the most efficient way
- Finding possibilities to produce energy within the UGS facility
- Finding applications for the ideas developed in this thesis for underground gas storage facilities in other areas of petroleum engineering

The first part is done by questioning the need of pressures and temperatures used in the processes and facilities during the modes injection, withdrawal and facility stop. This results in various options to safe energy in the forms of electricity, thermal energy and pressure. These options are audited on their economical and engineering feasibilities.

The second part is done by analyzing various options for energy production in theory, considering practical issues and finally analyzing these options economically, when the results seemed to be promising.

The economic evaluation is done by the Net Present Value Method. The standard data, like internal discount rate used in this thesis were provided by RAG. What this thesis does not include in any calculation are governmental aids. Especially these governmental aids would have a major impact on most of the processes and facilities described in this thesis, but have to be evaluated for each individual project.

All data, which could not be provided exactly, were assumed on the basis of reasonable commercial assessment. The economic numbers used were chosen on worst case scenarios. So the internal gas price, for example, is calculated with 20 Euro/MWh, which is valid for dry gas. Many applications described in this Master Thesis run with wet gas. Whenever calculations should be observed with another gas price than mentioned, this is done in different scenarios. If assumptions were taken this is explicitly mentioned.

The third part, finding applications outside underground gas storage facilities, is done by finding aspects with similar or related surroundings outside underground gas storage facilities and comparing them with the possible applications within underground gas storage facilities. These aspects are mainly related to certain gas wells and their reservoir conditions or the processes in the flow path of those wells, like high pressure drops and the potential of these wells to be used for producing geothermal energy.

Also the synergies and potentials for future underground gas storage facilities were observed. While some aspects in this thesis are economically not of interest for existing facilities, they might be interesting for projects with investment costs not taken now. Another promising idea is the use of methods for decentralized energy production in the field, which are as well covered in this thesis.

Additionally to ideas which could be realized immediately, some ideas will become interesting in the future, when energy prices will rise and the awareness of environmental problems and the room for improvement will increase.

Introduction

Why does a shoemaker's son always go barefoot? Because services and goods for own needs are often considered worth less than services and goods which can be sold to others. This is also valid within the world of petroleum businesses. Because E&P companies are producing oil and gas the focus of their business is more on the production itself and selling these products than on saving resources within their own facilities. With an increasing need on behalf of economics and the public image of petroleum businesses to increase the focus on energy saving policies, the need to have a close look on own facilities is becoming more and more important. But much more this can also be an advantage on other competitors. Especially in underground gas storage, where large volumes of gas are stored and withdrawn over the year and so large amounts of energy are needed, saving as much energy as possible is essential. While the demand is growing, the petroleum world is far from making the most out of the opportunities available.

Underground gas storage is the perfect way to overcome large transportation distances, because not the wells are the bottlenecks in the gas industry, but the pipelines are. Furthermore reservoirs in Europe are becoming browner and browner, which increases the need to import gas also from unstable countries or to transport it via pipelines which lead through unstable regions. All these reasons will increase the need for more storage capacity and bigger volumes to be injected and withdrawn. Because of many more advantages of underground gas storage than overcoming transportation distances, like overcoming peak consumption, providing safety of supply and others, the number of underground gas storage facilities is increasing. In Europe 31 operators are storing gas in 122 underground storage facilities in 16 countries with a total working gas volume of 70 billion cubic meters. By the year 2015 30 billion cubic meters will be added in 93 new projects, which are already projected or in the construction phase.[1] This increase leads to ideas to make these injection and withdrawal circles more efficient, which means to save energy and to produce energy with and within the facilities.

The underground gas storage facilities Haidach and Puchkirchen, which were analyzed for this Master Thesis, are operated by RAG.

The Underground Gas Storage Facility Puchkirchen was one of the first underground gas storage facilities in Austria in the year 1982. The storage capacity is 860 million m^3 and will be increased to one billion m^3 by 2010. In comparison to the UGS Facility Haidach, the whole storage facility is carried out as one string facility.

The Underground Gas Storage Facility Haidach is Europe's second biggest underground gas storage facility with a storage capacity of 1,2 billion m^3, which will be increased to 2,4 billion m^3 by 2011. The reservoir was discovered in 1997 and was the biggest discovery of natural gas since 1982. After signing the contract over an underground gas storage facility on May 13th 2005, the underground gas storage facility started operation on May 24th 2007. The facility is operated by RAG as a Joint Venture between RAG and WINGAS.

The Underground Gas Storage Project "Seven Fields", which is also carried out by RAG, consists of seven reservoirs, which will be used for underground gas storage and which will start operation by 2015. The storage volume will be 2 billion m^3.

The Underground Gas Storage Project "Aigelsbrunn" is the newest storage project within RAG and is in the planning phase right now.[2]

In January 2009 during the gas crisis RAG's inland production but mainly the gas from the two existing underground gas storage facilities supplied Austria with gas and showed the importance of underground gas storage facilities.

Energy Consumption in Underground Gas Storage Facilities

Energy Flow

To understand where energy can be saved it has to be understood how energy flows. But first of all following question has to be answered: What is energy?

The term energy is closely connected to the term work. In detail it describes the ability to do work. When a system carries out work in another system, then energy is exchanged between these two systems. Energy can't be lost. When energy within a system changes without another visible system around it, the surrounding holds the energy.

In terms of underground gas storage this means:

Work is done by compressors, by heaters or coolers, which lead to a change in energy which can be seen in pressure or in temperature increase or decrease.

This already shows that in underground gas storage energy is not only measured in electricity but also in pressures and temperatures, because every degree and every bar results in applying energy in some way.

The energy flow is dependent on the operation mode.

These operation modes are:

- injection with compressors
- injection without compressors
- withdrawal with compressors
- withdrawal without compressors

Of course the pressure and temperature distribution changes between the modes injection and withdrawal and with or without the use of a compressor.

While injecting gas into the reservoir or into the transfer pipeline by using a compressor the Joule Thompson Effect has to be considered.

When looking at the volume, pressure and temperature distribution, it has to be clear that the whole energy flow is restricted by mechanical limits, which are defined in the planning phase of an underground gas storage facility.

These limits later not only define the maximum and minimum pressures, temperatures and volumes, but also the costs of the facilities in a significant way.

These limits are the frame for all pressures and temperatures in the whole underground gas storage facility.

In the following chart these restrictions are shown on the example of the Underground Gas Storage Facility Haidach.

	Pressure max [bar]	Temp. min [°C]	Temp. max [°C]
Well Separator	200	-27	80
Manifold Separator	200	-27	80
String Separator	200	-27	80
Suction Header	200	-27	80
3 Phase Separator	200	-27	80
Cooler	200	-27	200
Cooler String	200	-27	60
Preheater	200	-27	120
Dehydration String	100	-27	330
Compressor String	200		200

Table 1: Energy Flow Limits in the UGS Facility Haidach[3]

To analyze the pressure and temperature distribution and the flow of the gas from the transfer pipeline into the reservoir or from the reservoir into the transfer pipeline the Underground Gas Storage Facility Haidach is taken as an example.

The UGS Facility Haidach consists of a two string header system, two outstations with six wells each, two compressors and two dehydration strings. The dehydration is carried out as an adsorbent dehydration system.

The facility is connected to the South German Pipeline System by a 40 km transfer pipeline.

Of course there are plenty of possibilities to run the gas stream through the facilities, concerning on the need to dehydrate or to separate the gas.

In the following analyzes examples were taken for the most common gas runs. The distances between the equipments in the graphs are not in scale.

All the data is from RAG's control system. The times were chosen because of certain stability in the data. Detailed flow charts of the UGS Facility Haidach can be found in Appendix A.

Injection without compressor

When gas is injected without being compressed the gas enters the facility via the transfer pipeline. It enters the transfer header and the pressure header and finally enters the storage reservoir via outstation 1 or outstation 2.

To inject without compressors high pressures in the transfer pipeline and in the facility have to overcome the lower pressure in the reservoir to provide the necessary pressure difference and the flow from the pipeline system into the storage reservoir.

Relating to the example of the UGS Facility Haidach injection without compressors is not done, because of a comparable low pressure in the transfer pipeline and a relative to that high pressure in the reservoir.

The temperature stays small, because after compression in the transfer station the gas cools down on the way through the transfer pipeline.

Injection with compressor

In general injection with compressors is done, when the pressure in the reservoir is higher than the pressure in the pipeline system and the facilities.

The energy flow while injection with compressor is explained on the example of August 20th, 2008, 00.05 am. The injection volume on this day was 7.034.637,95 Nm^3. The injection rate at this specific time was 294.970 Nm^3/h. The following pressures and temperatures were measured at 00.05 am and are representative for withdrawal with the use of compressors.

Pressure

The gas enters the facility via the transfer pipeline. It enters the transfer header and is lead to the compressor station, where the pressure is increased from 45,9 to 87,3 bar. After the coolers and a slight pressure decrease over the pressure header and right before the well because of valves, which give the possibility to bypass facilities and headers, the gas enters the reservoir.

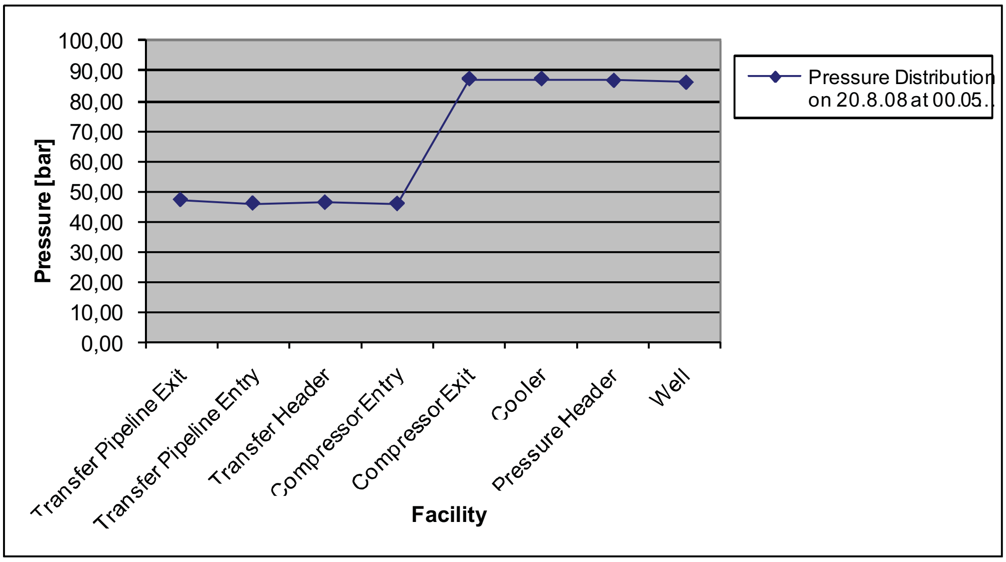


Figure 1: Pressure Distribution on August 20th, 2008

Temperature

Due to the compression of the gas the Joule Thompson effect appears. This leads to a temperature increase of 60 degrees Celsius to almost 75 degrees Celsius. Then the gas enters the coolers with a temperature of 74,4 degrees Celsius and exits the coolers with a temperature of 38,6 degrees Celsius.

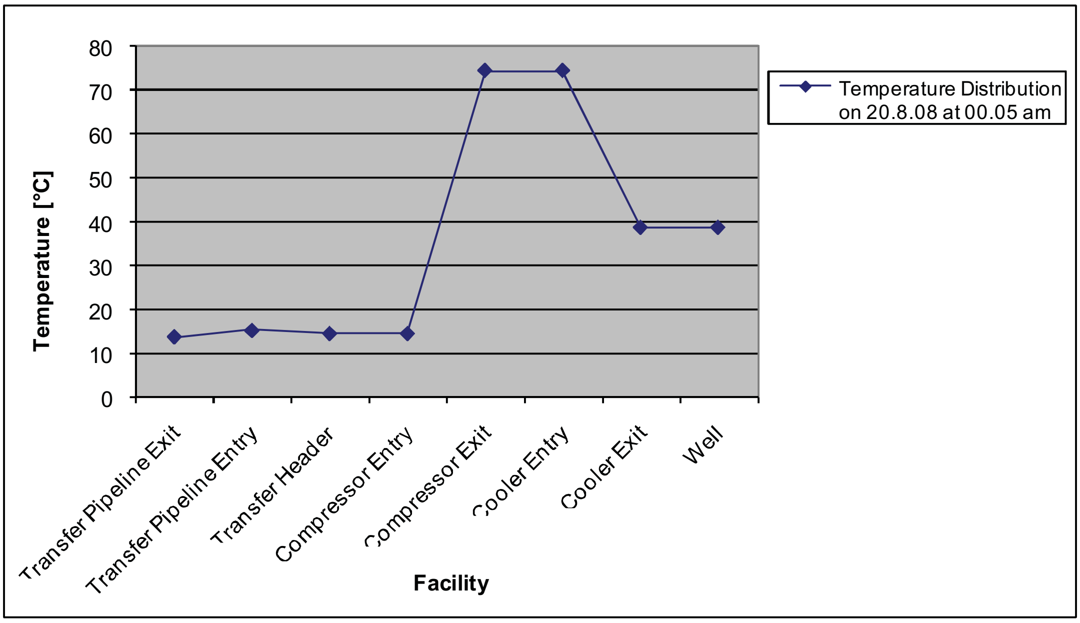


Figure 2: Temperature Distribution on August 20th, 2008

Withdrawal without compressor

The energy flow while withdrawal without compressors is explained on the example of January 1st, 2008. On this day a total volume of 5.528.754,13 Nm^3 was withdrawn.

The following pressures and temperatures were measured at 00.05 am and are representative for withdrawal without compressors.

Pressure

Along the path a very straight pressure distribution can be seen, except the pressure across the separator. There the gas expands and a pressure decrease of 16,8 percent occurs.

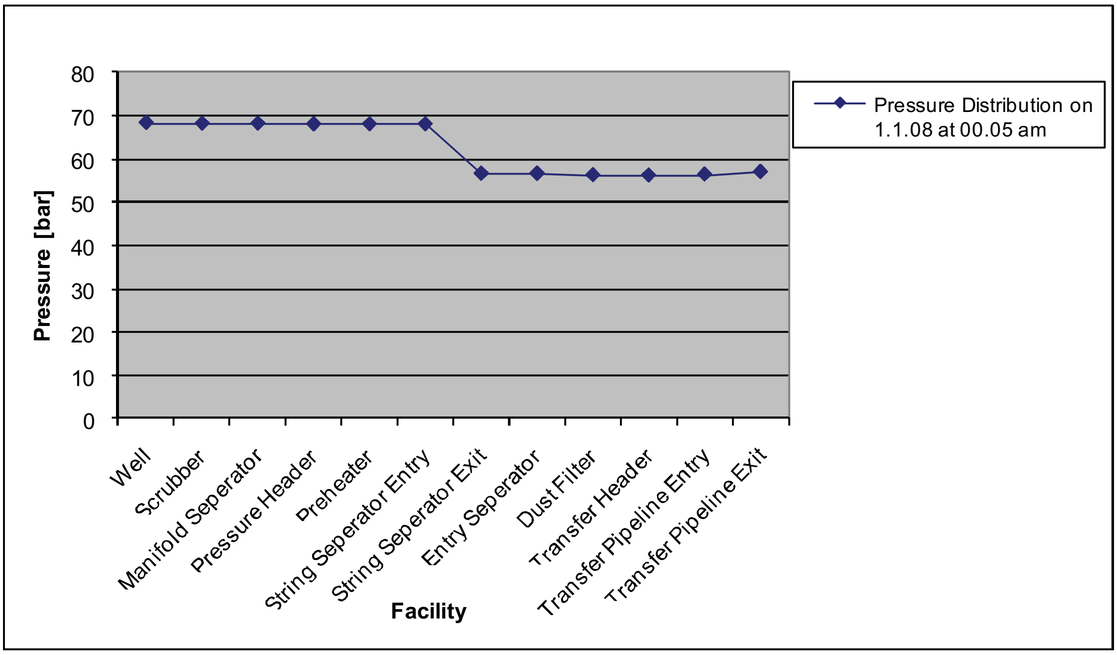


Figure 3: Pressure Distribution on January 1st, 2008

Temperature

When contemplating the temperature distribution in the mode withdrawal without compressors the temperature flow within the facility seems quite smooth.

There is just a small increase along the preheaters and a small decrease along the separators because of the pressure decrease, but the whole temperature distribution ranges between 25,8 degrees Celsius right after the preheater and 20,1 degrees Celsius right before leaving the transfer header.

Preheaters are just used while withdrawal without compressors.

The large temperature drop takes place in the transfer pipeline again, when the temperature decreases by 36 per cent to 7,2 degrees Celsius. This will be discussed later in the chapter "Heat Loss in the Transfer Pipeline".

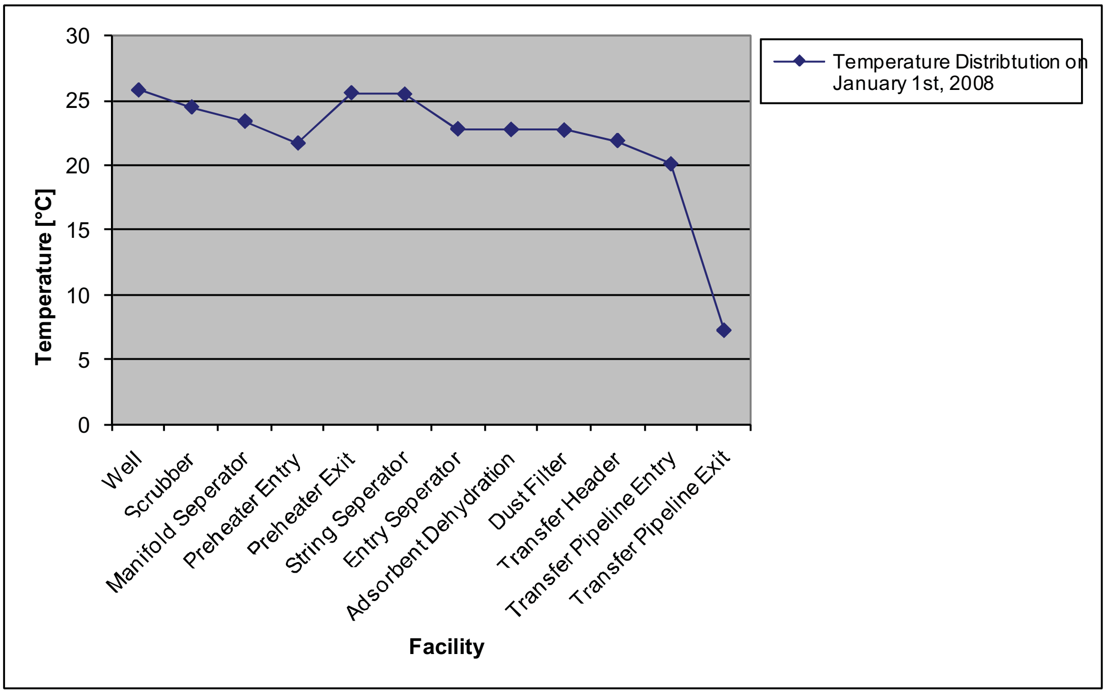


Figure 4: Temperature Distribution on January 1st, 2008

Withdrawal with compressor

Withdrawal with compressors is done when the pressure which is required along the facilities and in the pipeline system is smaller than the pressure in the reservoir.

The energy flow in the mode withdrawal with compressors is explained on the example of January 19th, 2008.

The total volume withdrawn on this day was 6.492.289,04 Nm^3. The following pressures and temperatures were measured at 00.05 am and are representative for withdrawal with the use of compressors.

Pressure

While withdrawal with the use of compressors the compressors increase the pressure before the gas enters the string separator, where the pressure decreases again. It can be seen that usually the pressure increase by the compressors while withdrawal is smaller than while injection, because the pressure which has to be overcome is smaller.

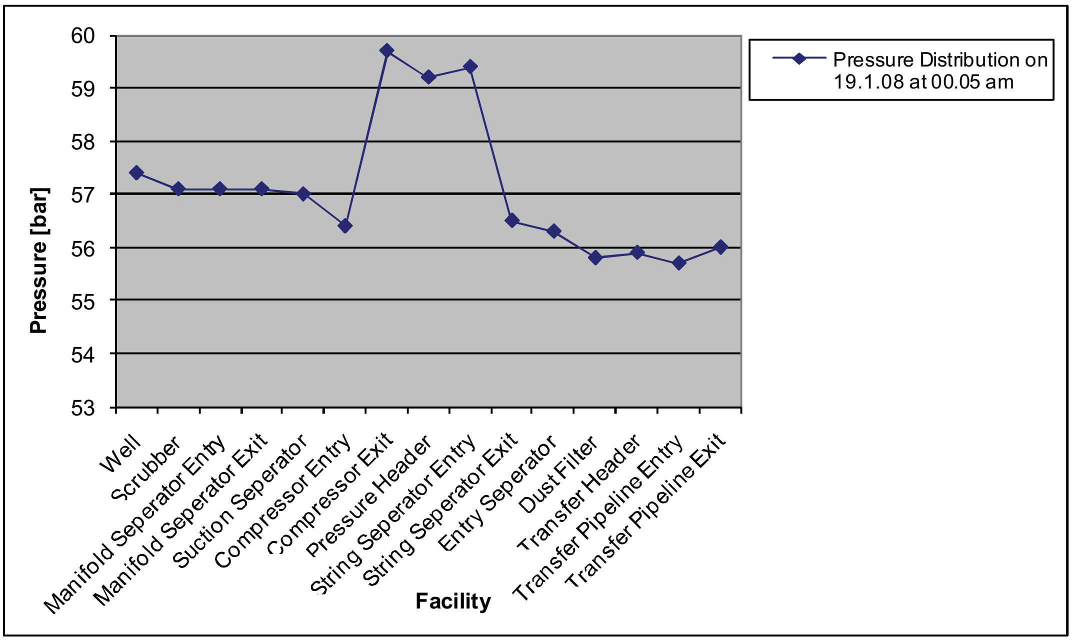


Figure 5: Pressure Distribution on January 19th, 2008

Temperature

Along the whole gas path there is a slight temperature decrease due to the exchange with the surrounding.

At the compressors the Joule Thompson Effect kicks in again and right after the compressors the coolers decrease the temperature of the gas. When looking at the graph the temperature drop at the end of the gas path states out.

This is again the temperature drop along the transfer pipeline.

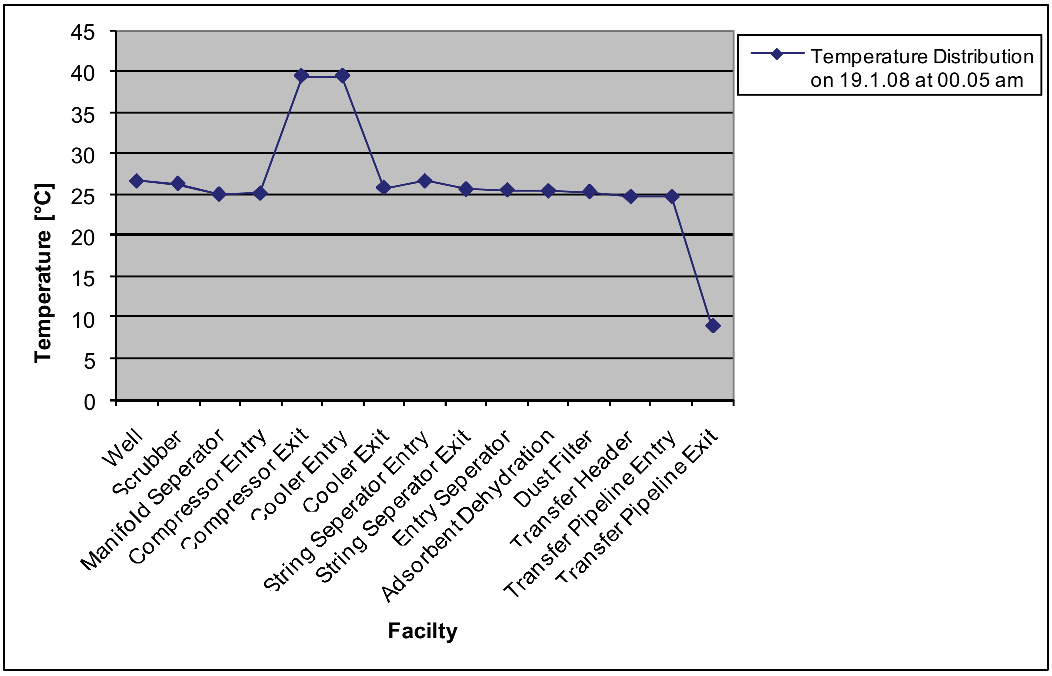


Figure 6: Temperature Distribution on January 19th, 2008

Supporting Systems

To support the facilities various auxiliary and supporting systems are needed. These systems provide for example energy in the form of pressure, temperature or current.

Instrumentation Air

The instrumentation air system provides compressed air for the instrumentation of the underground gas storage facilities and the outstations 1 and 2. Furthermore it provides compressed air for the production of nitrogen.

The air is compressed to 12 bars and afterwards split into the air which is used for the production of nitrogen and the air which is used for controlling the measuring devices. This part of the air stream is reduced to seven bars. In the chapter “Energy Savings Potential: Compressed Air for Nitrogen Production”, this problem is discussed in detail.

Hot Water System

The hot water system is used for heating facilities, protective housings and instruments. So the hot water system drives the preheaters and is used for prewarming the coolers. The water is heated in three vessels which are run with gas provided by the heating gas system. In the winter when the hot water system is essential for providing a safe operation of the underground gas storage facility, the temperature of the water is between 81 and 87 degrees Celsius.

On each outstation there is a single gas lighted vessel, which produces hot water, which is necessary during injection and withdrawal periods. The hot water at the outstations is used for heating pipes, protective housings and equipment.

Nitrogen System

Nitrogen is produced by the use of compressed instrumentation air. The air streams through a diaphragm, where oxygen and nitrogen are split because of their different diffusion gradients.

Nitrogen is needed for flushing the secondary gas sealing of the compressors and flushing the gaskets of the seal gas compressor.

The nitrogen is stored in a buffer tank and when necessary directed to the individual sealings of the compressors.

Seal Gas Compressor

Seal Gas, which is removed from the gas stream through the facility, is needed when a compressor is started for injection and during the whole injection process in the mode injection with compressors.

The capacity of the seal gas compressor depends very much on two aspects. Firstly if the compressor is running and in which mode and secondly which pressure has to be applied, concerning that there is already a certain pressure in the transfer pipeline. Usually the gas enters the compressor with less than 38 bars.

Cooling Water System

The cooling water system is needed for operating the compressors. In detail the cooling system is cooling the lube oil of the compressors, the electrical engines, which drive the compressors and the frequency converters.

The temperature of the cooling water is less than 40 degree Celsius and is heated up by the consumers to 50 degrees Celsius, before it is recooled.

Heating Gas System

Heating Gas is needed during injection and withdrawal. It provides the heating gas for heating the hot water system, the heating gas for heating the regeneration system of the absorbers and it provides the gas for the pilot heater of the flare.

Energy Savings Potential

In this thesis two different underground gas storage facilities were analyzed: The underground gas storage facility in Puchkirchen and the underground gas storage facility in Haidach. The main differences between these two facilities concerning energy efficiency are the way the compressors are driven and the dehydration system. While in the UGS Facility Haidach the compressors are driven with an electric motor, the UGS facility in Puchkirchen is driven by gas turbines, which produce exhaust heat, which is not used till now.

Furthermore saving energy can not only be done by using the heat or pressures to generate or to transform energy it can also be done by choosing the right facilities (TEG vs. Adsorbent dehydration). While in UGS Haidach an adsorbent dehydration system is used, UGS Puchkirchen uses a TEG dehydration system.

Coolers

The following charts show the temperature difference between the exit of the compressors and the exit of the coolers of string number 1 and 2 at the Underground Gas Storage Facility Haidach. It also shows the correlation between the speed of the compressor and the temperature. This chart shows the temperature in the months July till December. The temperatures in the months between January and June are less significant because of less operating hours of the compressors. But looking at the strings during the second half of the year it can be seen that over long periods of time large amounts of heat are exchanged with the surrounding air, which is not used. Especially because the temperatures range up to 80 degrees Celsius the use of this temperature is multiple. The only problem is that the operating hours are small. In 2008 the operating hours of the fans in the coolers were as follow:

	Fan 1	Fan 2	Fan 3	Fan 4	Sum
String 1	26,35 h	26,38 h	26,38 h	24,37 h	103,48 h
String 2	7,12 h	7,08 h	6,95 h	7,07 h	28,22 h

Table 2: Operating Hours of the Coolers in the UGS Facility Haidach

The question why the coolers are not working can be answered very simply. The heat which is produced by the compressors is used during withdrawal to achieve a better effect at the dehydration system. In Haidach the temperature produced during injection is used to heat up the reservoir. So the thermal energy is stored there. During withdrawal this temperature is used to decrease the load of the preheaters. Therefore the installation of a heat exchanger at the main stream coolers is not effective. Beside that the amount of heat energy gained would not be worth the investment costs.

But an important aspect is that the coolers are already designed for stage 2. So, when the volume and especially the pressure in the reservoir will increase the gas will have to be cooled. Otherwise during withdrawal, problems with the vegetation above the transfer pipeline will occur. When the coolers are used on a more frequent level it will be possible to use the thermal energy to regenerate the silica gel in the dehydration units of the underground gas storage facility.

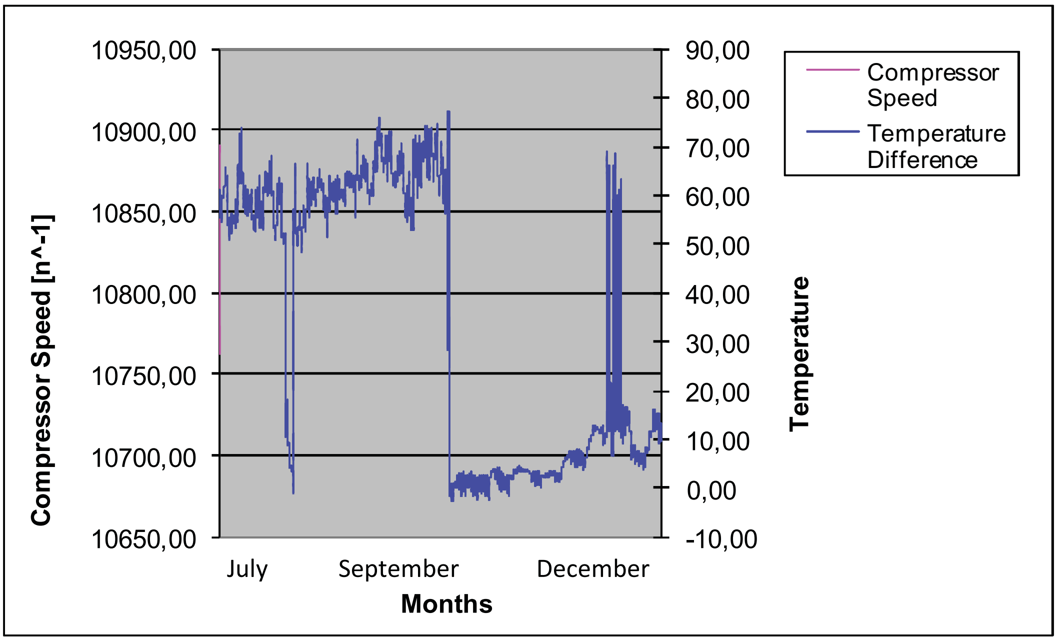


Figure 7: Temp Diff across the Cooler (in ° C) and Compressor Speed of String 1 July-Dec 2008

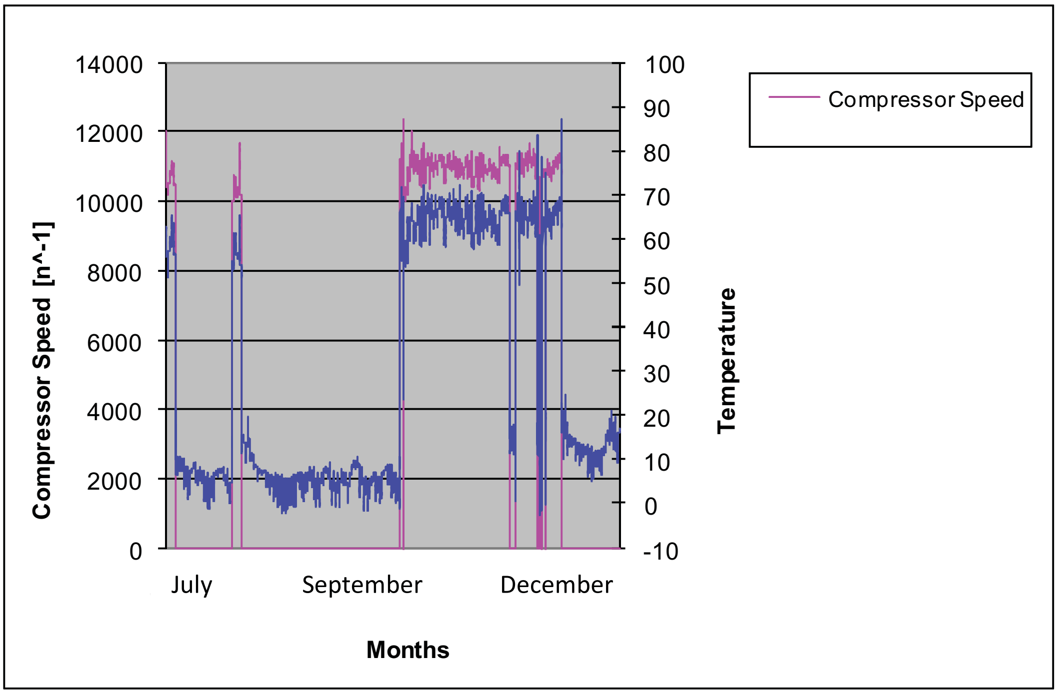


Figure 8: Temp Diff across the Cooler (in ° C) and Compressor Speed of String 2 July-Dec 2008

Dehydration Units

The Problem

When looking at the differences between the Underground Gas Storage Facility Haidach and the Underground Gas Storage Facility Puchkirchen the different dehydration systems come into mind. While UGS Puchkirchen uses a TEG dehydration system, UGS Haidach uses an adsorbent dehydration system. The main reason is that in Haidach higher hydrocarbons have to be removed.

There are two problems concerning the energy efficiency of a TEG dehydration system.

First the system needs about two hours to heat up the glycol to a temperature level, which is necessary for an efficient usage. That is why the glycol is kept at a certain temperature level also when the system is not in operation, even if there is no need and no flow through the system. This leads to a steady temperature loss in the glycol circle.

Second, after the glycol is heated up and loses its water content it has to be cooled again, before it can enter the dehydration circle again. This is done in the following two different ways.

Seven TEG dehydration systems are in use in the Underground Gas Storage Facility Puchkirchen:

Two at grid Puchkirchen I: Both use heat exchangers to cool down the Glycol after its regeneration.

Three at grid Puchkirchen II: Two using heat exchangers and one using a cooler.

Two at the outstation: Both using coolers.

While heat exchangers cool down the Glycol by heating up the gas stream, coolers cool down the Glycol with mechanical power and do not have any advantage or usage of the thermal energy of the flow.

The amount of heat the glycol is cooled down by the coolers is significant. The following table shows the maximum temperature difference measured before and after the coolers and the time the temperature difference was greater 50° and greater 100 ° Celsius in the year 2008.

	AS 1 String 1	AS 1 String 2	PU II String 3
Max Temp Difference [°C]	126,3	148,1	132,8
Time Temperature>50 °C [h]	3048,75	739,58	3815,4
Time Temperature >100 °C [h]	2459	197,25	3349,7

Table 3: Temperature Difference of the Coolers in the Glycol Dehydration Process

The in comparison small amount of time at Outstation 1 String 2 is because this cooler went in operation only on October 29th, 2008.

The Solution

The thermal energy could be recovered by an ORC Facility or a Kalina Process. Both processes are discussed in detail in the chapter “Energy savings using gas turbine exhaust heat”. A Kalina Process would be able to recover the most out of the energy, because the minimal temperature difference between heat source and sink has to be at least 50 degrees Celsius, so a significant amount of energy could be generated. Having a look at the table above, it can be seen, that 6.005,95 hours per year energy could have been generated.

Higher temperatures can be recovered by an ORC Cycle. Infinity Turbines offers small ORC units, which work with inlet temperatures between 70 and 120 degrees Celsius. The efficiency lies between 8 and 11 per cent and becomes better with increasing temperature. These are turbines with 12 kWe output and a price of about 20.000 Euro per unit.

This leads to following economical result:

IRR: 5,3%

NPV: -18.842

The calculations are done for three coolers. For a single cooler the Net Present Value becomes even smaller and the Internal Rate of Return becomes negative. A way to make this process economic will be to use the thermal energy of the glycol regeneration, as soon as the second stage of UGS Puchkirchen is in operation, to operate an ORC facility with a greater load, because the scenarios showed that this process is becoming more economic with an increasing number of ORC turbines and an increasing load. Exact calculations can be found in Appendix B.

Differential Pressure in the Transfer Pipeline

The Problem

In the transfer pipeline it is tried to keep a pressure difference of 5 bars between entry and exit. The reason is safety of supply and it is done by what is called pipeline storage. In the case of a problem in the underground gas storage facility and in the case that the facility can not handle any gas in withdrawal mode, the built up pressure and the built up volume in the transfer pipeline can be reduced and so the supply can be continued for a certain period of time.

Another reason for this policy is the injection or withdrawal of small amounts of gas. As seen in the chart of the mechanical limits in the chapter “Energy Flow” there are certain minimum pressures, temperatures and, which is important in this case, volumes. When less than 15.000 m^3/h are injected or withdrawn, the compressors and the dehydration system can not work optimized. The compressors in Haidach, but those in Haiming as well, have a certain pump limit and a certain suction limit. In this range certain volumes can be compressed. To be able to work within these limits, pressure is built up in the transfer pipeline while in this time the dehydration system and the compressors are not working. When a volume is built up in the transfer pipeline which insures that the whole facility can operate for a sufficient period of time in an optimum range the dehydration system and the compressors are started and the volume and pressure in the pipeline system is decreased.

As seen a differential pressure in the transfer pipeline is practical for small volumes. But it isn’t for large volumes and large rates, where the volume in the transfer pipeline is exchanged as fast as there is no real pipeline storage and the sense of the differential pressure is lost.

For example:

During the gas crisis in January 2009 the supply of gas in Central Europe was mainly secured by underground gas storage facilities. Also the Underground Gas Storage Facility Haidach was delivering into the Central European pipeline system and taking a major part in Europe’s gas supply. Therefore large volumes were withdrawn. On January 8th, 2009 between 6.30 pm and January 17th, 2009 9 am between 400.000 m^3/h and 500.000 m^3/h were withdrawn. In this time the average pressure difference was 4,69 bar. The minimum pressure difference was 1,8 bar, the maximum pressure was 10,8 bar. The maximum pressure was achieved in the end of the withdrawal period to build up pressure and to use the pipeline as a storage pipeline. Through the pressure difference an additional safety was not achieved, because of the transportation of high volumes through the transfer pipeline the safety of supply was given anyway or rather was given just for a very short period of time.

Average Inlet Pressure Compressor 1	63,98	bar
Average Outlet Pressure Compressor 1	74,88	bar
Pressure Difference across Compressor 1	10,9	bar
Average Inlet Pressure Compressor 2	63,99	Bar
Average Outlet Pressure Compressor 2	74,85	Bar
Pressure Difference across Compressor 2	10,86	Bar
Average Pressure Difference Transfer Pipeline	4,6	Bar
Average Pressure Transfer Pipeline Haidach	70,02	Bar
Average Pressure Transfer Pipeline Haiming	69,97	Bar
Average Pressure Transfer Pipeline SÜDAL	65,19	Bar
Average Volume AS 1	258.362	Nm3/h
Average Volume AS 2	230.453,04	Nm3/h

Table 4: Pressures and Volumes in the UGS Facility Haidach in January 2009

The Solution

The pressure in the transfer pipeline is not defined in a contract between RAG and WINGAS, it is an agreement of the dispatchers. So there is no legal reason to increase the differential pressure for large volumes.

To calculate the amount of energy which is spent on keeping the differential pressure up, the performance curve for one compressor at the Underground Gas Storage Facility in Haidach is taken for a suction pressure of 65 bar. For compressing 250.000 Nm^3/h gas from 65 bar to 75 bar, as done in the example of January 2009, the compressor is consuming 4 MW. Reducing the pressure from 75 to 72 bar, which still leads to a small pressure difference between Haidach and Haiming, leads to a consumption of 3 MW. This is valid for a single compressor. During the withdrawal period in January 2009 both compressors were working with average volumes of 258.362 Nm^3/h and 230.453 Nm^3/h, so the energy consumption has to be doubled. This leads to a total energy saving of 2 MW/h.

To calculate the money which could be saved the calculation is done with an energy price of 0,085 Euro/kW. This is the energy price paid for a single kW electricity in the Underground Gas Storage Facility Haidach. The pressure difference was higher than 3,5 bar in 425,25 hours in January 2009. So still a pressure drop of more than 0,5 bars along the transfer pipeline could be kept. In this simplified case 170 Euro could have been saved every hour, which leads to a total saving of 72.292,5 Euro during the withdrawal period of January 2009.

The assumption of a pressure reduction of up to three bars is realistic, but some circumstances have to be considered. When looking at the pressure graph in the chapter “Energy Flow for Withdrawal with Compressors”, it can be seen, that there is a decrease in pressure after the compressors in the separators. Of course this decrease in pressure has to be considered in the separator application. Of course what has to be considered as well is the dew point, which is dependent on the temperature and the pressure. How far the pressure can be reduced is not only dependent on the pressure which has to be reached at the transfer station in Haiming, but also very much on how far the dew point can be approached.

Further this calculation is based on a performance curve, which can not been taken as exact, because the pressures and volumes in this example are already located in the suction area of the compressor. But the example gives an approximation and makes aware of this certain problem. The performance curve can be found together with the exact calculation in Appendix B.

Compressed Air for Nitrogen Production

The Problem

In the compressed air system the air used for the instrumentation at the different facilities and the air which is later on separated into oxygen and nitrogen are compressed with the same compressors. Because the compressed air system for the instrumentation runs with 9 bar and the nitrogen production runs with 12 bar, the whole air is compressed to 12 bar. Later on the air used for the instrumentation is reduced to 9 bar, losing the energy which was needed to compress this portion of air. The compression of the air is done by two compressors. To use one for the compression of the instrumentation air and the second for the compression of the air, which is used for the production of nitrogen is not possible because of two reasons:

Because nitrogen is essential for the compressors there has to be a redundancy.

Over the year 2008 87,84 percent of the air compressed by the two compressors was used for the production of nitrogen. Only the rest of 12,16 percent was used for the instrumentation air system. So the use of a single compressor just for the instrumentation air would not be economic.

The Solution

When the consumption of air and the production of nitrogen are analyzed over the year 2008, following results can be obtained:

	January-June [Nm3/h]	July-December [Nm3/h]
	135,4	121,3
	135,4	120,6
	135,4	120,3
	135,4	119,5
	135,4	119,3
	135,4	119,1
	135,4	118,6
	135,4	118,6
	135,3	118,2
	135,3	118,1
Average:	92,835339	80,5634314

Table 5: Peak Nitrogen Consumption in the UGS Facility Haidach in 2008

The chart shows the top ten nitrogen consumptions in the year 2008 (measuring error adjusted), with a maximum of 135,4 Nm^3/h. The maximum consumption of air in the nitrogen production in the year 2008 was 484,75 Nm^3/h (measuring error adjusted). This leads to the conclusion that 11 bar would be enough to produce a sufficient amount of nitrogen with an inclusion content of 97 percent. This means, that 1 bar could be saved.

That this one bar is not economically worth being saved shows following example:

During the planning phase of UGS Haidach the energy costs for the compression of air were estimated. Two scenarios were analyzed: Compression to the minimum pressure necessary for nitrogen production, which is 6 bar and compression to the maximum pressure for nitrogen production, 14 bar. In scenario 1 the energy consumption would be 231.284 kWh per year. In scenario 2 the energy consumption would be 340.653 kWh, which shows a difference of 109.369 kWh.[4] Using the actual (Spring 2009; contract for UGS Haidach) price of 0,085 Euro/kWh, this leads to a price difference of 9.296 Euro per year. Remembering that the pressure difference in this example is 8 bar and that a saving of 1 bar is possible this leads to a possible saving of 1.000 Euro a year. This number is an estimate. For an exact number the performance curve is needed, but missing.

The disadvantage when reducing the pressure would be that in case a bigger volume of nitrogen would be needed this safety would not exist.

Entry Pressure Air [bar]	Volume of Nitrogen [Nm3/h]	Inclusion Content Nitrogen [%]	Volume of Air needed [Nm3/h]
12	156	97	546
11,5	148	97	518
11	140	97	490
10,5	132,5	97	464
10	124,5	97	436
9,5	117	97	410
9	109	97	382
8,5	101	97	354
8	93,5	97	328
7,5	85,5	97	300
7	78	97	273
6,5	72	97	252
6	66	97	231
5,5	58,5	97	205
5	50,5	97	177

Table 6: Pressures and Volumes for the Air and Nitrogen Production

Exhaust Heat

An area where exhaust heat is already used in its most basic modality is within the building where the compressors for the compressed air and nitrogen system are located. To operate the compressors in a safe and maintenance low way the temperature should be kept not lower than 5 °C. This heating is done by the exhaust heat of the compressor. Assuming the compressor working 12 hours a day and a heating period of 90 days a year, every year 3.080,4 Euro are saved. [5]

The use of the exhaust heat to heat the warm water cycle was not realized at the UGS Facility Haidach. This would have saved another 2.359,6 Euro a year.[6]

Engine Power	97 kW
Engine Efficiency	96%
Working Hours	12 h/d
Engine Rated Input	101,042 kW
Usable Energy	72,75 kWh
Days of Use	90 d
Energy Price	0,3 Euro/m3
Calorific Value	11,1 kwh/m3
Heating System Efficiency	90%

Table 7: Input Data for Exhaust Heat Recovery of the Air Compression System[7]

Heat Loss in Transfer Pipeline

The Problem

The Transfer Pipeline leads from the Underground Gas Storage Facility Haidach to the transfer station in Haiming and connects the underground gas storage facility with the Southern German pipeline system of WINGAS. The length of the pipeline is 40 km. Because of the temperature in the reservoir and the temperature increase due to the Joule Thompson Effect in the compressors, the temperature of the gas withdrawn is increased in comparison to the gas injected. On the way from Haidach to Haiming the temperature of the gas decreases again due to the lower temperature of the soil.

But the temperature of the soil is not the only thing which has to be considered. Because the main temperature is generated by the compressors and the Joule Thompson Effect the big temperatures differences appear when one or both compressors are working. Furthermore the volume of gas which is withdrawn and is sent through the transfer pipeline has to be considered. A larger volume means greater speed and finally leads to a smaller temperature decrease.

For example:

On January 15th 2008 at 12.50 a volume of 269.697 m^3/h was withdrawn with compressor 1 working. The temperature difference was 21 degrees Celsius with a temperature of 30 degrees Celsius when entering and 9 degrees Celsius when leaving the transfer pipeline.

On February 23rd 2008 between 2.00 am and 2.25 am a volume of 369.000 m^3/h was withdrawn with both compressors working and a temperature difference of 18.3 degrees Celsius.

On October 1st 2008 between 8 pm and midnight volumes between 33.600 m^3/h and 34.500 m^3/h were withdrawn without the compressors working. In this time the temperature difference was only between 8,9 and 9,7 degrees Celsius and has its origin in the heat energy which had been conserved in the storage reservoir.

The Solution

In the year 2008 compressor 1 was withdrawing during 3.519 hours, compressor 2 during 2.970 hours. During this time a total volume of 569.972.177 Nm^3 was withdrawn. During these withdrawal periods an average temperature of 10,51 degrees Celsius was lost. Of course this heat energy could be recovered, but the problem is to use it again. The use of this kind of low temperature is very limited. The only purpose to recover it would be to use it for heating in buildings, where a temperature of above 0 degrees Celsius is needed, e.g. in buildings with electrical sensitive equipment. But in most cases this equipment produces thermal energy on their own, which is used to heat the surrounding.

Furthermore the installation of a heat exchanger, which would be necessary to use the thermal energy, would be uneconomic.

	Average Temperature Haidach [° Celsius]	Average Temperature Haiming [° Celsius]	Delta [° Celsius]	Delta max [° Celsius]	Max Temperature Haidach [° Celsius]	Max Temperature Haiming [° Celsius]	Min Temperature Haidach [° Celsius]	Min Temperature Haiming [° Celsius]
Jan.08	22,8	8,55	14,25	21	30	9,4	15,4	7
Feb.08	23,47	9,28	14,19	18,3	27,8	10,2	17,8	7,5
Mar.08	21,27	7,64	13,63	19,8	28,2	8,7	15,9	7
Apr.08	15,36	5,06	10,3	19,7	28,2	9	4,6	2,6
Mai.08	11,64	6,56	5,08	8,3	13,4	9,4	10,8	4,3
Jun.08	12,74	9,63	3,11	5,3	13,8	11,8	11,5	6,6
Jul.08	14,16	11,76	2,4	4,1	15,2	13,2	13,7	10,1
Aug.08	15,05	13,24	1,81	3,7	16,2	14,6	14,7	11,8
Sep.08	15,46	12,09	3,37	5,4	17,9	14,1	14	10,1
Oct.08	18,47	11,98	6,49	11,9	25,6	13,7	13,8	8,6
Nov.08	18,46	9,95	8,51	13,7	24,2	11,3	13,1	8,2
Dec.08	18,25	8,34	9,91	14,5	23,2	10,1	7,3	7,1

Figure 9: Temperature Difference between UGS Haidach and Transfer Station Haiming

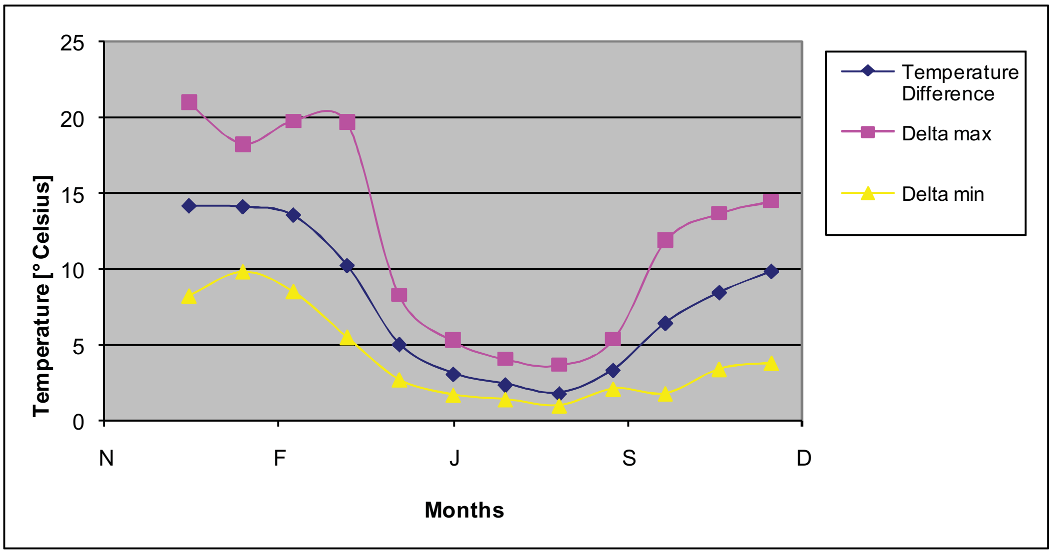


Table 8: Temperatures in the UGS Facility Haidach in 2008

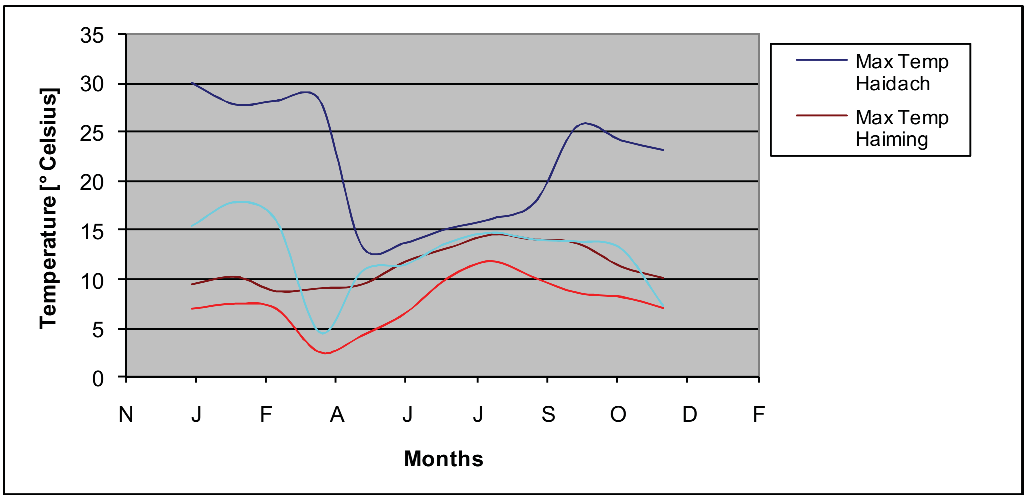


Figure 10: Max. and Min. Temperatures in the UGS Facility Haidach and TS Haiming

Dynamic Engines

Seal Gas Compressors have two operation modes. Number one is off and number two is on. This is called a static engine. So there is a pressure to be built up, when this pressure is built up, the compressor switches off, while a measuring device is measuring the pressure and turns on the compressor again when a certain minimum is reached. Of course switching on and off a compressor and driving the compressor with either 100 or 0 percent does not seem very economic. The solution would be a dynamic engine. Dynamic engines do not have two driving modes, but react on the exact capacity needed.

Although a saving potential can be found in this area, the saving is minimal, has no economic sense and is not further covered.

Flare

When having a look at the energy flow and temperature distribution of the Underground Gas Storage Facility Haidach a high temperature of the exhaust heat of the flare stands out. This temperature occurs in winter times and is produced by the pilot heater, which has to work when the temperature drops under a certain limit and which provides a safe operation. The pilot heater produces a temperature of about 100 °Celsius. The average temperature detected on some days is higher than 100 ° Celsius and comes from flaring gas. In summer time the sensor is measuring the outside temperature, except the times when gas is flared. Of course significant higher temperatures occur when gas is flared, but these temperatures come up just for a very short period of time. Another reason, why the heat produced by the flared gas can not be used is, that these temperatures come up very aperiodic, which makes it difficult to sell or use it immediately, which would lead to the need of a heat storage facility. The topic of heat storage is covered in a later chapter of this thesis.

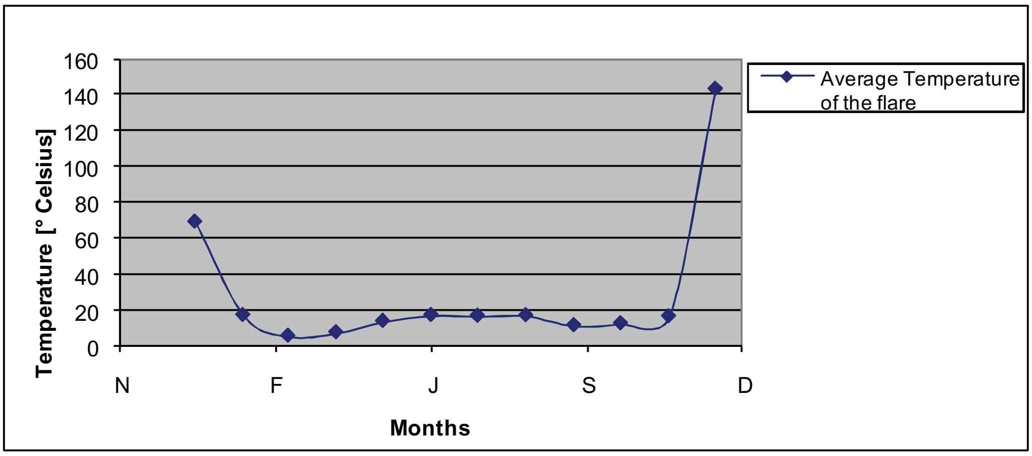


Figure 11: Average Temperature of the Flare

In the year 2008 the temperature exceeded 500 degrees Celsius 49 times which indicates, that gas was flared. Because these temperatures are reached only for some minutes the use of this heat is not economic. Of course in this case not only the economic aspect has to be considered, but also the HSE aspect. The usage of the flare has to be provided at any time. So the installation of a heat exchanger at the top of the flare, where the heat appears, is problematical. So the use of this heat is not practical, because of HSE reasons, economical reasons (there is no stable temperature which can be used) and technical reasons (the installation of the heat exchanger as near as possible at the pilot heater is not possible).

Another way to solve this problem and to overcome the use of energy would be to find a way not to use the pilot heater, which means to find a flare, which does not need a pilot heater being in operation all the time in the winter operation mode.

Energy Savings using Gas Turbine Exhaust Heat

The Problem

In comparison to the UGS Facility Haidach the compressors in Puchkirchen are not driven by electric motors, but by gas turbines. As in every combustion process this leads to the production of exhaust air with a certain temperature and today still to the loss of energy via this process.

	Turbine 1	Turbine 2	
Load Capacity	88,59	87,42	%
Hours operating in 2008	2.972,133	2.367,067	H

Table 9: Operating Hours and Load Capacity of Turbines in the UGS Facility Puchkirchen

The gas turbines have got an efficiency of about 30 percent, which states, that a big part of the energy lead into the turbines is lost via exhaust heat. But wasting such a big portion of energy is not just an image problem, but also an economical, because most of the gas burnt just increases the temperature of the exhaust air, which is further on lead into the environment.

While on the process itself nothing can be changed, the thermal energy of the exhaust air could be used.

The Solution

There are three ways to use the exhaust heat of a turbine

- The first possibility is to use this temperature within the turbine itself
- The second possibility is to use the temperature for evaporating a fluid in order to operate a turbine and to produce electrical energy
- The third way is to sell the heat directly to a customer

Direct Usage

A possibility to use the heat is to increase the performance of a turbine by preheating the compressed air stream. In winter this has to be done for operational reasons. This would be a possibility to use the heat directly in the turbine. The advantage of this usage is that the temperature is needed when it is produced and neither storage nor transportation is needed.

Furthermore the exhaust heat can be used to preheat the water in the hot water cycle or to heat facility buildings.

ORC

The so called “Organic Rankine Cycle” perfectly fits into the “loss of the exhaust heat” problem. ORC facilities transform heat into current or mechanical power. The temperature needed is low and so especially suitable for exhaust heat.

In this thesis ORC equipment from Infinity Turbines is analyzed. Infinity Turbines is an US company, which offers waste heat recovery equipment for all common types of turbines and engines.

Another supplier is the Italian company Turboden. Turboden is well known for producing ORC equipment for biomass plants. In Austria 26 such plants are working with Turboden ORC equipment, furthermore one is applied in a geothermal plant. Although a focus on biomass applications their equipment is also suitable for applications in waste heat recovery. [8]

ORC is a steam turbine process, which does not work with vaporized water, but with liquids with a lower evaporating temperature. The exhaust heat enters the process via a heat exchanger. It heats up a thermal oil and exchanges the thermal energy with the secondary cycle, with the working liquid (e.g. ammoniac, isobutene, silicone oil), which evaporates. The steam drives a turbine or an expansion engine which produces electrical power. The liquid afterwards cools down again and is reused.

In detail the process works in following three steps:

- The heat is provided in the form of thermal liquid (water, glycol or oil). If heat exchanger equipment already exists at the facility, then the use of just water or glycol is recommended, while a better alternative, because of better efficiency, is thermal oil. If there is no heat exchanger to capture the waste heat, then a hot air to thermal oil exchanger is recommended, which is a common equipment and available. The source of the heat can be geothermal, engine exhaust heat, thermal energy produced by solar collectors, industrial waste heat, steam produced in other processes or in the case of the Underground Gas Storage Facility Puchkirchen turbine exhaust heat. This heat source in the form of a liquid then flows through the preheater and evaporator heat exchanger. This is where the working fluid for the ORC turbine gets vaporized and pressurized. The heat source should be at least 80 degrees Celsius. Though also lower temperatures are possible the efficiency becomes practical with temperatures above 80 degrees Celsius. Once it passes through the evaporator, it leaves at about 10 to 20 degrees Celsius cooler. This thermal energy can then be used as additional process heat (combined heat and power, hot water or chiller)

- The working fluid for the ORC closed system is pressurized by the evaporator, then is expanded by the turbo generator. This produces the shaft horsepower to turn the generator and to produce electricity. Of course the turbine power can also be used to power a pump or any other equipment which is required
- The expanded working fluid then flows through a condenser to return from the vapor to a liquid state. The condenser requires some method of cooling fluid, typically water which is provided from a cooling tower, or ground based geothermal (the ground has a constant temperature of 15 degrees Celsius or less). The liquid is then pumped back into the evaporator unit to complete the cycle. Concerning HSE requirements only environmentally friendly working fluids are used in these systems

So, the basic system has an evaporator, a turbo generator unit and a condenser. The temperature difference between the evaporator and condenser must be at least 65 °C, but as mentioned, at least 80 degrees Celsius to work in an economical array.

The heat rate of Infinity Turbines is about 42.000 BTU / kilowatt electricity which is about 8-11 per cent efficiency. This system is geared towards waste heat so it can be considered as free power. With a sufficient high temperature it is also possible to use steam or steam condensed hot water to put into the evaporator (boiler) to run the system if this is available on site. But at the UGS Facility Puchkirchen thermal oil should be preferred.

The technical advantages of an ORC cycle are the following:

- High cycle efficiency
- High turbine efficiency (up to 85 percent)
- Low mechanical stress due to low peripheral speed
- Low RPM of the turbine allowing the direct drive of the electric generator without reduction gear
- No erosion of blades, thanks to the absence of moisture in the vapor nozzles

The operational advantages are the following:

- Simple start/stop procedure
- Automatic and continuous operation
- No operator attendance needed
- Quiet operation
- Very high availability
- Partial load operation down to 10 per cent of nominal power
- High efficiency even at partial load
- Low operator/maintenance requirements (3-5 hours/week)
- Long life[9]

The advantage of the product produced by the OR Cycle is, that current is easier to sell than heat. Furthermore the compressors are in operation mainly in summer when gas is injected. This is exactly the time when other green energy sources, like water power, are weak, because of the river's low tide.

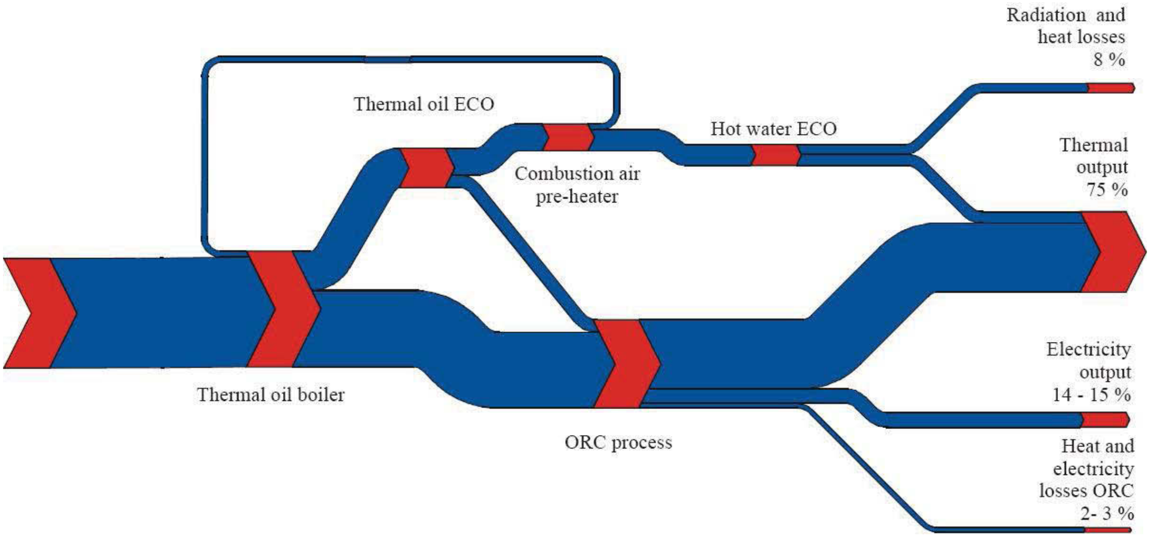


Figure 12: Energy Balance of an ORC Facility[10]

As an example: In the Underground Gas Storage Facility Puchkirchen a Caterpillar Solar Mars 90 Turbine is used. The specifications of this turbine are as follow:

ISO Continuous Duty Output: 11.185 kW

Heat Rate: 11.300 kJ/kW-hr

Exhaust Flow: 144.590 kg/hr

Exhaust Temperature: 465 °C

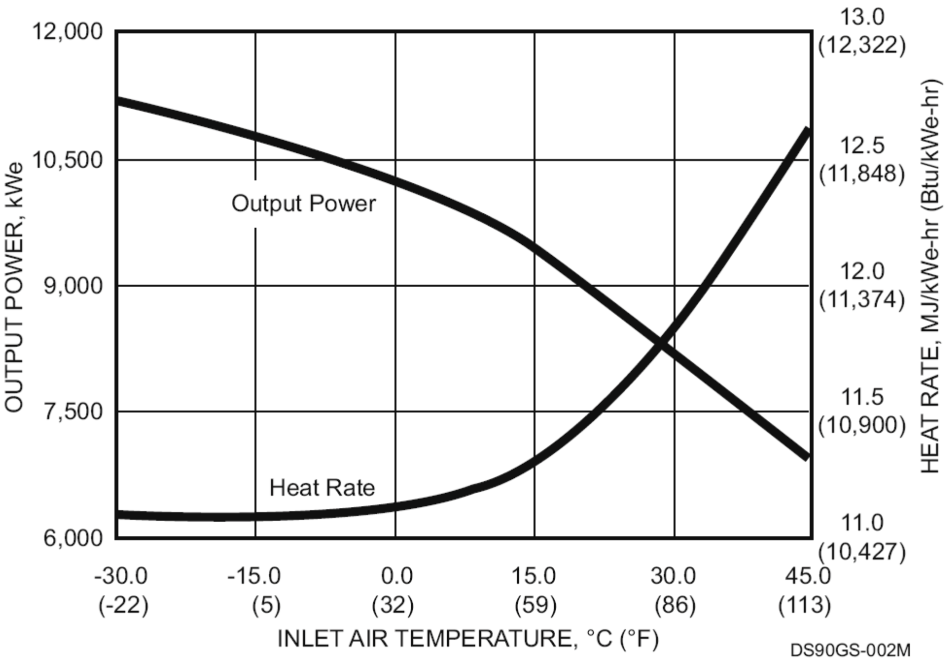


Figure 13: Mars 90 Performance[11]

Assuming one turbine working with full power, 1.687 kWe per hour can be recovered. Within 24 hours a total of 40.484 kWe or within a year, assuming the turbines would work all year long, a total of 14.776.587 kWe could be produced.

In terms of economics two aspects are important:

- The money which can be made by producing energy:

  Because the price of energy bought is higher than the revenues of energy sold, the money, which can be made is the money which can be saved by using the energy in own facilities.

  The biggest energy demand in the Underground Gas Storage Facilities Haidach and Puchkirchen are the two compressors in Haidach. The energy consumption in the year 2008 is shown in the table beneath:

	Compressor 1	Compressor 2
January	239,293	186,146
February	449,54	442,643
March	699,907	606,733
April	470,292	676,046
May	1.436,916	1.126,49
June	2.032,599	2.067,65
July	2.602,1	2.623,696
August	2.539,443	3.041,111
September	46,422	2.571,498
October	16,18	843,434
November	7,5	714,394
December	0	0
SUM	10.540,192	14.899,841

Table 10: Energy Consumption of Compressor 1 and 2 in UGS Facility Haidach in MWh

To give an estimate of the amount of energy produced in Puchkirchen and because of the performance curve is missing, the energy produced was reduced by the load percent wise.

Because Turbine 1 and Turbine 2 are running parallel most of the time, two ORC facilities are suggested. So Turbine 1 would have produced 5.013,988 MW and Turbine 2 would have produced 3.993,247 MW in the year 2008. Reducing these numbers by the loads, this leads to Turbine 1 producing 4.444,89 MW (reduced by the load of 88,59 percent) and Turbine 2 producing 3.490,90 MW (reduced by the load of 87,42 percent) in the year 2008.

So with two ORC facilities a total energy production of 7.932,79 MW can be achieved in one year, like shown on the example of the year 2008.

This means, that 75 percent of the energy need of Turbine 1 in Haidach or 53 percent of the energy need of Turbine 2 in Haidach could be produced by two ORC facilities in Puchkirchen.

The final economical number has to be reduced by the transportation costs, which are 16 Euro/MWh.

- The money which has to be invested:

  The investment costs for the ORC Equipment are as following: Infinity Turbine offers ORC equipment in the range of up to 700.000 Euro. These are power skid units only and include a heat exchanger evaporator, a turbine, an induction generator, a condenser heat exchanger, a recirculation pump and basic grid connection switchgear. This is the absolute minimum equipment necessary for an ORC facility. Not included are any fluids, further transportation, taxes, installation and commissioning.[12]

Using the Net Present Value Method following results can be achieved:

To calculate the Internal Rate of Return and the Net Present Value it is assumed that the energy is not sold to an electricity provider, but transported from the Underground Gas Storage Facility Puchkirchen to the Underground Gas Storage Facility Haidach, where the electrical energy is used to run the compressors.

So not the money, which can be earned is calculated, but the money which can be saved. The costs are assumed for the worst case. So the whole investment costs are calculated for 1.000.000 Euro and maintenance is calculated with 15 Euro/MWh. The transportation costs within the electricity grid of Energie AG are calculated as 16 Euro/MWh, which finally leads to following economics after taxes:

IRR: 22,8 %

Net Present Value: 1.927.122

Pay Back Time: 3,7 years

The exact calculation can be found in Appendix B.

Beside the actual economics there is another interesting aspect which may kick in in a couple of years: Carbon Credits.

Although RAG is not affected by the trading of carbon credits, it is a positive side effect, that with the use of ORC or other possibilities to use exhaust heat, emissions are reduced. Even in the case, that RAG will be affected by carbon credit trading, this optimization in energy efficiency will give an advantage over other competitors.

Carbon Credits were introduced to mitigate global warning. These certificates can be traded and have got a certain value. Based on 1 kW, which is 1 pound offset of CO2 or 2.000 kW per ton of CO2 and based on December 2008 EUA futures price of Euro 22,54 per ton, the total savings of carbon credit in one year would be 166.532 Euro.

Because the ORC facility is just producing energy when there is exhaust heat, which means the turbines are working, the energy produced must not be seen as alternative to ordinary power supply, but as an additional way to supply the facilities with energy.

Figure 14: ORC Facility[13]

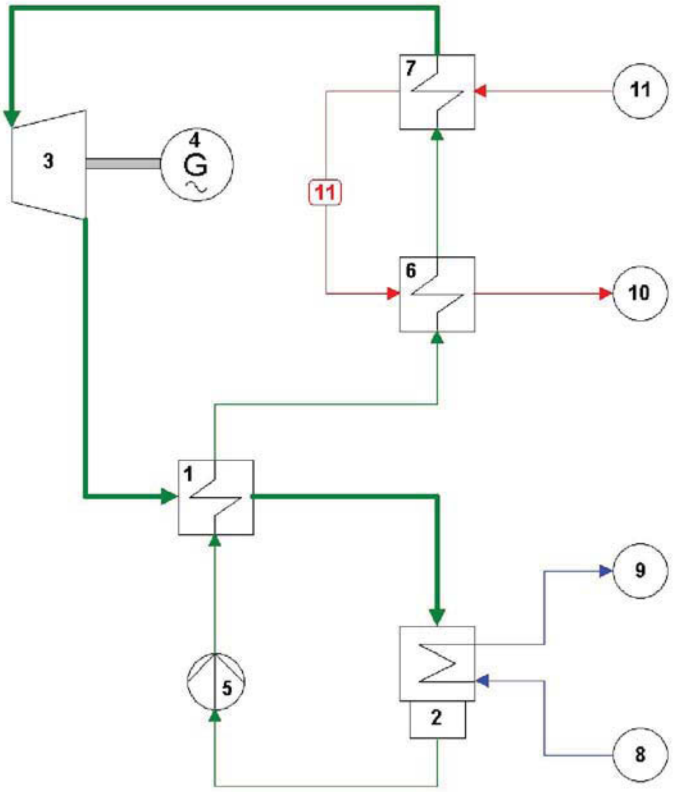


Figure 15: Schematic ORC[14]

Kalina Process

The Kalina Process is a further development of the OR Cycle. Siemens holds various patents on this process. The Kalina Cycle uses an ammoniac water mixture. The big advantage is that this mixture boils at a variable temperature, which means not at a certain temperature but in a temperature range, which is dependent on the ammoniac concentration. So the working fluid maintains a temperature closer to the temperature of the hot combustion gases in the boiler.

The ammoniac water mixture is heated up and starts to boil. The ammoniac rich vapor is separated from the ammoniac poor solution. While the vapor expands in the turbine and drives a generator, the solution is used to heat up the ammoniac water mixture, before both, the solution and the vapor are brought together and the cycle is started again.

With this process already temperatures of less than 80 degrees Celsius can be economically used, furthermore the efficiency is 10 to 60 per cent better than the efficiency of an OR Cycle.[15]

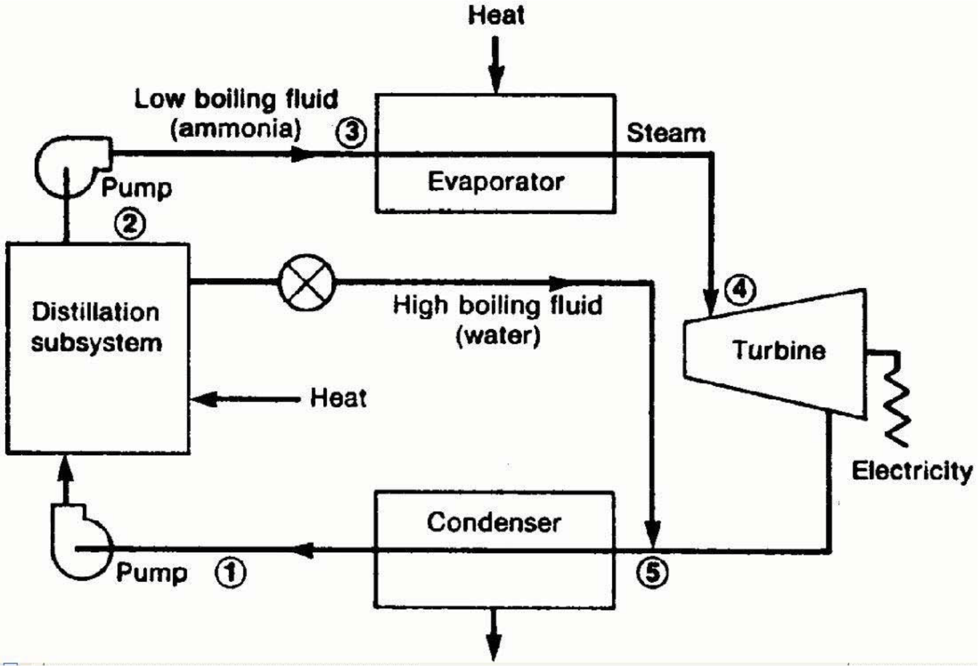


Figure 16: Kalina Cycle[16]

1. An ammoniac water mixture enters the distillation system
2. The ammoniac rich vapor is separated from the ammoniac poor solution
3. The vapor is further evaporated and pressurized
4. The vapor expands in the turbine
5. Vapor and solution are reunited and the cycle starts again

The main differences between the Kalina Process and the OR Cycle are:

- The single organic working fluid is replaced by for example NH_3/H_2O
- The liquid working fluid circulates in a closed loop system
- Separation of steam and liquid (superheating of steam is possible, but is normally not done)
- Condensation (absorption) of vapor can be done at a low pressure level
- A substantial part of the absorption energy can be given back to the cycle[17]

The investment costs are higher than those of an ORC equipment, because more heat exchangers with larger heat exchange areas are necessary.

But this is not the only reason why a Kalina Process is not applicable in exhaust heat processing. The Kalina Process has got some very difficult to controllable problems, like corrosion in the steam turbine. These problems occur where the ammoniac contacts the steam turbine, for example at the blades. Overall the disadvantages preponderance the advantages and if possible an OR Cycle is used. The only applications for Kalina Processes yet are in geothermal power generation, but because of the difficult controllability even there ORC equipment is favored.[18]

Steam Turbine

While ORC facilities work in a temperature range between 50 and 150 degrees Celsius, not the whole temperature of the turbines exhaust heat could be used. The fluids used in an ORC equipment have got a low vaporization temperature, which makes it usable for low temperature applications. With an exhaust heat temperature of 465 degrees Celsius, like at the Caterpillar Mars 90 turbines, fluids with higher vaporization temperatures could be used. What comes into mind is to use water as a very easy to handle and available fluid. Furthermore a simple steam turbine, which is available and widely used, can be operated and neither a special cycle with thermal oil nor heat exchangers are needed. Furthermore steam turbines, as mentioned, are used in many applications and industries, which makes it an easy available equipment, which has been proved in operation for thousands of hours. Steam turbines, like manufactured by Siemens are available in the range from 45 kW to up to 10 MW and work with steam temperatures of 200 to 400 degrees Celsius.

But the reasons why an ORC cycle is preferred over a steam turbine in the case of exhaust heat of gas compressors at the Underground Gas Storage Facility Puchkirchen are as follow:

- Because the turbines are not working frequently a fast start up is necessary.
- Furthermore the temperature which can be brought from the thermal energy of the exhaust flow to a water flow and the energy to evaporate this water is too high. The temperature of the steam would be at the lower limit and the steam turbine would not work efficient.

Selling the Thermal Energy (Community Heating Provider)

Concerning the third way to use the exhaust heat of the gas turbines in the Underground Gas Storage Facility Puchkirchen, already in the year 1999 the idea came up to use this thermal energy, by selling it in a direct way. Because the community heating facility Timelkam is just about 1,5 km airline distance away, the opportunity to use this energy there was given. So the project “Exhaust Heat Usage” started as cooperation between RAG and Energie AG Oberösterreich.

The project was configured as follows:

RAG delivers heat energy in form of hot water with a maximum temperature of 120 degrees Celsius and a maximum capacity of 15 MW. A yearly purchase quantity of 17 GWH was expected. The hot water is created by a heat recovery unit. This unit consists of a heat exchanger, which absorbs the heat of the exhaust air and transfers it to a hot water cycle. Because the amount of heat energy is very much dependent on the customers of the Underground Gas Storage Facility Puchkirchen and if there is withdrawal, injection or no operation at all, RAG does not guarantee a special volume or a special capacity.

The contract between RAG and Energie AG Oberösterreich will last till the end of the storage contracts. The price of the energy is dependent on government aid, which is expected to be 30 per cent of the investment costs. Because the support by governmental aid was not certain, two possible prices were developed for every option, one with and the other without the help of governmental aid.

Two options were developed, which were described as follows:

Option 1: Energie AG Oberösterreich pays 220 ATS/MWh when there is no governmental aid or 162 ATS/MWh when there is governmental aid for every MW they need and want to buy.

Option 2: Option 2 is a take or pay option. Energie AG Oberösterreich pays 198 ATS/MWh when there is no governmental aid or 146 ATS/MWh when there is governmental aid. This option states, that a certain amount of energy has to be bought. This energy can be used or not, which is a choice of the buyer. If a delivery is not possible in one year the missing amount will be delivered in the following calendar year.

RAG and Energie AG Oberösterreich proved the profitability of this project and came to the conclusion that this project is only economically interesting if there is a 30 per cent governmental aid. But this governmental aid was refused, because governmental aid is just authorized for projects dealing with renewable energies. Because the exhaust heat is produced by burning gas, the letter of inquiry was declined.[19]

New Aspects

Since the program was stopped, some surroundings in energy policy and the oil industry have changed. Gas crisis and the decreasing European gas reserves led to increased notice of ways to save energy. Furthermore the public image is more and more affected by the way companies deal with environmental questions and environmental challenges.

So the realization of this exhaust heat project would increase the CO2 balance, by saving thousands of tons of CO2, because the use of primary energy, used for heating the vessels, could be decreased. This leads to the result that the community heating project Timelkam becomes even more economical and environmental friendly. For the study “Exhaust Heat Usage” the year 1997 was analyzed. In this year 4,8 million Nm^3 of gas were used to operate the Underground Gas Storage Facility Puchkirchen. This usage leads to a production of 23 tons of CO, 56 tons of NOx and 65 tons of CH4. By selling clean energy, this balance can be improved.

Another important aspect, which has changed are energy prices. Since 1999 not also the prices for hydrocarbon fuels have increased, but also the price for thermal energy in community heating processes. This means, that the value of the thermal energy, which could be provided by RAG’s two gas turbines in Puchkirchen increased. Furthermore in economical difficult times the import of gas can be decreased and the Austrian balance of trade could be increased. In total 2.000.000 m^3 of gas could be saved every year. Of course this project would create jobs during the planning and construction phase and would secure the location of the community heating facility Timelkam.

To find out if a governmental aid is still needed, concerning the increased energy prices, to run this project economically, following aspects have to be proved:

Investment Costs:	The investment costs consists of the 1,5 km transfer pipeline between the Underground Gas Storage Facility Puchkirchen and the community heating power station in Timelkam. Furthermore the investment costs of the Solar Waste Heat Recovery have to be taken and furthermore certain replacements to make the installation of the heat recovery equipment possible, for example the movement of the existing exhaust stack of the turbines. In 1999 a total investment of 30 million ATS was suggested.[20]
Need of the energy:	Because the community heating facility Timelkam has increased its capacity over the last few years by building a new biomass power station and further the thermal energy would be available in summer, when the need of thermal energy is low anyways, it has to be proved by Energie AG if the thermal energy provided by RAG would be able to be used.

Selling the Thermal Energy (Brewery)

Another possibility to sell the heat directly is to produce hot water via a heat exchanger and to transport it via a pipeline to the brewery Zipf. RAG is already working on an energy supply concept, which is based on a geothermal well. This geothermal well produces steady thermal energy, which can be directly used within the brewery. But the need of power by the brewery can not be satisfied by the geothermal well only; a block heat and power station would be an option. This block heat and power station is gas driven and operated by RAG, but it produces much more energy than actual needed by the brewery. Because in this scenario all the energy is produced by RAG, whenever gas is injected or withdrawal and the turbines are in operation and producing thermal energy, the block heat station could be turned off or the load could at least be reduced. So gas is saved, and the thermal energy which is produced anyway could be used in a reasonable way. The energy, produced by the exhaust heat of the turbines would be additional green energy and could also be used to overcome peak consumption, when energy from conventional sources would have to be applied.

A main problem in selling the heat is the transportation of the hot water or steam. In the case of a pipeline between Puchkirchen and Zipf there is the advantage, that between these two places a pipeline built and operated by Oberösterreichische Ferngas AG already exists.

Usually when a pipeline is built, a second pipeline string on the same alignment is requested and usually granted. Therefore the commissioning of the pipeline would be lapsed, especially because this community heating pipe is no competing pipeline to the gas pipeline of Oberösterreichische Ferngas. This would lead to the advantage that no stakeholders have to be bothered.

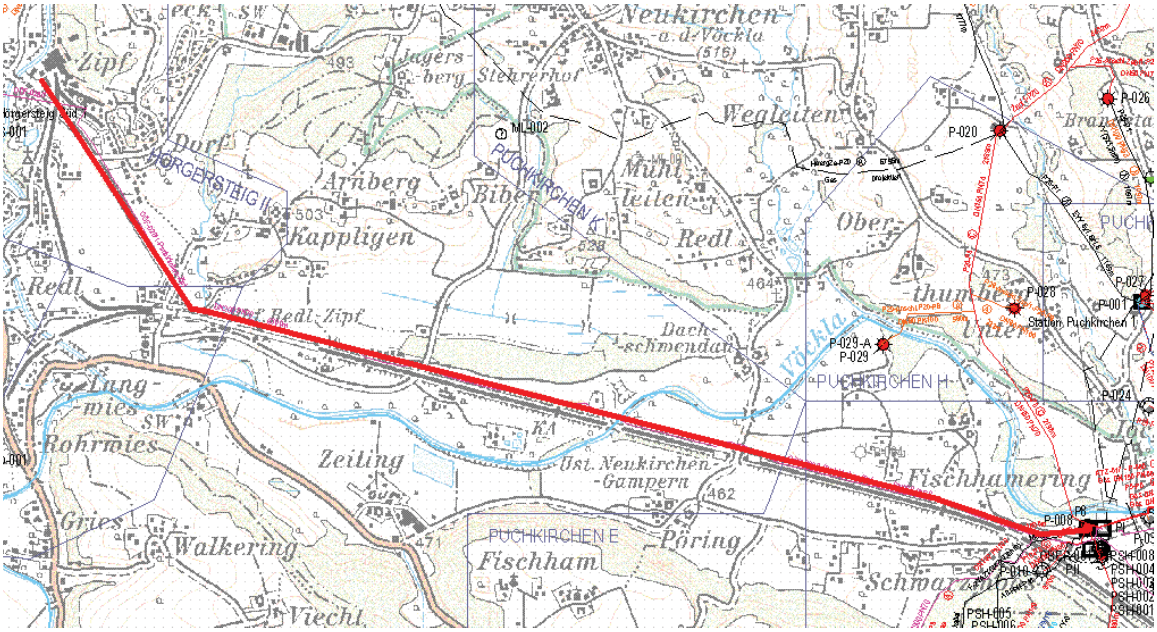


Figure 17: Possible Hot Water Pipeline from Puchkirchen to Zipf

The pipeline can be realized as a community heating pipe transporting 19 tons of oversaturated steam with a pressure of 10 bar in one hour.[21] The water for example could be taken from the river Vöckla in Puchkirchen, heated up and transported via the pipeline to Zipf, where it is cooled down and entering the river again.

This would have got the advantage that not a closed cycle with two pipelines has to be built, but just a one way pipeline would be sufficient. But legal details concerning the circulation of water via a pipeline and a river are not clarified.

Alternate Generation/Conservation of Energy

Conservation of Thermal Energy (Conventional and Alternative)

Theory

The law of conservation of energy states, that the amount of energy within a closed system remains constant. The only thing which can change is the type of energy, for example changing thermal energy to electrical energy. In theory this is possible to 100 per cent, but there are mechanical and thermo dynamical losses, which can amount to a big portion of the overall efficiency, sometimes even up to 95 per cent. In the Underground Gas Storage Facility Puchkirchen enormous quantities of air are heated up by gas turbines. Air is a very inefficient storage medium. Therefore not only the type of energy, but often also the medium can be changed.

This is the solution to the big challenge of selling heat energy of an underground gas storage facility. The problem is that the heat energy is produced in the summer time, when gas is injected and not in the winter time, when thermal energy is needed. This mismatch of supply and demand makes it necessary to take advantage of the first law of energy conservation and put the heat energy in a closed system in summer in order to regain it in the winter time when the energy is needed. Of course a closed system does not exist and there are losses, but there are several ways to store thermal energy in an efficient way.

Thermal energy storage started its raise with the introduction of solar energy. Short term storage was needed for the nights and long term storage was needed to store thermal energy in the summer in order to withdraw it in the winter. Still solar energy is the main application for short and long term thermal energy storage. There are three basic principles to store thermal energy:

- Sensible storage is based on the temperature change in a material
- Latent storage works with a phase changing material
- Thermal chemical storage is based on the reaction between two chemicals [22]

Sensible Storage

Water Tanks

The storage of thermal energy in water tanks is quite simple, but leads to certain problems. Water is heated up and stored in a tank. The heat capacity of water is good for applications in homes, where this principle is very common to store solar energy. But for industrial applications, with temperatures above 95 degree Celsius it can not be used. But if higher temperatures are needed, thermal oils can be used. A problem with water tanks is the insulation, which becomes a major cost factor especially in big applications.

But storage of big volumes can be done and is done with capacities beyond 12.000 m^3. These cylindrical storage tanks consist of steel or concrete with special insulation additives. Because films are not heat proofed for long time applications and temperatures above 80 degrees Celsius, the inner line is carried out by steel. The capacity of such water tanks ranges between 60 and 80 kwh/m^3.[23]

Water/Gravel Storage

Water/Gravel Storage tanks work after the same principle as water tanks, but no tank has to be built. Usually these facilities are dug into the soil. The advantage is that the storage medium consists of gravel and water, which provides the ability of statically carrying of other facilities on top.[24]

Concrete

The heat is transported via steel pipes into a concrete block. This works for temperatures up to 400 degrees Celsius. The problem is to find the right concrete mixture. Because of certain humidity in the concrete thermo mechanical stresses have to be withstood by the concrete block. This is one reason, beside of thermo physical reasons that a basalt concrete is chosen. [25]

Ground Probes

The storage of heat in ground probes is also called "Borehole Thermal Energy Storage" (BTES). Simplified it is an underground heat exchanger, which can be used to store heat, which is for example generated by the compressors during the injection cycle, in order to use this thermal energy in the winter.

This system is mainly used when large quantities have to be stored. Therefore it is for example used in the Drake Landing Solar Community, where energy, gained trough solar collectors on every house in the whole village, is stored in the summer time and regained in the winter. This application is used as an example:

144 boreholes with a depth of 35 meters and a diameter of 150 mm are storing energy. Usually the depth of the wells is between 150 and 200 meters, but is dependent on the ground water level and the geology.

In the wells a pipe with a U bend at the bottom is installed. The whole borehole is filled with a high thermal conductivity grouting material to improve the thermal contact to the surrounding.

There are two principles:

In the open regime the outlet is placed at the bottom of the well, while the inlet is placed at the top, right beneath the ground water level.

In the closed regime there is just a thermal interaction between the soil and the fluid, which is guided in a closed circle through the well. The disadvantage is that a medium between the pipes and the soil is needed to allow thermal interaction.

The whole borehole field has got a diameter of 35 meters. Hot water is pumped to the middle of the field and through the U pipe series, from the middle to the outside. While moving outside the water cools down and temperature is transferred to the soil. In general there are various options to arrange the wells, for example in circles or in squares.

When the thermal energy should be regained cooler water is pumped through the pipes, where it is heated up by the soil. The capacity of the ground probes system ranges between 15 and 30 kWh/m^3.[26]

For borehole thermal energy storage a rock with high specific heat, a medium to high thermal conductivity and a compact rock mass with no ground water flow is needed. Further the grain size and the types of minerals are of importance.[27]

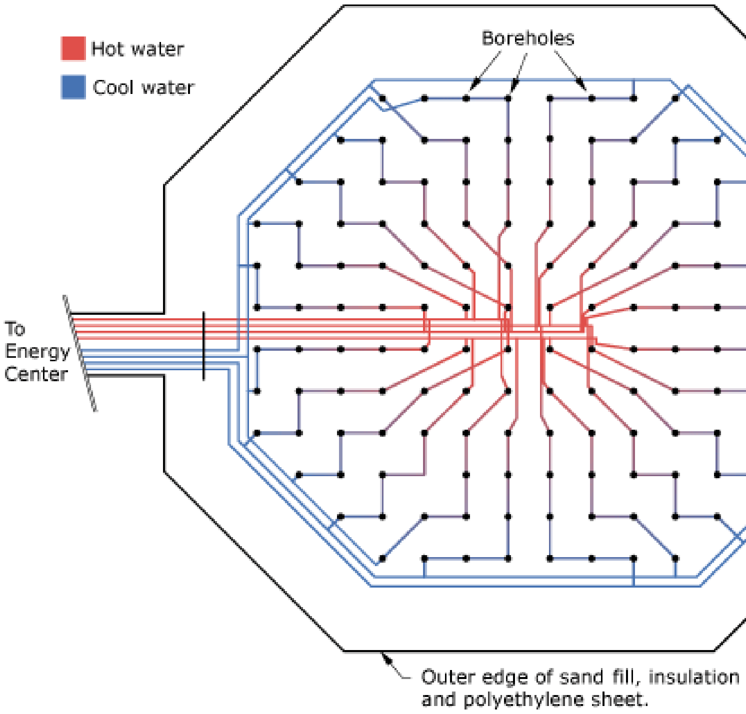


Figure 18: Aerial View of a Borehole Thermal Energy Storage Facility[28]

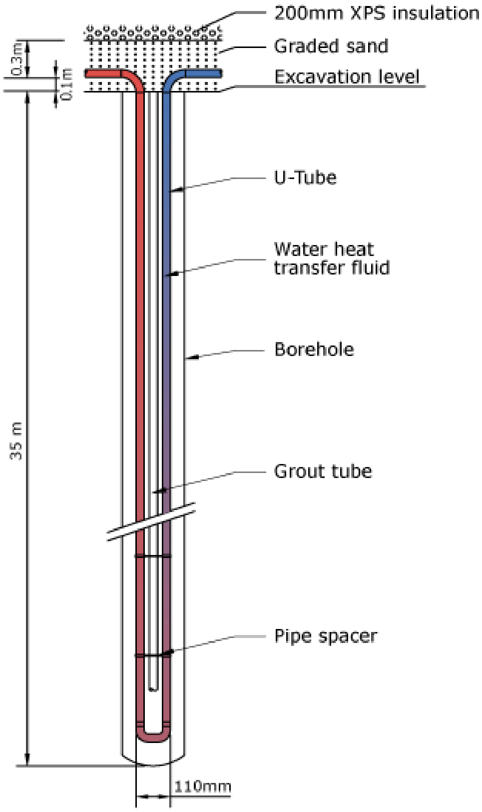


Figure 19: Side View of a single Borehole Thermal Energy Storage Tube[29]

Aquifer Conservation

The difference between the storage in soil via boreholes and storage in an aquifer is the medium. Therefore aspects like a minimum flow through the reservoir and the ground water chemistry are of importance. Because water has got a bigger heat capacity than soil, the capacity of an aquifer conservation facility is bigger than that of borehole storage facility. The capacity of an aquifer storage facility ranges between 30 and 40 kwh/m^3.

There are two principles:

In the cyclic regime the hot water is injected by all wells. In the winter time when the thermal energy is consumed this thermal energy is produced by the same wells again, which makes it necessary for wells to be able to inject and to produce water.

In the continuous regime there are wells for injection and wells for production. In this case the temperature range is more limited than in the cyclic regime. [30]

The problem with storing thermal energy in an aquifer is the temperature increase in the aquifer, especially concerning on the thermal energy of the turbines and the temperatures, which are high above those which are usually achieved with solar panels. This temperature increase leads to a disturbance of the microbiological balance in the aquifer. Bacteria, which are important for the recreation of water can only survive in a certain temperature environment. Further the aquifer is only several meters beneath the surface. So the temperature distribution of the whole soil will change, which will lead to visible changes in the environment.

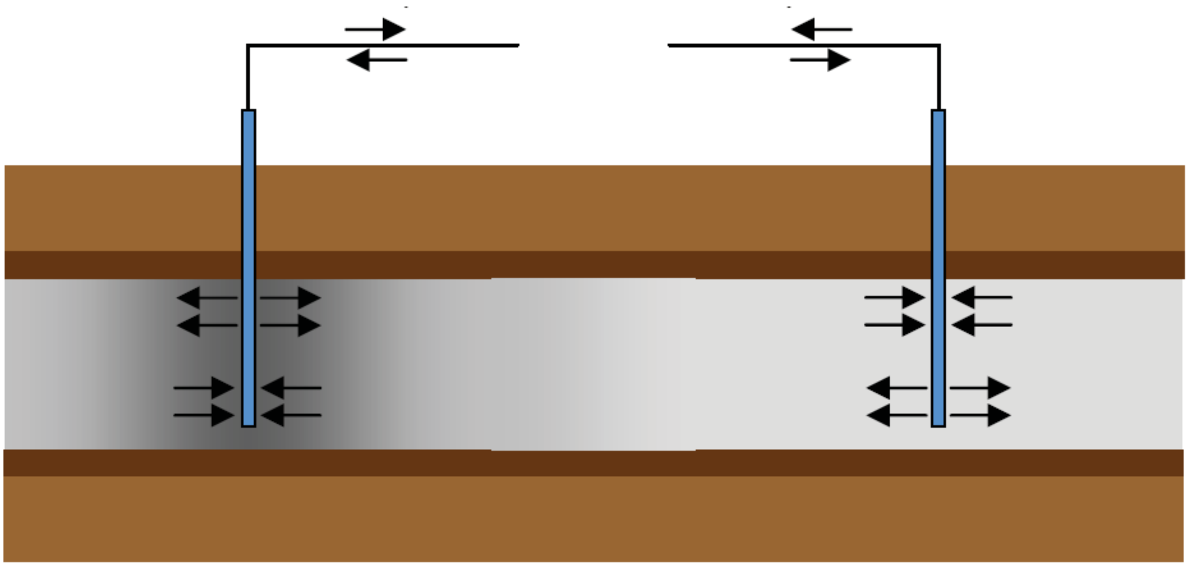


Figure 20: Thermal Energy Conservation in an Aquifer[31]

Conservation in the Reservoir

In the Underground Gas Storage Facility Haidach thermal energy is already stored in the reservoir. While the gas is injected into the reservoir it is not cooled. The temperature stays constant in the reservoir and is used during withdrawal to reduce the energy which is needed to preheat the gas. Furthermore the warmer gas is of advantage at the dehydration process.

Storage in Wells

The technical principle of storage in wells is the same as in ground probes or in the reservoir. But there are two big advantages.

For RAG wells are available. They are located around the underground gas storage facilities, which used to be producing fields. Around the Underground Gas Storage Facility Puchkirchen there are several wells, with a very low production rate or abandoned wells, which could be used for heat storage and later recovery.

The second advantage is the depth of the wells. Because when storing heat in aquifers, for example, concerns in the public could come up, that the storage and the increase of the temperature in the aquifer could lead to a problem in the balance of the natural aquifer household.

But the advantage of the depth leads to several problems. First the temperature difference between the bottom of the well and the circulating water is much smaller than in wells with a smaller depth, because of the natural geothermal energy of the soil, which increases with increasing depth. The geothermal gradient varies between 15 and 30 degree Celsius per 1000 meter, which leads to a temperature of up to 60 degree Celsius at the bottom of the well. Furthermore at the top section of the well there is another problematic temperature difference, a difference between the annulus and the tubing. So when thermal energy is stored, the hot water transmits thermal energy via the tubing to the cold water, coming out of the well and vice versa. Finally a big problem is that the temperature of the transportation fluid does not increase linear with the depth, because of the exchange with the surrounding during the way up and because of smaller volumes, which can be transported through the smaller diameters of deep wells.

Another problem is that there is no grid of wells. If there should be an application like with ground probes, pipelines between these thermal energy storage wells are needed. Those pipelines have to be insulated and will lead to several problems like crossing properties. Further a better solution could be achieved with the wells being close to each other, so the soil is able to be heated up and a thermal energy grid can be produced.

CO2 as Heat Carrier

The idea is to use a CO2 storage reservoir as a storage reservoir for thermal energy. The CO2 is heated up and stored in the reservoir. Via a closed second circle the carrier fluid enters the reservoir. In the reservoir the temperature of the carrier fluid is increased and produced. Back on the surface the thermal energy is regained via a heat exchanger.

The advantage of this system is that there are no losses in the process of exchanging the thermal energy between the carrier fluid and the storage reservoir, because the CO2 in the storage reservoir is the carrier fluid on the way down.

The disadvantage is that the thermal capacity will increase over time. Because the volume in the reservoir will increase and the thermal energy is abstracted in regular periods of time there will be an exchange of thermal energy between the CO2. Furthermore of course there will be an exchange between the gas and the formation, which has a significant impact when gas is stored for several months. Another problem is that there has to be enough CO2 and a CO2 storage facility available, which is not the case in Puchkirchen.

Compressed Air Energy Storage

A way not to store thermal energy, but electricity is to compress air. Compressed Air Energy Storage Facilities are mainly used to overcome peak loads. The working principle is simple. While in times with a low demand air is compressed and the pressurized air is stored in salt caverns, it is withdrawn in times of peak demand. On the surface again it is expanded over an expansion turbine and electricity is produced. Because a certain temperature has to be reached before the expansion to overcome gas hydrates in the turbine, this kind of storage process is combined with a gas turbine power station. The temperature produced by the Joule Thompson Effect can be stored and used to preheat the air before it is expanded in the expanders.

So at the Underground Gas Storage Facility Puchkirchen electrical energy could be produced by ORC facilities. If this energy is not supposed to be sold, but used in own facilities, this electrical energy can be stored and be withdrawn when this energy is actually needed.

Compressed Air Energy Storage has already proved its possibilities in reality. Two CAES Facilities are in operation, one in Huntorf, Germany and one in McIntosh, USA. Huntorf can produce 290 MW over 2 hours, while the facility in McIntosh can produce 110 MW over 26 hours. The efficiency in Germany is 42 percent, the efficiency in the USA is 54 percent.[32]

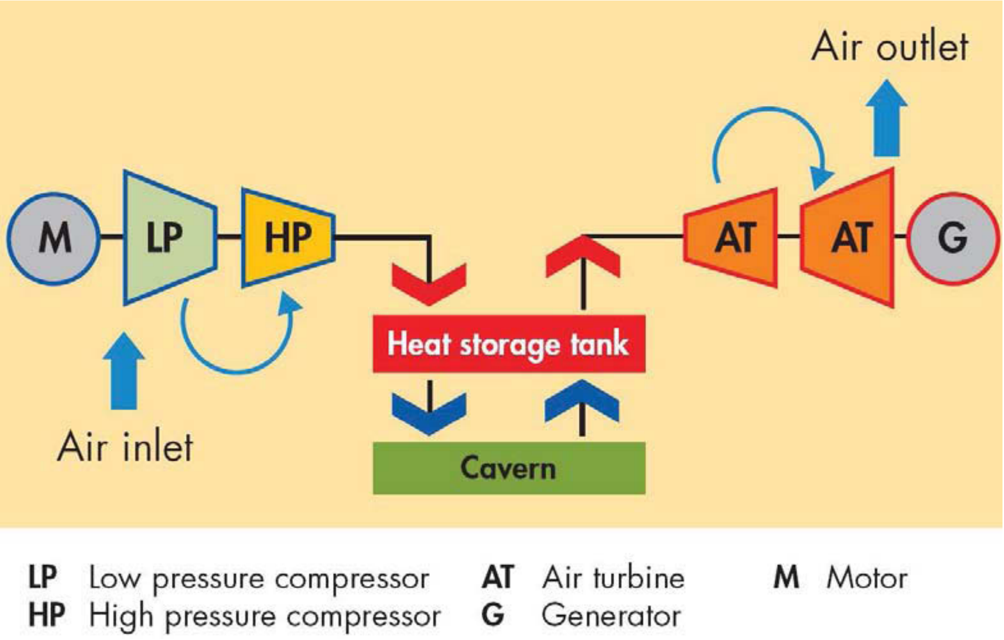


Figure 21: Working Principle of a Compressed Air Energy Storage Facility[33]

Latent Storage

The essential part of latent heat storage is a phase changing material. These materials usually have got a very low melting point. So beyond the melting point, the phase changes from solid to liquid, due to the absorption of heat (melting enthalpy). Although the change of the phase due to the heat energy, there is hardly any increase in temperature of the phase changing material.

Such phase changing materials are for example Latent Heat Paraffins with melting points between -4 and 82 °C and a heat storage capacity of 132 and 222 kJ/kg, or Latent Heat Granulate with melting points between 28 degree Celsius and 79 degree Celsius and heat storage capacities between 63 and 72 kJ/kg.

In general these materials have got melting points between -21 degree Celsius and 200 degree Celsius.

But the application of these latent storage methods with a storage capacity of up to 0,1 MWh/m^3 is of very small scale today.[34]

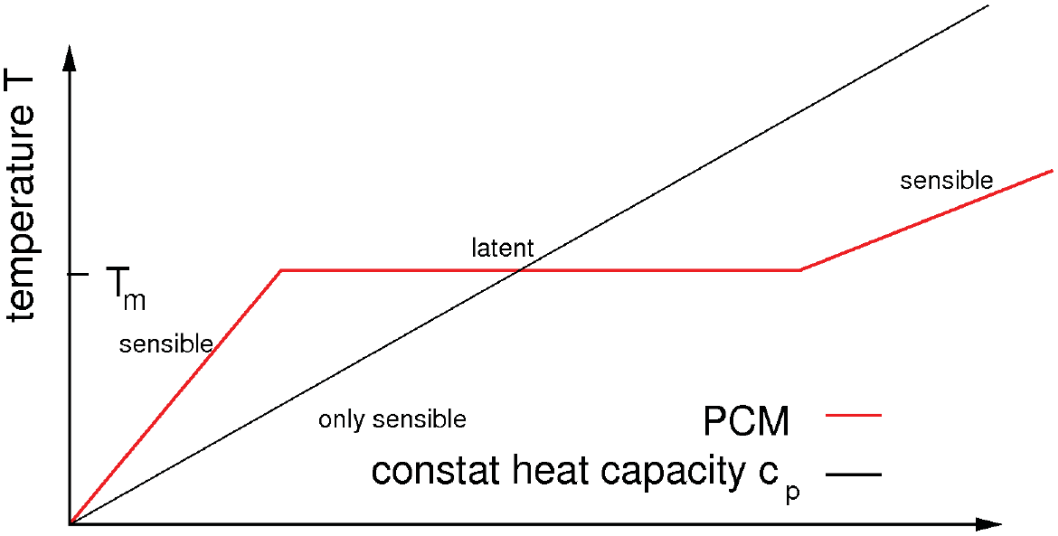


Figure 22: Latent and Sensible Heat Storage Temperature [35]

Chemical/Sorption Storage

Chemical Storage is a process of a reversible chemical vapor absorption reaction. The reaction works as follows:

Charge: AB + heat = A + B (gaseous)

Discharge: A+B (gaseous) = AB + heat

A chemical, which includes an easy to evaporate component (e.g. water) is heated up to the point where a chemical reaction begins.

One component is evaporated. This is the part where heat is stored. When heat has to be produced the two chemical components are added again and heat is produced.

With chemical reactions storage capacities of up to 1 MWh/m^3 can be achieved, of course dependent on the chemicals. The big advantage of this way of storing energy is that it is very flexible.

The following picture shows a circle, which works with magnesium sulfate and water.

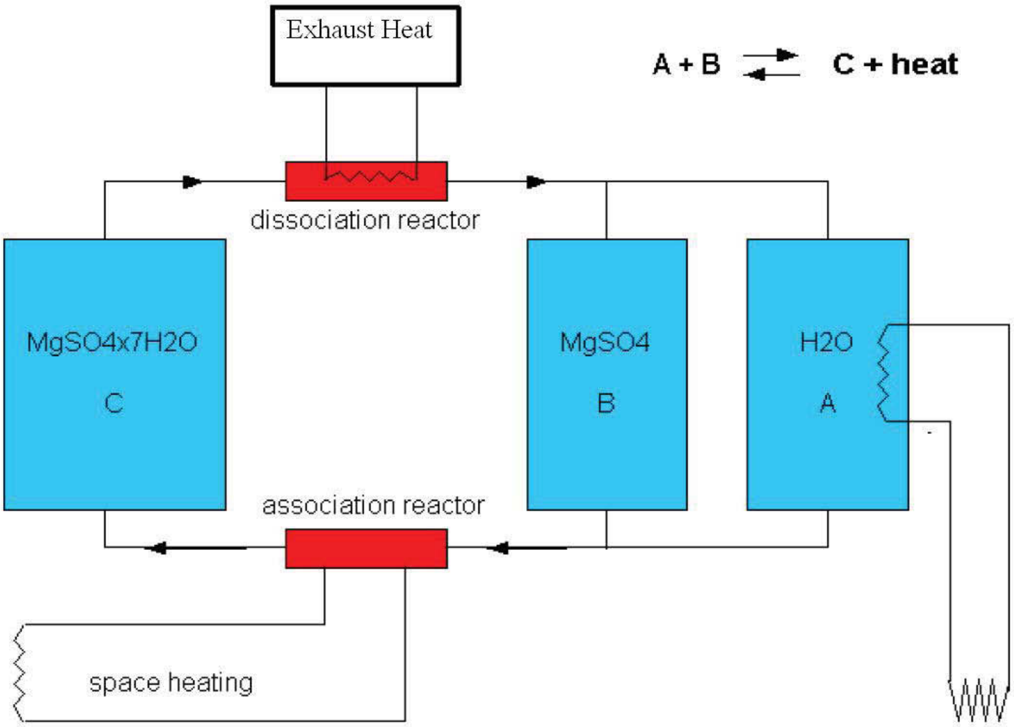


Figure 23: Chemical Storage Cycle[36]

Another possible reaction is the one between sodium sulfide and water. Therefore the heat, for example of a turbine, can be used to evaporate water. This process has already been done successfully in the lab, but because of problems with corrosion and air tightness the application on field is not possible now.

A reaction which is already used is the reaction of water vapor in a zeolite material. Zeolite has got a high micro porosity and an open structure. When vaporized water enters this crystal lattice it causes a reaction which leads to the release of heat. When temperatures of more than 100 degree Celsius are applied the water is driven off and energy is stored.

The big advantage of this storage option is that the cycles are repeatable without losses of the chemical components, which leads to low operation costs.[37]

Application

Finding solutions to gain energy in the form of heat is an important aspect, but in Central Europe heat can not be sold or very limited be used during the summer time. So also concerning thermal energy it is an important part of increasing energy efficiency to store or conserve the energy while there is no need and to be able to gain it and to sell it when there is demand. Beside producing electricity and using the heat in own facilities, selling the thermal energy is the only option to sell the energy, which is wasted now. As soon as energy is sold the consumer comes into the game and further supply and demand. Because as mentioned, in summer the initial supply is not compatible with the demand, the energy has to be stored.

Although on the first sight there are applications, these applications face difficult engineering problems. The thermal energy storage technology comes from solar technology. The major difference is the temperature. Solar panels can heat up water up to 110 degrees Celsius [38], but the exhaust heat of the turbines is 465 degrees Celsius. In borehole storage this would lead to problems, which were already discussed. When stored in former production wells, there is the problem that there is just one single well, as already discussed either. Water storage is just economic with temperatures, which are in the range of the temperatures achieved with solar power and chemical storage and latent storage is either in the experimental stage or only done in small scale yet.

Costs and Benefits

Defining costs for thermal energy storage, especially in big scale, is very difficult, because there are no standard designs. Every facility is tailor made, because the market is small and of course the investment costs are very dependent on the size of the facility and the storage principle used. In the figure below following trend can be seen: Hot water storage is done for small volumes. Storing high volumes in water basins is expensive. For large volumes aquifer storage or borehole storage is preferable, but as already discussed, uneconomic for high temperatures.

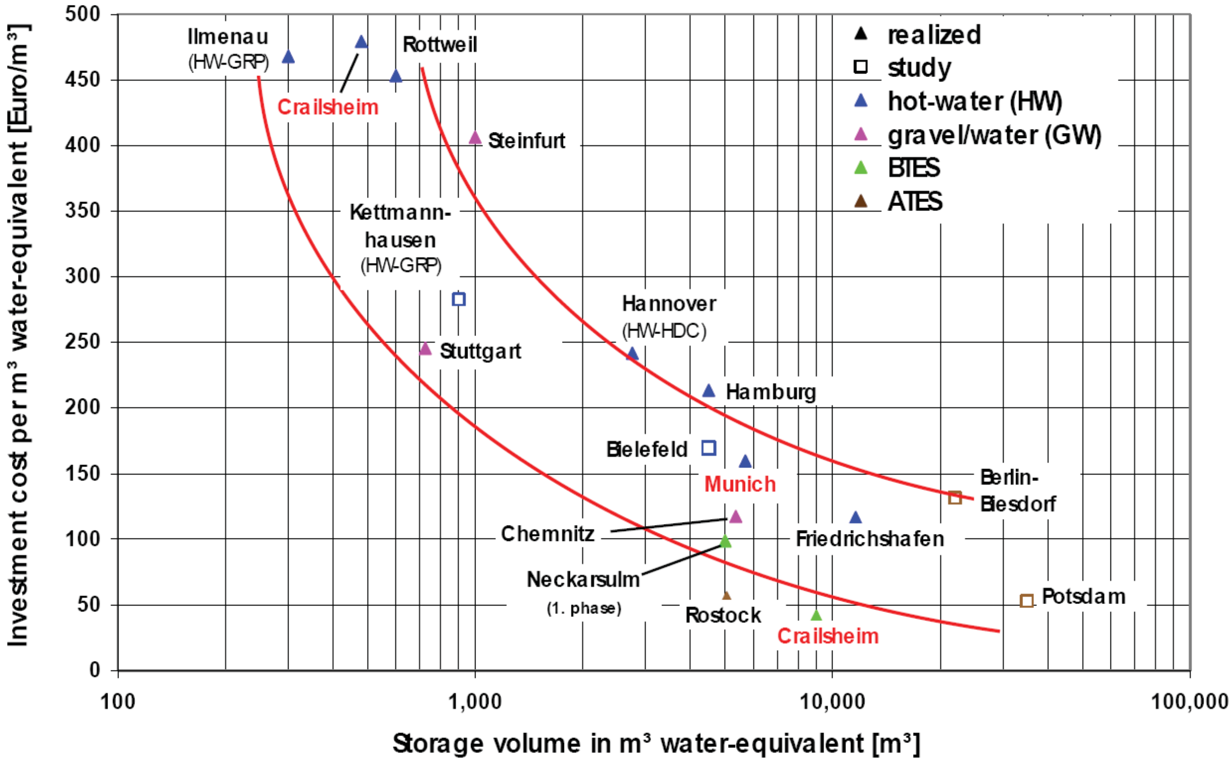


Figure 24: Investment Costs of Seasonal Heat Storage Facilities in Germany[39]

Considering all the aspects discussed above storage of thermal energy is possible, but technically and economically difficult, when dealing with temperatures of far above 400 degrees Celsius.

Microturbines

Theory

In this thesis Capstone Microturbines are analyzed only. The advantage of Capestone Microturbines over other competitors is that those turbines are very reliable in operations with a lot of starts. Furthermore Capestone already has experiences within the oil and gas industry and operates microturbines all over the world, also in Austria.

Microturbines are small onsite power generation equipments. The power ranges from 30 kW to 1 MW, which consists of a serial connection of five 200 kW microturbines. Microturbines run with a variety of fuels, both, liquid and gaseous. They run with natural gas as well as with flash gas. Because there is just one moving part, microturbines are highly reliable and maintenance is low. So they are also used for power generation on unmanned offshore production platforms.

The application of microturbines is widely spread. In countries with high energy prices it can be used as heat and energy producer for buildings, or it can be used as energy producer in remote areas, like on gas transmission sites in Alaska. It can be used as stand by set instead of diesel engines, where high power is required. As mentioned, Capstone also produces microturbines for offshore applications. These turbines resist highest environmental and safety obligations. So Capstone Microturbines are in use on offshore platforms in the Gulf of Mexico for example.

Microturbines stand out, because they symbolize the idea of decentralized energy production, which states that every house has got its own power plant, which is a way how energy supply could look like in the future. Although microturbines are still too big and have got too much power for a single household, they are also in use outside of the petroleum business, like supplying power to the Ronald Reagon Library in Simi Valley, California.

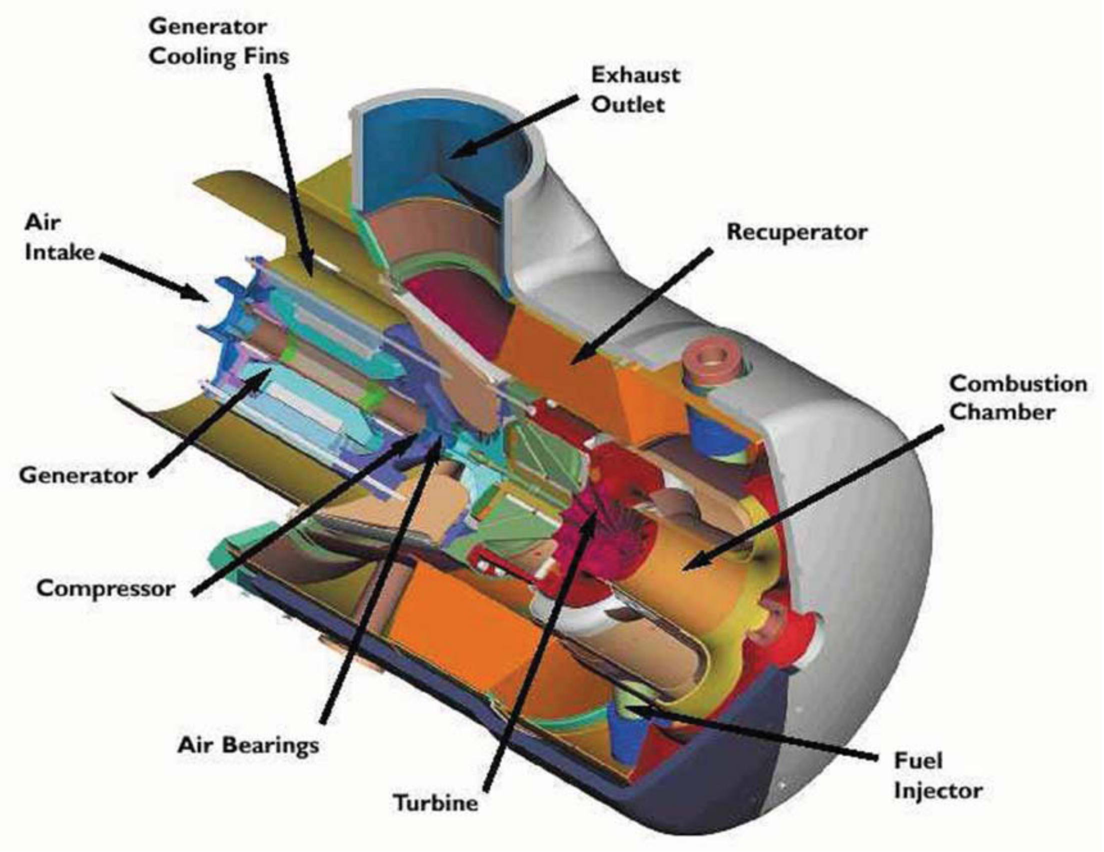


Figure 25: Components of a Microturbine[40]

Application

Concerning the energy efficiency of underground gas storage facilities there are two possibilities to use Capstone Microturbines: First of all to produce energy for the facilities and secondly to produce energy for office buildings. Microturbines not only produce electricity, but also heat. This heat can be used to preheat the gas stream and to increase the efficiency of the microturbine.

For the use as energy supplier for facilities a Capstone C1000 Megawatt Power Package High-Pressure Natural Gas is suggested.

The C1000 consists of five C200 200 kW microturbines which produces the power in five stages and offers one megawatt of reliable electrical power paired with low emissions and high efficiency.

The characteristics of this C1000 Megawatt Power Package, driven by high pressure natural gas are the following:

- “High electrical efficiency over a very wide operating range
- Low maintenance air bearings require no lube oil or coolant
- Ultra low emissions
- High availability-part load redundancy
- Proven technology with tens of millions of operating hours
- Integrated utility synchronization and protection with a modular design
- 5 and 9 year factory protection plans available
- remote monitoring and diagnostic capabilities
- internal fuel gas compressor available for low fuel pressure Natural Gas applications”[41]

Electrical Performance	
Electrical Power Output	1.000 kW
Voltage	400 to 480 VAC
Electrical Service	3-phase, 4 wire
Frequency	50/60 Hz, grid connect operation 10-60 Hz, stand alone operation
Maximum Output Current	1.450 A RMS @ 400 V, grid connect operation 1.200 A RMS @ 480 V, grid connect operation 1.550 A RMS, stand alone operation
Electrical Efficiency LHV	33%
Fuel/Engine Characteristics	
Natural Gas HHV	30,7 to 47,5 MJ/m3
Inlet Pressure	517-552 kPa gauge
Fuel Flow HHV	12.000 MJ/h
Net Heat Rage LHV	10,9 MJ/kWh
Exhaust Characteristics	
Nox Emissions @ 15 % O2	9 ppmvd
Nox Electrical Output	0,14 g/bhp-h
Exhaust Gas Flow	6,7 kg/s
Exhaust Gas Temperature	280 °C
Exhaust Energy	7.100 MJ/h

Table 11: Performance of a C1000 Capestone Microturbine[42]

As seen in the table, the exhaust heat temperature is 280 degrees Celsius. Because this turbine is supposed to work steady, this temperature would be available all year long, which would make a heat recovery useful. Therefore Capstone will offer microturbines with an included heat recovery system in the future.

For the use as energy supplier for office buildings a Capstone C30 Microturbine Natural Gas can be used. This microturbine can provide the energy the office building needs, which concludes in the fact, that the office building is supplied by an energy source which is almost emission free.

The characteristics of this C30 Microturbine, driven by natural gas, are as follows:

- Ultra low emissions
- One moving part: Minimal maintenance and downtime
- Patented air bearing: No lubricating or coolant
- 5 and 9 year factory protection plans available
- Remote monitoring and diagnostic capabilities
- Integrated utility synchronization and protection
- Small, modular design allows for easy, low-cost installation
- Reliable: Tens of millions of run hours and counting

Electrical Performance	
Electrical Power Output	30 kW
Voltage	400 to 480 VAC
Electrical Service	3-Phase, 4 wire
Frequency	50/60 Hz, grid connect operation 10-60 Hz, stand alone operation
Maximum Output Current	46 A, grid connect operation 54 A, stand alone operation
Electrical Efficiency LHV	26%
Fuel/Engine Characteristics	
Natural Gas HHV	30,7 MJ/m3 to 47,5 MJ/m3 (825 to 1.275 BTU/scf)
Inlet Pressure	379 to 414 kPa gauge (55-60 psig)
Fuel Flow HHV	457 MJ/hr (433.000 BTU/hr)
Net Heat Rate LHV	13,8 MJ/kWh (13.100 BTU/kWh)
Exhaust Characteristics	
NOx Emissions @ 15 % O2	9 ppmvd (18 mg/m3)
NOx/Electrical Output	0,22 g/bhp-hr (0,64 lb/Mwhe)
Exhaust Gas Flow	0,31 kg/s (0,69 lbm/s)
Exhaust Gas Temperature	275 °C (530 °F)

Table 12: Performance of a Capstone Microturbine C30[43]

Costs and Benefits

Analyzing the costs and benefits there is one important aspect which has to be considered: How is the energy produced used? There are three different ways to use energy, which concludes in three different prices the electrical energy can be calculated with:

- The energy is used in own facilities and does not have to be transported via an electrical grid, which is owned by a third party. This does not lead to profits, but to savings, which end up in the highest benefits
- The energy is used in own facilities, but has to be transported via a grid, which is owned by a third party. In this case the transportation costs have to be deducted from the savings

- The lowest profits are made when selling the energy to third parties, especially in the case of microturbines where hydrocarbons are burnt to produce this energy. This not only leads to an energy price which will not be supported by governmental aids, but also to the lowest profits.

Energy costs at the Underground Gas Storage Facility Haidach are 0,085 Euro and at the Underground Gas Storage Facility Puchkirchen 0,095 Euro.

To compare the electricity costs of the electricity supplied by Energie AG and the electricity produced by a microturbine two different costs have to be considered:

The investment costs:	The investment costs consists of the microturbine, which is the highest investment to be taken and the equipment needed to run the microturbine, for example, gas connection as power supply and electricity connection to transport the gained energy. The investment costs for a Capestone C30 Turbine, natural gas driven, are 41.000 Euro. The investment costs for a Capestone C1000 Power Package are 720.000 Euro.[44] Both investments do not include a heat recovery system for the microturbines and sales tax, but include toll, transportation and installation.
The operation costs:	The operation costs mainly consist of the gas used. Because the gas stored in the underground gas storage facilities belongs to the customers of the underground gas storage facility and not the operator, gas produced from nearby wells could be used. The gas price is RAG`s internal gas price. Because microturbines are very flexible concerning the gas used for operating the microturbine, also flash gas could be an alternative. Maintenance costs are lower than those of comparable equipment with following intervals:

After 8.000 operating hours:	Changing the fuel filter
	Changing the internal combustion filter
	Cleaning the electronic air filter
	Change of the back up battery of the UCB Boards
	Change of ignition
	Functional Check
After 20.000 operating hours:	Change of injectors
	Change of thermo elements
	Change of electronic air filter
	Functional Check
After 40.000 operating hours:	General Maintenance

Maintenance costs are about 4 Euro per MWh produced.

Considering only the fuel costs as operating costs and the investment costs, this leads to following cost assumption:

C30: In scenario 1 we assume that the microturbine is in operation 95 percent of the year and all the energy produced is used within one of RAGs facilities. Then the Net Present Value is negative.

The gas price this calculation was done with was 69 Euro/MWh, which is the price of a MWh electricity (85 Euro) minus the transportation costs of 16 Euro/MWh. So, the operation of a 30 kW microturbine is not economic.

The operation becomes profitable as soon as the electricity price exceeds 102,5 Euro/MWh or the internal gas price becomes smaller than 8,8 Euro/MWh gas. The exact calculation can be found in Appendix B.

In scenario 2 the electricity does not have to be transported. So the savings is calculated for the electricity, which does have not to be bought. Taking this price for a MWh electricity bought as 85 Euro the process becomes economic for an internal gas price lower than 10,55 Euro/MWh. Also this calculation is found in Appendix B.

C1000: Again, assuming, that the microturbine is in operation 95 percent of the year and all the energy produced is used within one of RAG's own facilities the Net Present Value is negative, when the gas has to be transported. The calculation can be found in Appendix B.

But when the energy is produced where actually the energy is needed, so the money which can be saved is 85 Euro/MWh, then the results of the economic calculation would look as follow:

IRR: 8,4 %

NPV: 103.351

Payback period: 11,4 years

Having an independent energy supply has got several advantages. First of all any incidences outside will not affect the underground gas storage facility.

In the US black outs have caused serious problems and break down in supply not only of energy but of industries, public life and safety.

The advantage of a cheaper price per kWh occurs in one of the researched existing underground gas storage facilities, but independent energy production should be considered as an alternative for future underground gas storage projects already during the planning phase.

What is not considered in the calculation and what gives a further advantage is flash gas. Flash gas, which is usually flared, can also be used as fuel of a microturbine, but leading to a lower efficiency.

This flash gas is for free, which would still improve the cost/benefits balance.

Expansion Turbines

Theory

An expansion turbine, or turboexpander as it is sometimes called, is a turbine with axial or radial flow, which produces energy, by the expansion force of gas, driving a fan. This process is almost fuel free.

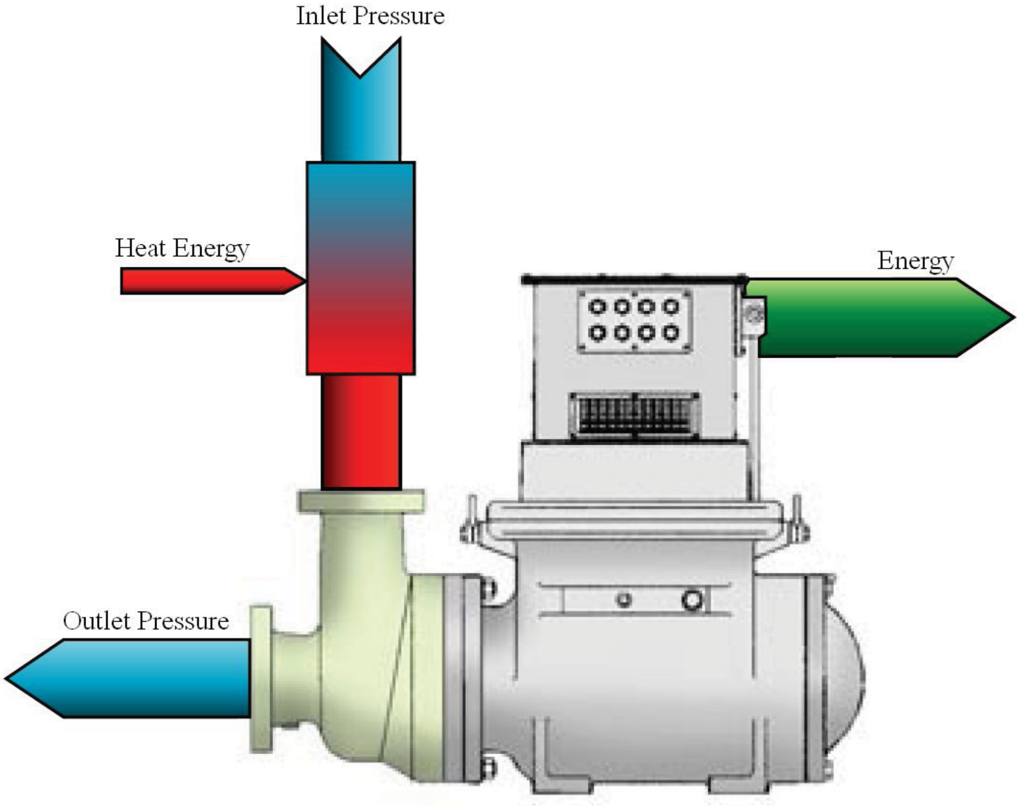


Figure 26: Principle of an Expansion Turbine[45]

Pressurized dry gas enters the expansion turbine and is preheated to increase the efficiency. In a chamber the gas expands and drives a wheel, which drives a generator and produces electrical energy.

Application 1

In underground gas storage facilities the gas has to leave the facilities at a certain pressure. This pressure is finally dependent on the pressure in the pipeline system. This is the first consideration in planning to install an expansion turbine. In the Underground Gas Storage Facility Haidach, respectively at the transfer station in Haiming, the minimum pressure has to be 55 bar. The inlet pressure is given by the facility and the reservoir.

The second consideration has to be the volume.

There are various suppliers like Atlas Copco, MAN, RMG and GE, who are offering expansion turbines of various sizes and pressure requirements.

Because it would make no sense to reduce the pressure we have produced before by the compressors, the expansion turbine only is in operation when the facility mode is withdrawal without compressors.

Start Date	Start Time	End Date	End Time	Inlet Pressure [bar]	Pressure Rate	Averaged Volume [Nm^3/h]
01.01.2008	0.00	15.01.2008	9.00	68,6	1,25	285.233
15.01.2008	17.35	18.01.2008	11.00	65,4	1,19	288.501
21.01.2008	8.40	21.01.2008	15.05	65,2	1,19	19.222
22.01.2008	6.10	22.01.2008	12.10	63,4	1,15	17.072
23.01.2008	7.30	24.01.2008	9.30	62,5	1,14	120.198
28.01.2008	14.15	13.02.2008	8.45	75,2	1,37	264.271
23.02.2008	11.20	23.02.2008	16.25	56,9	1,03	19.758
23.02.2008	18.00	24.02.2008	12.25	56,6	1,03	17.169
24.02.2008	14.50	26.02.2008	4.45	57,4	1,04	15.892
26.02.2008	8.30	26.02.2008	15.40	57	1,04	18.952
26.02.2008	21.35	27.02.2008	19.50	57,5	1,05	17.333
27.02.2008	23.25	01.03.2008	6.35	57,2	1,04	18.017
27.03.2008	18.35	28.03.2008	0.55	55,2	1,00	16.092
28.03.2008	4.05	28.03.2008	7.30	55,3	1,01	15.996
29.03.2008	11.20	01.04.2008	3.20	54	0,98	16.798
01.10.2008	7.00	06.10.2008	5.45	84,6	1,54	63.342
10.10.2008	11.15	11.10.2008	6.00	82,7	1,50	57.766
13.10.2008	4.45	18.10.2008	6.05	82,3	1,50	85.582
20.10.2008	10.25	21.10.2008	8.05	83,3	1,51	147.975
23.10.2008	10.05	25.10.2008	8.00	81,8	1,49	164.810
30.10.2008	15.20	31.10.2008	5.00	81,9	1,49	26.096
05.11.2008	6.40	06.11.2008	7.50	85,4	1,55	50.610
10.11.2008	6.50	12.11.2008	14.05	83,5	1,52	51.738
13.11.2008	10.10	16.11.2008	23.40	81,7	1,49	37.246
17.11.2008	5.40	27.11.2008	6.05	84	1,53	123.432
27.11.2008	13.30	27.11.2008	20.30	87,9	1,60	51.006
29.11.2008	5.20	19.12.2008	8.35	81,7	1,49	118.097
23.12.2008	14.50	24.12.2008	8.40	78,5	1,43	21.230
25.12.2008	11.35	26.12.2008	1.50	78,2	1,42	18.176
26.12.2008	10.05	26.12.2008	21.40	78,7	1,43	20.065
27.12.2008	3.25	27.12.2008	9.45	78,2	1,42	19.427
27.12.2008	14.40	28.12.2008	5.10	78,5	1,43	19.052
28.12.2008	15.35	29.12.2008	8.40	78,3	1,42	19.052
29.12.2008	11.05	31.12.2008	24.00	78,6	1,43	21.276

Table 13: P Input/P Output Ratio for an Expansion Turbine at the UGS Facility Haidach in 2008

A very important indicator for expansion turbines is the pressure input/pressure output ratio. The ratios, which appear in the Underground Gas Storage Facility Haidach are very low, as it can be seen in the table above (data for withdrawal without compressors only).

The ratio should be at least 2,0, with no projects being realized beyond 3,0 today. The maximum ratio, which can be handled by expansion turbines, is about 20. A possibility to avoid this ratio is to operate the expansion turbine with high volumes.

Costs and Benefits 1

The table below lists the pressures and volumes a General Electric Expansion Turbine can work with on the example of the year 2008 and shows the benefits of this turbine. The investment costs for this expansion turbine are 2.000.000 Dollar.

Inlet Temp [°C]	Outlet Temp [°C]	Inlet Pressure [bara]	Outlet Pressure [bara]	Volume [m^3(Vn)/h]	Electrical Power [kW]	Operation Hours in 2008 [h]	Benefits [Euro/a]
27	4,30	90	64	312.500	2103	64	11440,32
27	14,70	90	75	312.500	1145	64	6228,8
40	8,00	90	55	312.500	3035	64	16510,4
27	4,70	90	64	208.333	1354	1387	159629,83
27	5,50	90	64	156.250	949	115	9276,475
27	5,30	90	64	125.000	709	77	4640,405
27	5,80	90	64	104.167	603	269	13787,595
27	23,10	68	64	312.500	365	64	1985,6
27	16,50	75	64	312.500	995	64	5412,8
27	8,10	85	64	312.500	1769	64	9623,36
							238.535,585

Figure 27: Benefits of a General Electrics Expansion Turbine[46]

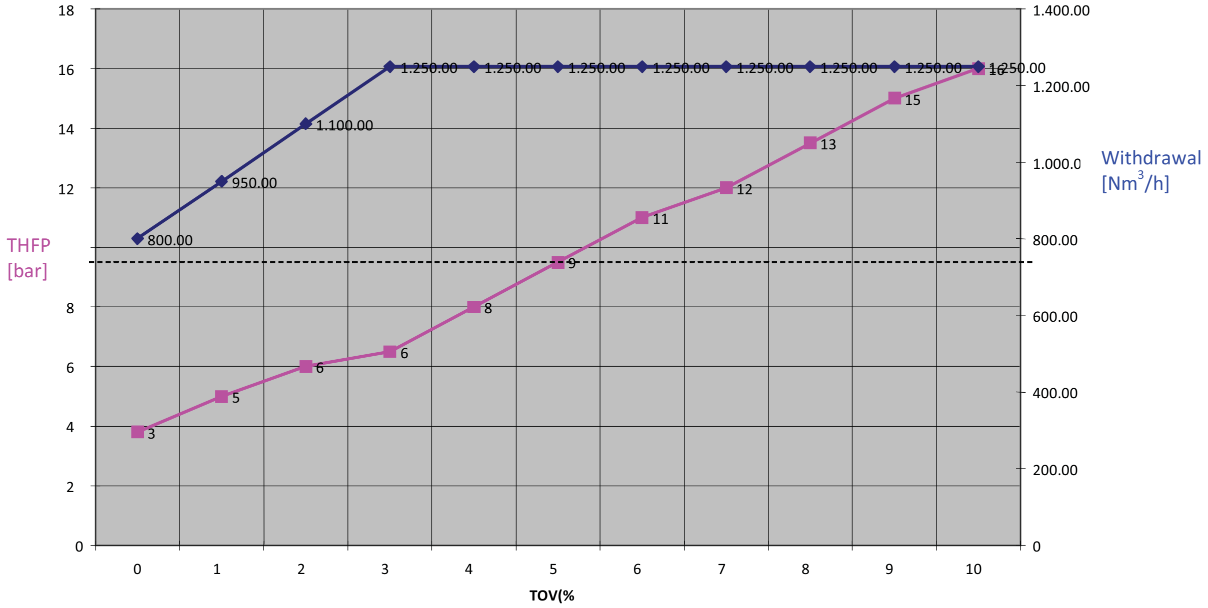


Figure 28: Total Observed Volume versus Withdrawal Volume and versus Pressure

Calculating the economics of the expansion turbine leads to following results:

IRR: 6,4 %

NPV: -147.250,9 Euro

Payback Period: 23,3 years

The calculation can be found in Appendix B again.

As seen it is obvious that this turbine does not work efficient concerning the internal discount rate of 7 percent. The reason is that although there are high volumes these volumes are run only for a rather short period of time during the year.

Application 2

To illustrate what can be done with expansion turbines and not as a picture of the reality at the underground gas storage facilities, which were analyzed in this thesis, the output pressure is expected to be defined by the operator and not the customer, which means, that the output pressure just has to be high enough to transport the gas through the transfer pipeline.

Under these circumstances, analyzing the Underground Gas Storage Facility Haidach two expansion turbines could be installed, one in every string, for example, a dual stage ETG 360 MS /560 MS expansion turbine by Atlas Copco. The inlet pressure is 50 bars, which would fit into the application in Haidach. The outlet pressure is 5,6 bar and the volume is 165.000 Nm^3/h. Because at peak withdrawal periods more than 250.000 Nm^3/h are withdrawn via every string there has to be a possibility to bypass these expansion turbines for a volume above an expansion turbine can handle.

Every expansion turbine would produce 9,5 MW of energy when being operated by full load. Turbine 1 and Turbine 2 are withdrawing 165.000 Nm^3/h each 1559,6 hours a year, which leads to a production of 14.816 MWh/year. Regarding the energy which could be produced and being used in the facility this would lead to a total saving of 1.259.360 Euro a year (relying on an energy price of 0,085 Euro/kWh in the Underground Gas Storage Facility Haidach).

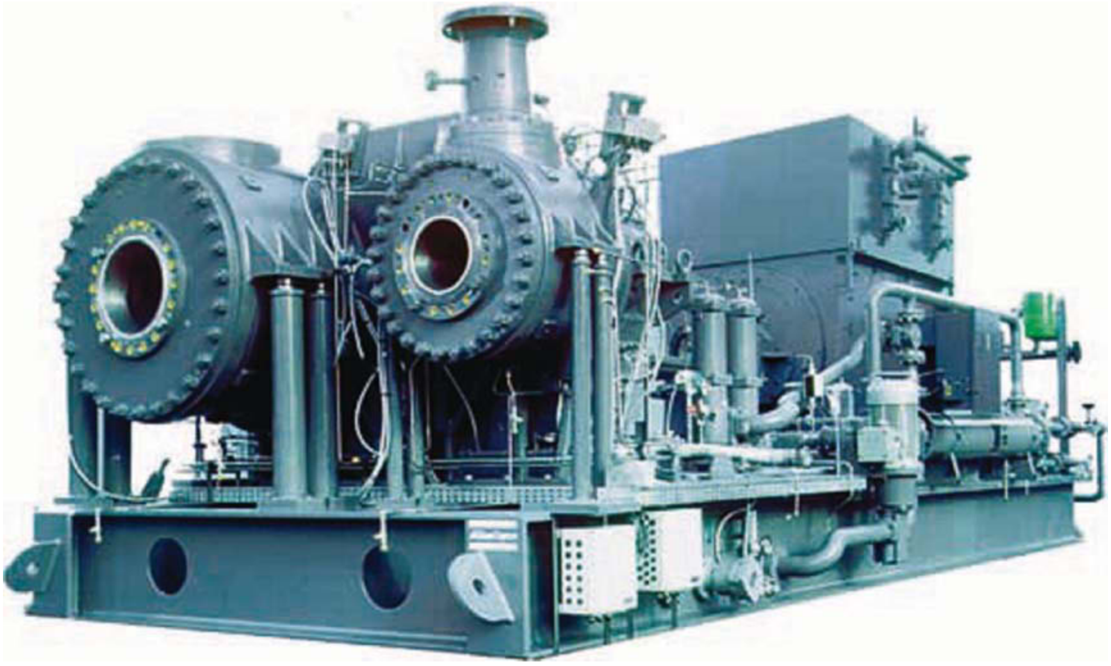


Figure 29: Atlas Copco ETG 360 MS-2 Expansion Turbine[47]

But expansion turbines can not only be used in underground gas storage applications. Especially in the first phase of production of a new drilled well high pressures occur. These pressures could be used for the generation of energy. Expansion turbines can be located in a container, which makes them transportable and applicable at well grounds.

For this application an expansion turbine with a smaller maximum flow and a smaller inlet pressure should be considered, for example a MTG 160 by RMG. The maximum inlet pressure is 40 bar and the maximal flow is up to 10.000 Nm^3/h. The pressure difference between inlet and outlet is between 2,5 and 4,5 bar. With a weight of 800 kilogram the expansion turbine is portable in a container. It produces 160 kW of electrical energy.[48]

A problem will be that the gas has to be preheated. This might not be a problem in the application at the Underground Gas Storage Facility Haidach, but this will be a problem when an expansion turbine is used at a well with low temperature gas.

Another problem is the Joule Thompson Effect. While the temperature of gas is increased when compressed, the temperature of gas is decreased when expanded. In refrigerators expansion turbines therefore are often used for cooling purposes. In gas applications this effect leads to problems. The temperature decrease is dependent on the pressure difference. The pressure difference is between 2,5 and 20,25 bar, when the expansion is proceeded in serial.[49] This decrease in temperature can lead to temperature ranges, where free water in the gas starts to build hydrates. Especially in applications before the dehydration system or at applications right after a well, this has to be considered.

An important aspect is that the expansion turbine should be able to be started while the withdrawal process is started. Taken an expansion turbine, which is working in Arlesheim, Switzerland, and where practical data exists, as a reference, the turbine can be started within less than 15 minutes, assumed that the turbine is in stand by modus. This means, that the turbine is gas filled and the preheating system is already working. During the summer period, the turbine in Arlesheim is not working. In this time the whole turbine is flushed with nitrogen. After this process the start up process takes several hours.

Costs and Benefits 2

An Atlas Copco ETG 360 MS/560 MS Expansion Turbine produces 9,5 MW with an expansion volume of 165.000 Nm^3/h, an inlet pressure of 50 bar and an outlet pressure of 5,6 bar.

In 2008 the UGS Facility Haidach withdrew during 3518,73 hours via String 1 and during 2969,33 hours via String 2. When just considering a maximum flow through the expansion turbine there would still be 315,91 hours of operation in String 1 and 29,33 hours of operation in String 2.

	String 1	String 2
Withdrawal	3518,73 h	2969,33 h
Withdrawal beyond 165.000 Nm3/h	315,91 h	29,33 h
Energy produced by full expansion turbine load	3001,145 MW	278,635 MW

Table 14: Withdrawal Hours of String 1 and 2 in UGS Facility Haidach

Relating on the energy price of 0,085 Euro/kWh the expansion turbine at String 1 would have generated energy which is worth 255.097 Euro in the year 2008. An expansion turbine at String 2 would have still generated energy worth 23.683 Euro in 2008.

These numbers are just for peak load. Smaller loads were not considered because of a missing performance curves. So, in real operation, this number will be significantly higher.

Investment costs are hard to estimate, because equipment in this scale is a custom made product and varies from application to application.

This calculation is for an expansion turbine, which is already in use and is just taken as an example. Atlas Copco provides tailor made expansion turbines, which means that the expansion turbine is aligned to the conditions of every application, in this case for the application in the Underground Gas Storage Facility Haidach.

The economics for the real application has already been shown before.

Convective Generator

When electrical energy is generated from thermal energy not the whole temperature range can be used. In the end the fluid still has got a temperature of up to 80 degrees Celsius, dependent on the fluid and the entry temperature.

This thermal energy is usually unused. The convective generator gives the possibility to use this energy.

The convective generator is a closed circle, where a working fluid, for example butane, circulates. The circle consists of a riser and a faller. On top of the riser the fluid evaporates and decreases the density and the pressure of the column. At the bottom of the faller the condensed fluid drives the generator. So the generator is driven by the technical working force of butane in the faller and the pressure drop of the phase change between fluid and gaseous phase.

On the surface a cooling tower is installed where the butane is cooled down to the liquid phase again and where it condenses and the circle starts again. A newer process is the Schwark-Becker Process.

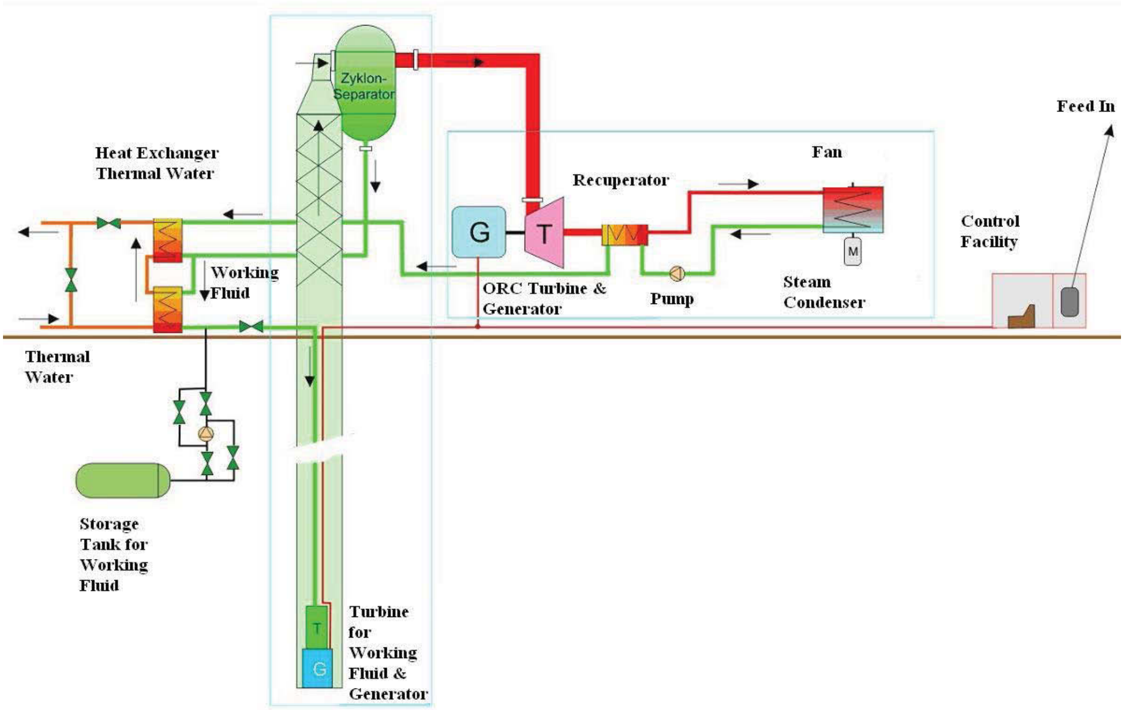


Figure 30: Working Principle of the Schwark Becker Process

In this process the working fluid is led through the ORC Turbine after it passed the thermodynamic circle.

Afterwards the working fluid cools down and enters the well again. With this process the efficiency of the ORC Process can be increased by 60 percent.

Iso Butane	Melting Point	-160 °C
	Boiling Point	-12 °C
n-Butane	Melting Point	-138 °C
	Boiling Point	-0,5 °C

Table 15: Characteristics of Butane

This process has not been tested under real conditions yet, but calculations state that with a 350 meter deep well 300 kWe could be produced.

Figure 31: Fluid Turbine of a Convective Generator[50]

Photovoltaic

Theory

Photovoltaic was introduced in 1839 by Alexandre-Edmond Becquerel. To simplify how a photovoltaic process works a silicon solar cell is taken, which is the easiest cell used in photovoltaic. Silicon has got four electrons around its core. Light enters the solar cell and concentrates the electrons. The electron separates and leaves a positive atom. Because the electrons should flow in one direction, the solar cells have got a different upside and downside polarity. DC has to be converted into AC in order it can be used within electrical devices, which is done with an AC DC converter.

Application

Photovoltaic produces low current, which is perfectly usable for households, but which is almost not useable in underground gas storage facilities. Nevertheless there are a lot of roof areas, especially on top of the compressor buildings, but also on top of the office buildings.

But the energy produced does not have to be consumed within the facilities. The photovoltaic can be connected to the public energy grid and the energy produced can be sold.

An important aspect in the oil and gas industry is the public image. Because exploration, drilling and production in Austria do not take place in remote areas, but right in the neighborhood of villages and houses, a safe and environmental friendly view of the public on an E&P company is important.

A company drilling for a geothermal well is always welcome, but a company drilling for an oil or gas reservoir is suspected to be environmental unfriendly, although both wells are drilled by the same company, by the same drilling rig and the same crew and the same technology. Therefore photovoltaic within an underground gas storage facility could be a project which could be introduced to the public and which could be the start for a change in the image of the oil and gas business in everyday people’s mind.

	Stage I	Stage II
	m²	m²
Buildings		
Office Building	832	-
Supply Building	630	-
Instrumantation Air Boiler Housing	300	-
Container Heat and Seal Gas	25	25
Compressor Building	570	570
Switching Substation	555	605
MS Control Station	140	-
Gas Treating Building 1	44	44
Gas Treating Building 2	44	44
Weather Housing		
Manifold	120	-
3 Phase Absorber	56	-
Tanks	125	125
Terminal	32	-
502-01F20	6	6
502-02F20	6	6
502-01F30	10	30
502-02F30	10	30
502-01F80	14	14
502-02F80	14	14
502-01 F90	35	35
502-02 F90	35	35
504-01F10	17	17
504-02 F10	17	17
Heater 1	115	115
Heater 2	115	115
506-01	53	53
506-02	41	41
		-
Roofing (VG-BK-KH)	280	-
	4.241	**1.941**

Outstations:	Stage I	Stage II
	m²	m²
Buildings		
Methanolstation OS I	280	-
Methanolstation OS II	215	-
Weather Housing		
101-01F10	20	-
101-02F10	20	-
201-01F10	20	-
201-02F10	20	-
107-01B10	43	-
207-01B10	43	-
Well Housing 1	10	10
Well Housing 2	10	10
Well Housing 3	10	10
Well Housing 4	10	10
Well Housing 5	10	10
Well Housing 6	10	10
Well Housing 7	10	10
Well Housing 8	10	10
Well Housing 9	10	-
	751	**80**
Total Roof Area:	4.992	2.021
	7.013	

Table 16: Roof Areas in the Underground Gas Storage Facility Haidach

Costs and Benefits

The power of photovoltaic installations is measured in kW peak. This is the maximum production, which can be achieved. This maximum production is tested under standard conditions, which are usually not achieved in operation. In Salzburg and the area around Salzburg, which also includes the Underground Gas Storage Facility Haidach the relation kWh to kWp is 971 kWh/kWp.[51] The material costs can be averaged at about 4.250 Euro/kWp.

With increasing area, the material costs of the panels become percentage wise smaller, but the costs for the inverter increases.

The roof space required is of course dependent on the material used and lies in the range between 18 to 24 m^2 for the production of 1 kWp, at which 22 m^2 would be a good approximation.[52]

This leads to following results regarding energy production at the Underground Gas Storage Facility Haidach:

Stage I:	226,9 kWp	220.319 kWh
Stage II:	91,86 kWp	89.193,06 kWh
Total:	318,77 kWp	309.525,67 kWh

The investment costs of this photovoltaic plant would be approximately:

Stage I:	965.000 Euro
Stage II:	391.000 Euro
Total:	1.356.000 Euro

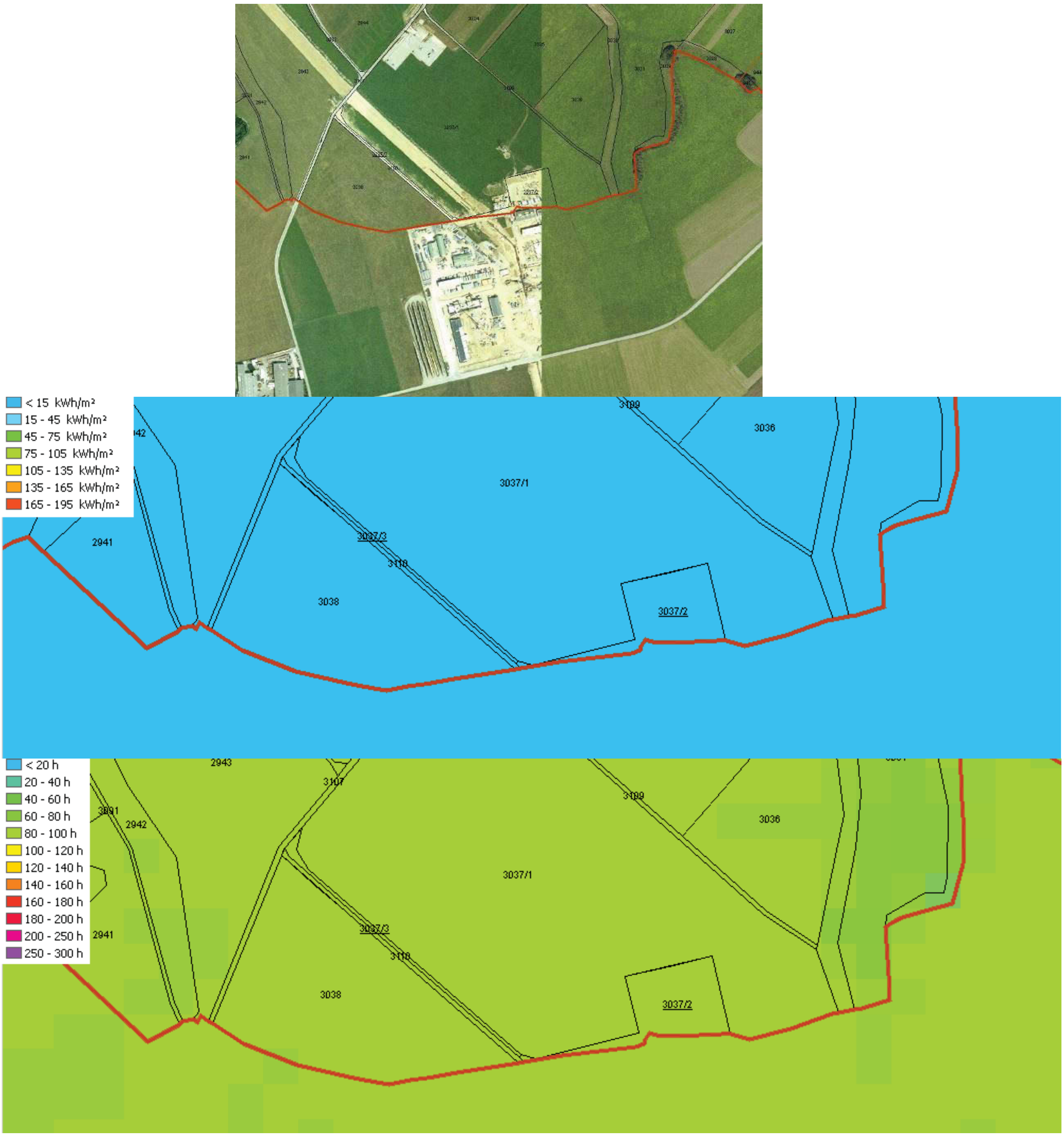


Figure 32: Satellite Picture of UGS Haidach, Solar Radiation and Sun Hours

In Austria there are three different prices, how energy, produced by photovoltaic panels can be sold. An energy supply up to 5 kW peak is compensated with 45,90 Cent/kWh, between 5 and 10 kW peak with 39,98 Cent/kWh and beyond 10 kW peak with 29, 98 Cent/kWh.[53] This price is valid after paragraph 20 of the "Oekostromgesetz", for contracts which are signed in 2009 and these prices are valid for 11 years. In the 12th year 50 percent of the compensation will be paid. This leads to the conclusion that this investment is not economical. Exact calculations can be seen in the Appendix. What would be economical and what can be seen in the Appendix at Scenario 2 is that if the photovoltaic power station is not considered as one big single power station, but, because it is installed on several buildings, as several small power stations, it would be economical. This would lead to the fact, that each of these power stations is producing less than 5 kW peak and this would lead to a new energy price of 45,90 Cent/kWh and the project would not only be economical, but also profitable.

The results after the Net Present Value Method are as follow:

Scenario *1*

The electricity can be sold for 29,98 Cent/kWh:

The Net Present Value is negative. Although money is earned the payback time exceeds 33 years.

IRR: 4,9 %

Net Present Value: -340.609

Payback period: -

Scenario 2

The electricity can be sold for 45,90 Cent/kWh:

The project is profitable in every sense.

IRR: 8,3 %

Net Present Value: 227.464

Payback period: 16,2 years

Details to the calculations can be found in Appendix B.

What also has to be included beside the profits over the years by selling the electricity is the governmental aid for renewable energy, which is valid for private households as well as for companies but which has to be proofed in detail.

Beside the profits measured in Euro, the profit which can not be measured directly, but which is measured in an increasing reputation, has to be considered.

Of course a photovoltaic system can not only be installed at the Underground Gas Storage Facility Haidach, but also at the Underground Gas Storage Facility Puchkirchen and other facilities of RAG.

Others

Expansion Engines

An Expansion engine is a vertical, single acting and reciprocating type of engine, which converts energy from pressurized gas into electrical energy by driving pistons and a generator. An expansion machine consists of a drive unit, a cylinder unit for air expansion and a hydraulic system for operating the valves.

Pressurized gas enters the engine through an inlet valve at the start of the downward stroke of the piston. Later during the downward motion the inlet valve closes and the gas within the chamber expands. This leads to the upward stroke, while the outlet valve opens and the inlet valve stays closed.

So during the downward stroke gas enters the cylinder and expands. During the upward stroke the expanded gas leaves the chamber and is pushed to the outside.

Figure 33: Expansion Engine[54]

Expansion engines are suitable for volumes between a couple of hundreds up to 100.000 Nm^3/h. This would suit for applications at wells, where the pressurized gas is used to produce energy as for applications in underground gas storage facilities.

The problem at wells is that the gas is wet. Because of the opposite Joule Thompson Effect the wet gas will form hydrates, which can block the valves and cause severe problems. That is why a heat source is installed before the gas enters the expansion engine.

The generation of electrical power in underground gas storage facilities is possible without any problems, when the expansion engine is installed after the dehydration unit.

The advantage in underground gas storage facilities is the flexibility concerning volumes as long as they do not reach certain limits.

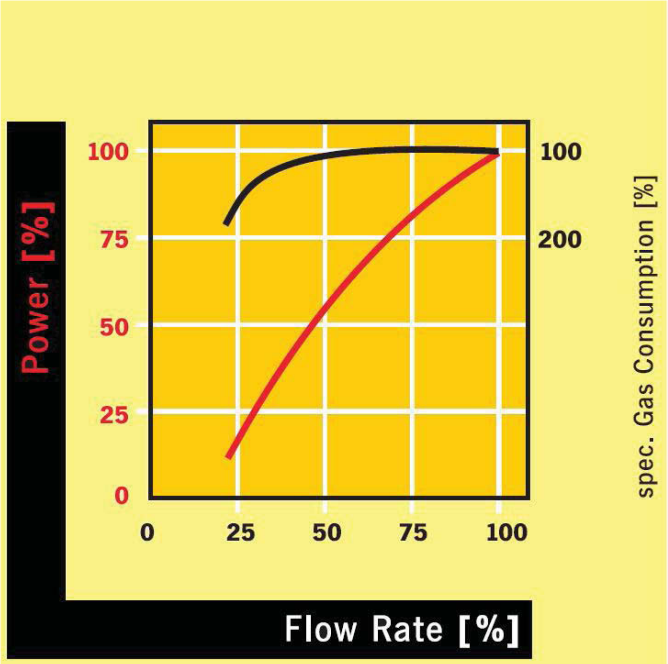


Figure 34: Performance Curve of an Expansion Engine[55]

Expansion engines produce energy up to 3.000 kW and accept intake pressure between 6 to 60 bars.

Screw Type Expansion Machine

A screw expansion machine works like an expansion turbine, with the only difference, that the gas is expanded in a screw type engine. The screw type engine drives a generator and electrical power is produced.

The working principle is comparable to a two cycle engine, when the up and down stroke is exchanged by rotary movement. Two rotors, which are twined about each other are building a empty space between the two rotors and the enclosure.

The gas enters this empty space and expands and starts to move forward and with it the rotor. A part of the energy of the gas is transformed on the rotor.[56]

Screw type expansion machines are very flexible concerning the working fluid. They are working with wet gas as well as with steam or dry gas. The best efficiency is achieved by equipment with much less than 1.000 kWe and rather small facilities. Because of the construction of the shaft there are limitations, especially concerning the volume. Big screw type expansion engines have got a maximum volume of 36.000 m^3/h.[57]

Exactly because of this limitation concerning the volume a single engine will not be applicable within underground gas storage facilities but a possibility to use this technology is to produce electrical power at certain wells. But in underground gas storage facilities a number of engines can be used to produce electrical energy. This will be discussed on the next page.

Because of the flexibility concerning the working fluid no separation would be necessary within the well application. Furthermore, like expansion engines, they are much more flexible than expansion turbines, concerning the volume below the maximum.

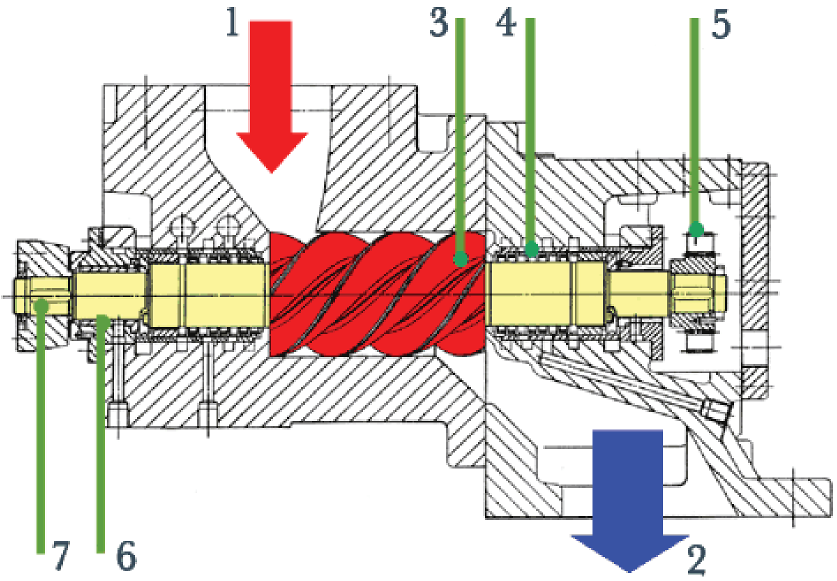


Figure 35: Cross Section of a Screw Expansion Machine[58]

1. Gas Entry
2. Gas Exit
3. Main Rotor
4. Rotor Sealing
5. Synchronization Gear
6. Bush Bearing
7. Driven Shaft

To have a look on underground gas storage facilities again the data already used in the chapter expansion turbines is taken. As a maximum volume 36.000 m^3/h are assumed. Because the volume withdrawn is usually bigger, more than one screw type expansion turbine could be used.

Inlet Temp	Outlet Temp	Inlet Pressure	Outlet Pressure	Volume	Electrical Power	Operation Hours in 2008	
[°C]	[°C]	[bara]	[bara]	[m3(Vn)/h]	[kW]	[h]	kWh/a
27	4,30	90	64	312.500	283,96	64	18.173,44
27	14,70	90	75	312.500	154,63	64	9.896,32
40	8,00	90	55	312.500	313	64	20.032,00
27	4,70	90	64	208.333	283,96	1387	393.852,52
27	5,50	90	64	156.250	283,96	115	32.655,40
27	5,30	90	64	125.000	283,96	77	21.864,92
27	5,80	90	64	104.167	283,96	269	76.385,24
27	23,10	68	64	312.500	52,14	64	3.336,96
27	16,50	75	64	312.500	134,89	64	8.632,96
27	8,10	85	64	312.500	237,9	64	15.225,60
							600.055,36

Table 17: Energy produced by a Screw Type Expansion Engine at the UGS Facility Haidach

This leads to a total energy production of 600.055 kWh electrical energy a year (second stage of the Underground Gas Storage Facility Haidach in operation and with one screw type expansion engine working). Because the volume possible is much bigger than the 36.000 m^3/h, more than one engine could be used. Using the minimum volume listed, up to three engines are possible, which would lead to a total production of 1.800.055 kWh/a or 1.800 MWh/a. The economic calculations for one engine are as following:

IRR: 8,0 %

NPV: 42.304,4 Euro

Payback Period: 17,3 years

As mentioned the flow volumes of screw type expansion machines are smaller than those of expansion turbines. This problem can be overcome by installing more than one screw type expansion machine. Again the previous data is taken. To be able to use the small volume of 104.167 m^3/h, which is achieved for a long period of time, it is assumed that three screw type expansion machines are installed with a volume of 36.000 m^3/h each. This leads to following result:

IRR: 10,7 %

NPV: 462.266 Euro

Payback Period: 11,5 years

Again exact calculations can be found in Appendix B. As seen the process becomes more economic with a raising number of individual expansion machines. This results from no gas costs, which usually kick in at combustion engines; there are just operation costs which are assumed to be comparable low. Further it is possible to use smaller volumes too, by operating a single or two machines when small volumes are withdrawn. This fact makes the whole process even more economic.

Different but also very interesting application areas are pressure reduction stations. There the gas is preheated anyway, so there is no chance for hydrates to be built. Furthermore the pressure is already reduced, which leads to the conclusion that it is proved that no problems will come up with a reduction of the pressure. This is the ideal case for using screw type expansion machines.

Of course the medium the screw expansion machine is driven with, does not have to be gas, but can also be steam or an ORC fluid, when thermal energy should be used to create electrical power.

Screw type expansion machines are already in use in some industrial areas. The machines used are usually former screw type compressors which function was turned the other side round. Nevertheless there is no application with operation hours, which would be applied at the Underground Gas Storage Facility Haidach. Furthermore such high volumes and such high pressures have not been applied to any screw type expansion machine yet.

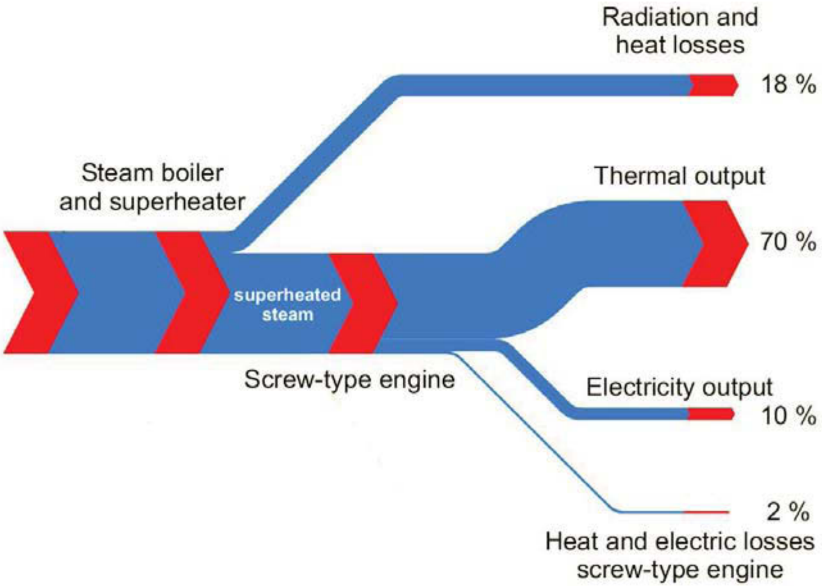


Figure 36: Energy Output of a Screw Type Engine[59]

Fuel Cell

Fuel Cells consist of a pair of electrons on either side of an electrolyte layer. Like within a battery an electrochemical reaction takes place, with the difference, that the fuel cell does not contain any reactants.

The reactants are added from outside, for example through a pipeline. Another difference is that fuel cells are not charged, rather continuously fed, which means that if the fuel cell is off it only undergoes minimal changes during its lifetime. The electrochemical reaction usually works with hydrogen and air, but can also work with methane or methanol, where hydrogen is produced by reformation of methane or methanol.

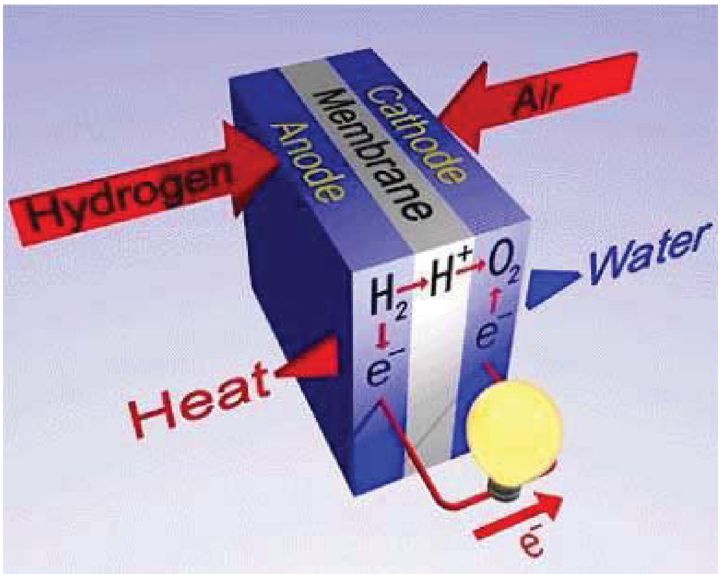


Figure 37: Fuel Cell Working Principle[60]

This process is an electrochemical process, which means that the fuel is not burnt and this results in cleaner and greener energy.

Because of the various possibilities to run a fuel cell there is more than one type. The most important ones are listed beyond.

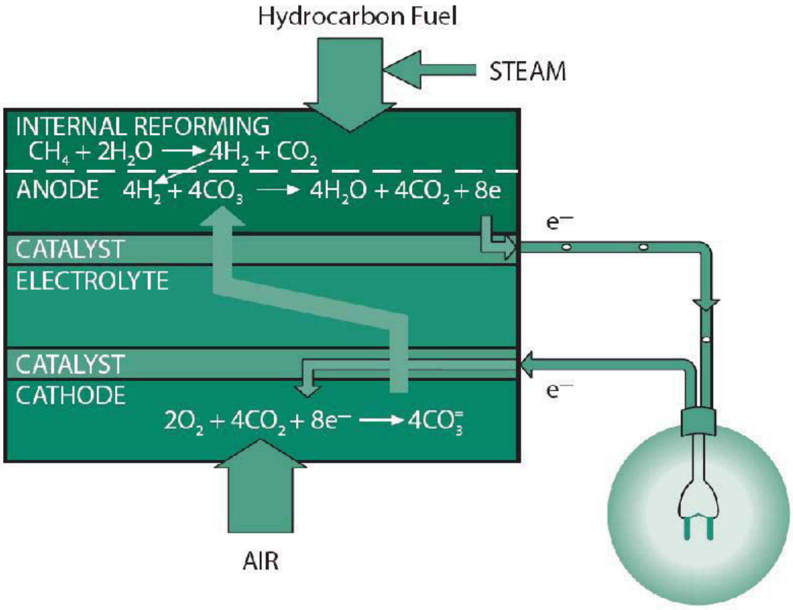


Figure 38: Hydrocarbon fuelled Fuel Cell Principle[61]

Polymer Electrolyte Membrane

Polymer electrolyte membrane fuel cells are also called proton exchange membrane fuel cells, because they use a solid polymer as an electrolyte and porous carbon electrodes, which contain a platinum catalyst. They have to be supplied by hydrogen, take the oxygen from the air and need water to operate. Usually they are fuelled by pure hydrogen.

The advantage of this cell type is the low operating temperature of about 80 degrees Celsius and therefore the fast start up time. The costs of this type are significant higher than the costs of other cells, because of the costs for the platinum catalyst, which is also very sensitive on CO poisoning. This is also the reason why it is not applicable to run a polymer electrolyte membrane fuel cell with hydrocarbon fuel.

Because these cells are small and light weighted they are supposed to be applied in vehicles, when the problem with hydrogen storage within the vehicles is solved.

Phosphoric Acid

The difference between the polymer electrolyte membrane fuel cell and the phosphoric acid fuel cell is the liquid phosphoric acid, which is used as the electrolyte. The acid is located in a Teflon-bonded silicon carbide matrix and the electrodes contain a porous carbon containing the platinum catalyst.

The phosphoric acid fuel cell is used for heavy applications, like stationary use and for large vehicles. The reason is the weight and the dimension of this type of cell. This cell is already beyond testing phase and in use in real surroundings.

Although CO is reducing the efficiency of the fuel cell by the time, they are less sensitive on it than the polymer electrolyte membrane fuel cell.

Direct Methanol

Relatively new developments are fuel cells, which are fed by methanol instead of hydrogen. The methanol is mixed with steam and fed directly to the fuel cell anode.

Alkaline

Alkaline fuel cells were developed for the space industry and for their needs. So they are very effective with efficiencies of more than 60 percent, but they are also very sensitive on CO, which is a minor problem in space. They are very reliable for operating hours less than 8.000 hours, but unreliable for operating hours for more than 40.000 hours, which would be necessary to work economically as alternative to conservative energy production.

Molten Carbonate

Molten carbonate fuel cells are those, which would fit best into the portfolio of an E&P company. They are high temperature fuel cells, which use an electrolyte composed of molten carbonate salt mixture suspended in a porous and chemically inert ceramic lithium aluminum oxide matrix. They reach efficiencies of up to 60 percent. Because of the high temperature the waste heat can be used by an ORC process, which increases the efficiency up to 85 percent.

They are not sensitive to carbon monoxide or carbon dioxide, they can even be fed by carbon oxides. The hydrogen is produced in the cell itself by internal reforming. The fuel is for example natural gas.

The disadvantage of this cell is the limited lifetime because of corrosion, which is the main topic in researching this fuel cell type.

Solid Oxide

Solid oxide fuel cells work with a hard, non porous ceramic compound as electrolyte, which makes it possible to construct the cell not in a plate like configuration. Again they are working with high temperatures, about 1.000 degree Celsius, which makes the use of the waste heat practical. This increases the overall efficiency from 60 to 85 percent.

They are not poisoned by carbon monoxide and can be run with natural gas. Because of the high temperature level the start up is slow and the materials are either cost effective or have got a limited life time.

Regenerative (Reversible)

Regenerative fuel cells work like all other fuel cells as well with hydrogen and oxygen. The difference is the way how hydrogen is produced. These cells can use electricity produced by solar panels to split water into hydrogen and oxygen in an electrolyses process. [62]

Applications

For the application within underground gas storage a DFC 3000 Fuel Cell by Fuel Cell Energy is analyzed.

Fuel Cell Energy produces fuel cells, which are already in operation worldwide. They have produced 70 MW of fuel cell power capacity for commercial, industrial and utility customers around the world, 35 MW are produced by products with an output of more than 1 MW.

The DFC 3000 operates with natural gas and propane or methane containing biogas and is designed for stationary use.

The DFX 3000 fuel cell has got several advantages, which are also valid for all other fuel cells:

- Efficiency: Modern fuel cells generate more electricity using less fuel with unparalleled electrical power generation efficiency of 47 percent, when considering the use of the exhaust heat up to 85 percent. Equipment with high output, like those in the range of the DFC 3000, have got the best electrical efficiency on the market
- Environment: The DFC 3000 emits low CO2 and almost zero pollutants into the atmosphere, which makes fuel cells one of the cleanest energy production methods and which makes it possible to build such facilities in areas with emission restrictions
- Stake Holders: Fuel cells can be operated in heavy populated areas, because they operate unnoticed, without any noise
- Reliability: The DFC 3000 is designed to achieve an availability of 95 percent and has proved its availability in various real life applications
- Fuel Economy: The DFC 3000 produces more electrical power than other generation possibilities with the same fuel input. Further they produce heat
- Simplicity: Real time monitoring controls the fuel cell and the energy production
- Versatility: It is possible to connect a number of fuel cells to increase the power output. Furthermore this fuel cell can be operated on a variety of fuels
- Cogeneration of Electricity and Heat: The fuel cell combines heat and power generation. With the heat the efficiency of the process can be increased

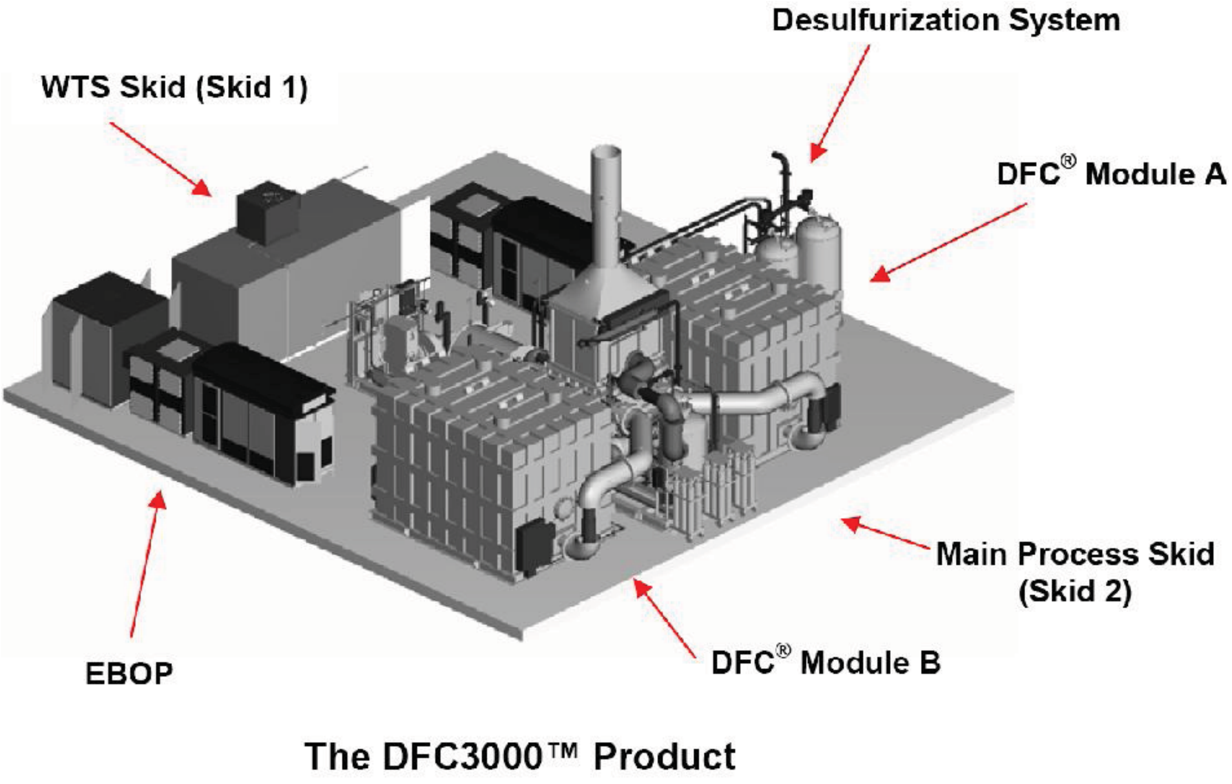


Figure 39: The DFC 3000 Fuel Cell[63]

The economics for this fuel cell can be calculated as follows:

	Costs/kW	Costs for a DFC 3000 Fuel Cell with 2.8 MW
Investment Costs	3.400 $/kW	9.520.000,00
Shipping	300 $/kW	840.000,00
Installation	800 $/kW	2.240.000,00
Total Investment Costs	[$]	12.600.000,00

Table 18: Investment Costs of the DFC 3000 Fuel Cell

The efficiency of the fuel cell, concerning the feed gas is better than the efficiency of turbines, 47 percent of the energy is converted into electricity. The costs for a kWh are about 1,5 times higher than the power generated by turbines. An ORC Cycle can be included, which increases the efficiency.

Although this fuel cell is ten times cleaner in NOx emissions than other comparable energy sources and although it is the most fuel efficient and lowest CO_2 base load power generation technology in this size, the extraordinary investment costs make it uneconomic. Projects, where these fuel cells are in operation are primarily done with governmental support. If there is a governmental aid in Austria has to be clarified by the legal department.[64]

Fuel cells will be a future energy source, which are heavily researched. With increasing knowledge and better efficiency the investment costs will decrease and fuel cells will become economically comparable to energy sources, which are used today. So it will be an advantage to use this technology as soon as possible to gain experience with it.

Microturbines and fuel cells have got the same application and in way of efficiency and almost zero emission, they both achieve good results.

But the main difference is that fuel cells are not applicable for fast start ups. In the stacks high temperatures occur. To avoid thermal stresses fast changes in the temperature and in the following in power output are not permissible.

Synergies and Potential for Future Projects

Monitoring Systems

To find a way to increase the efficiency of facilities, inside as well as outside underground gas storage facilities, it is necessary to monitor not either pressure or temperature or power consumption, but to monitor all three aspects in all equipments. These aspects must not only be measured in the areas which are known to be energy consumption intensive, but also in the support systems, like in the instrumentation air system. A small leakage with a diameter of 1,5 mm in this system can lead to an energy loss, which is worth 2.400 Euro a year. Without a monitoring system either the leak would not catch someone’s eye, or if an above the average compressed air consumption would be observed, the leak can be hard to be found.

When a working monitoring system is installed the results have to be checked regularly. Within a short time various optimizations in terms of energy efficiency would become obvious.

Not only a working, but also a right dimensioned monitoring system is important. While metering systems, which are dimensioned too small, will not work at all, metering systems, which are dimensioned too big, will work wrong, which probably will not lead to direct problems, but to a wrong and inefficient configuration.

Of course this is not only valid for underground gas storage facilities, but for all gas treating equipment and facilities, for all wells and processing plants.

Sensitization

As already mentioned in the introduction goods which are produced and used within the own facilities are considered less worth than goods which have to be bought from outside. This makes every attempt to increase the efficiency very difficult, because having an idea to improve efficiency is one hand side, to realize this improvement is the other hand side. The realization is not possible without the assistance of every employee and therefore sensitization on the topic is an important aspect.

Of course the first goal of an underground gas storage facility is to store gas, as for a well is to produce, but the fact that everything is working fine is not an argument not to change anything for good.

Arguing with concentrating on the core business is not valid either, because the core business of an oil and gas producer is energy and what else should be more important than to safe energy.

Underground Gas Storage Project Aigelsbrunn

The best way to invite new ideas is to invite them already in the planning phase of a new project. This could be the case with energy efficiency, especially with alternative generation of energy and the Underground Gas Storage Project Aigelsbrunn. The energy demand of the production station Haidach, which will be upgraded to the storage facility Aigelsbrunn will be about 4.5 MW. Because of this size and energy demand of this underground gas storage facility a big part of the energy consumption could be covered by energy, produced within the facility. Beside the possibility that energy could be produced by expansion and of course the possibility of photovoltaic, a big part of the energy could be produced by microturbines and in the future, when the pricing of fuel cells will have become comparable to other production ways, with fuel cells. The advantage of using several microturbine units instead of a single gas power pack or a gas turbine would be that in the case of a failure several other microturbines could produce energy. Furthermore in times of lower energy demand several microturbines can be switched off and the energy needed is produced by the remaining microturbines. These microturbines can always work with the optimal load.

Of course, what has to be considered is a decision about the size of the whole facility and the solution which is preferred: A small solution, which supports the conventional energy supply, or a big solution, which offers the possibility to deliver thermal energy into the community heating system or to deliver thermal energy to industrial consumers.

7 Fields

Because the compressors in 7 Fields are driven by electrical engines, like at the Underground Gas Storage Facility Haidach, and not by gas turbines, there is no exhaust heat, which could be recovered.

But a lot of aspects, which can not be realized at the Underground Gas Storage Facility Haidach and the Underground Gas Storage Facility Puchkirchen, because the state was set by the construction of these facilities, could be realized in the project 7 Fields, or in future underground gas storage projects.

This should already be considered in the planning phase. While changes after building the facilities are often uneconomic, while considering experiences and potentials from other projects already in the planning phase can safe money on the long turn.

Some of these aspects are listed beneath:

- Finding a flare which can be operated without a pilot heater in the winter mode
- Dynamic Engines instead of engines with just two modes: On or off

- Adjusting the processes and the facilities in a way, that the temperature of the gas when leaving the facility and entering the transfer pipeline, is as equal the temperature in the pipeline system as possible. In case the temperature in the facility is higher, possibilities to use the temperature difference should be proved, for example possibilities to heat buildings or to preheat the gas flow
- Adjusting processes where certain pressures are needed in a way that the pressures are kept as small as possible
- Considering additional energy production, for example by expansion turbines, already in the planning phase

Synergies outside of Underground Gas Storage Facilities

Use of Screw Type Expansion Machines at Gas Wells

Within RAG there are 133 gas wells. Each of these wells is producing with a certain pressure, which is usually not used. Often the pressure is reduced to a certain level, which is convenient for the pipeline system.

This is energy, which is not used, but wasted. A way to use this pressure is to drive a screw type expansion machine. The output of a screw type expansion machine is influenced by the volume and the pressure difference.

For the following example an input pressure of 30 bar and an output pressure of 5 bar is assumed.

Volume [Nm³/h]	Volume [Nm³/s]	Mass Flow [kg/s]	Volume Flow [m³/s]	delta P [bar]	delta P [Pa]	Density [kg/m³] @ 1 bar	Density [kg/m³] @ operating pressure	Output [kW]	Output including efficiency [kW]	Output/year [kWh]	Benefits [€]
1.000,00	0,28	0,21	0,0159	25,00	2.500.000,00	0,74	12,95	39,68	27,78	243.333,33	17.033,33
1.500,00	0,42	0,31	0,0238	25,00	2.500.000,00	0,74	12,95	59,52	41,67	365.000,00	25.550,00
2.000,00	0,56	0,41	0,0317	25,00	2.500.000,00	0,74	12,95	79,37	55,56	486.666,67	34.066,67
2.500,00	0,69	0,51	0,0397	25,00	2.500.000,00	0,74	12,95	99,21	69,44	608.333,33	42.583,33
3.000,00	0,83	0,62	0,0476	25,00	2.500.000,00	0,74	12,95	119,05	83,33	730.000,00	51.100,00
3.500,00	0,97	0,72	0,0556	25,00	2.500.000,00	0,74	12,95	138,89	97,22	851.666,67	59.616,67
4.000,00	1,11	0,82	0,0635	25,00	2.500.000,00	0,74	12,95	158,73	111,11	973.333,33	68.133,33
4.500,00	1,25	0,93	0,0714	25,00	2.500.000,00	0,74	12,95	178,57	125,00	1.095.000,00	76.650,00
5.000,00	1,39	1,03	0,0794	25,00	2.500.000,00	0,74	12,95	198,41	138,89	1.216.666,67	85.166,67
10.000,00	2,78	2,06	0,1587	25,00	2.500.000,00	0,74	12,95	396,83	277,78	2.433.333,33	170.333,33
50.000,00	13,89	24,17	1,8662	25,00	2.500.000,00	1,74	12,95	4.665,38	3.265,77	28.608.108,11	2.002.567,57

Table 19: Example Screw Type Expansion Machine

As already mentioned the big advantage is that the screw type expansion machine withstands wet gas. So the gas can be expanded before the separators or the dehydration. This concept would also fit into small underground gas storage projects, where smaller volumes are withdrawn than there are currently at the underground gas storage facilities in Haidach and in Puchkirchen.

These screw type expansion machines could be built in container design, which makes it transportable whenever the pressure undergoes a certain level. A number of different machines with different pressures and volumes are possible. Whenever a well changes into another pressure level the screw type expansion engine could be easily exchanged.

A problem could be hydrates. When high pressures occur they are usually expanded within the well to use the thermal energy of the rock to overcome the hydrate problem. A solution to the problem could be the combination with solar panels. These solar panels produce hot water which preheats the gas stream before it enters the expansion equipment.

Microturbines at Uneconomic Gas Wells

Another possibility to use wells, which are not economic enough to connect them to the pipeline grid, is to produce electricity. The connection to the electrical grid is much easier and cheaper than building a pipeline.

Rate [Nm3/h]	210	210	105	105
Production Time [months]	45	102	135	294
Cum Production [MM Nm3]	6,5	7,8	9,9	10,9
Recovery Factor [%]	38	46	58	65
Reservoir Pressure [bar]	152	144	104	89

Table 20: Well Data of GEO-001

As an example the well GEO-001 is taken, which is an uneconomical gas well. Even after 294 months the gas well would produce more than enough to drive a 200 kW microturbine. To use all the power of this turbine and because we do not have to produce all of the gas possible the calculation is done for one single 200 kW microturbine.

The price for this kind of electricity, produced by burning hydrocarbons, is 45 Euro/MWh. Calculating the Net Present Value, including the internal gas price of 20 Euro/MWh results in a negative solution. This means, that the project is uneconomic. But taking another look on the project and taking a different point of view the results change. Because the gas in the reservoir is not produced because of economical reasons the gas in the reservoir does not have any internal rate of return. It is a frozen asset. Therefore an internal gas price of 20 Euro/MWh is not valid. When reducing the internal gas price from 20 Euro/MWh to 0 Euro/MWh the result looks as follow:

IRR: 14,8%

NPV: 316.501 Euro

Payback Period: 7,5 years

The calculations can again be found in Appendix B.

Of course electricity can not only be sold, but also used within the own facilities. This leads to the point of view, that money is not earned by selling electricity, but money is saved by using the electricity produced by own facilities. So the money which can be earned is calculated by the money we save minus the transportation costs. Depending on where the electricity is used we would save, for example at the Underground Gas Storage Facilities Haidach, 69 Euro/MWh and at the Underground Gas Storage Facility Puchkirchen 79 Euro/MWh.

The usage of this system is especially useful at wells, which would be abandoned. The usage at wells, which are conserved has to be discussed in every individual case.

Combination of Screw Type Expansion Machine and Microturbine

As already seen there is a possibility to use the pressure of a well and to use the gas, which has got an economical value, which is too low to transport and to sell the gas. The idea is near, that both processes could be combined. Again we take the well GEO-001 as an example.

The first step is to calculate the electrical output of the screw type expansion machine. Again the minimum pressures are taken, which means the pressure after 294 months. Because the minimum inlet pressure for the microturbine is 6,5 bars, we expand the gas from 89 to 7 bars. Also the smallest rate is assumed, which is 105 Nm^3/h.

Volume [Nm³/h]	Volume [Nm³/s]	Volume Flow [kg/s]	Volume Flow [m³/s]	delta P [bar]	delta P [Pa]	Density [kg/m³] @ 1 bar	Density [kg/m³] @ operating pressure	Output [kW]	Output including efficiency [kW]	Output/Year [kWh]	Benefits **[€]**
105,00	0,03	0,02	0,0006	82,00	8.200.000,00	0,74	35,52	4,98	3,49	30.553,54	2.138,75

Table 21: Benefits of the Combination of a Screw Type Machine and a Microturbine

The second step is to produce energy in the microturbine. The results for this step can be seen in the previous chapter. Combining these two processes leads to following results:

Again assuming the gas price with 20 Euro/MWh the process is not economic. But when reducing the gas price to 0 Euro/MWh, because the gas could not be used in any other way, the Net Present Value becomes positive.

IRR: 16,0 %

NPV: 346.616 Euro

Payback Period: 6,8 years

More details to this calculation can be found in Appendix B.

This process becomes economic for a gas price of 5,30 Euro/MWh. In comparison without the screw type expansion machine the gas price has to be lower than 4,70 Euro/MWh. The calculation for scenario 2 can be found in Appendix B as well.

Turbine Krift

The gas turbine, which produces electricity for the site Kremsmuenster, produced a maximum of 266 kW an hour in the year 2008. This is exactly the range, where microturbines can be applied, for example by two 200 kW Capestone Microturbines. This gives a maximum power of 400 kW. Working with 150 kW each gives an optimum range for both microturbines.

The investment costs for a single turbine are 166.000 Euro. These costs include transportation to Austria, but exclude taxes, exhaust heat recovery, installation and commissioning. Because of a missing performance curve for the energy consumption the gas consumption is assumed with 75 percent for 75 percent load.

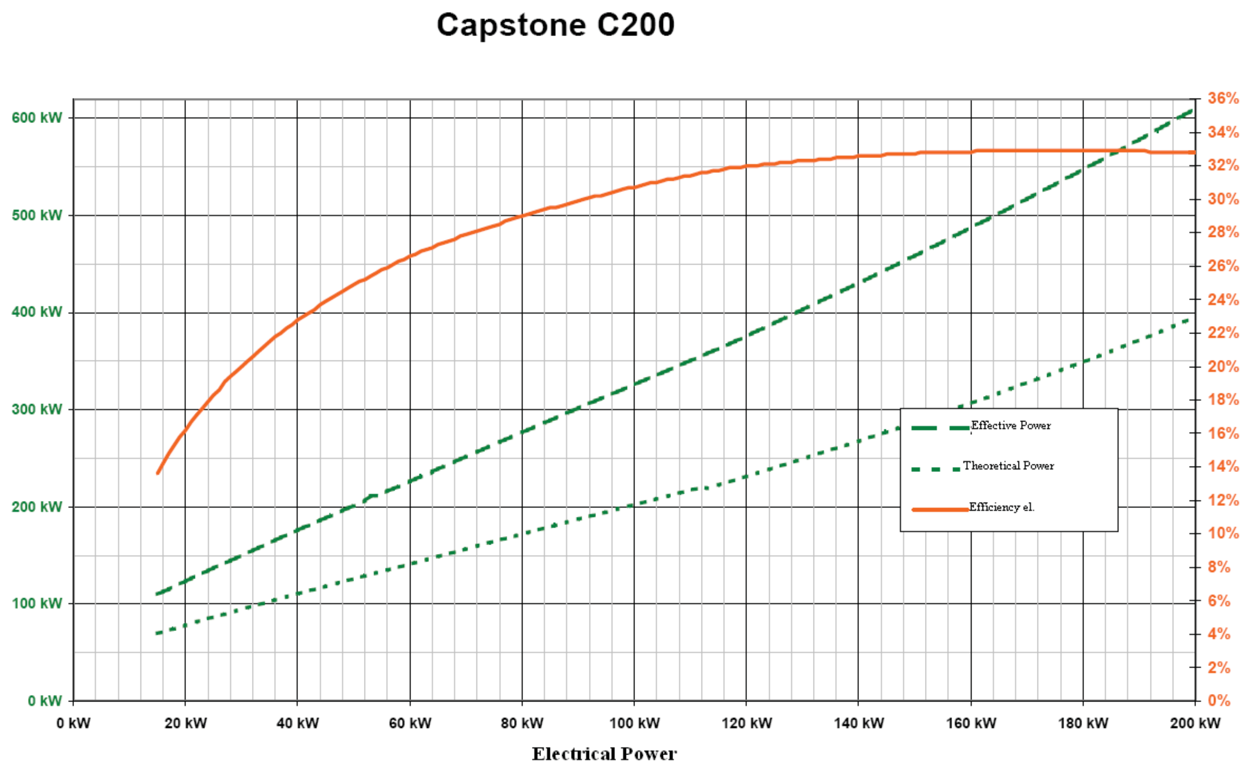


Figure 40: Performance Curve of a Capestone C200 Microturbine[65]

An exact economical calculation can be found in Appendix B. Again several assumptions were taken. First the transportation costs are 16 Euro/MWh. Furthermore the gas is transported to a facility where RAG is buying kWhe for 85 Euro/MWh. So the electrical energy produced is not sold but used within own facilities.

Again there are two scenarios, because of course the internal gas price is a major cost driver. Considering the gas price of 20 Euro/MWh those two C200 Capstone Microturbines can not be run efficiently. The Net Present Value is negative and beyond zero percent Internal Rate of Return.

The maximum gas price for this option is shown in scenario 2. If the gas price is 15 Euro/MWh or beyond, these microturbines will work with an Internal Rate of Return of more than 7 percent. What can be considered is that of course the internal gas price is valid for dry gas, but microturbines could be run with wet gas, too.

Energy Efficiency of Tail Gas Compressors

Tail gas compressors run all year long to compress the gas produced at the wells. Moreover also tail gas compressors produce exhaust heat. In the winter this exhaust heat is used to heat the weathering housing, but in the summer this energy is unused. Of course the amount of energy, produced by the tail gas compressors is not as high as by turbines in the Underground Gas Storage Facility Puchkirchen, but when the Kalina Process is becoming more applicable, the temperature of 55 degrees Celsius would fit into the application range perfectly.

A question which should be reasked is if tail gas compressors fit into the application of compressing gas all year long. Furthermore the energy efficiency of the operation modus can be reasked. Running two tail gas compressors with 50 percent load does not mean, that they are consuming 50 percent of the energy each.

Photovoltaic and Solar

Photovoltaic panels can be installed everywhere with roof areas and a direct insulation available. Beside the application at the Underground Gas Storage Facility Haidach, this is possible for the office buildings and workshops at the sites in Kremsmuenster, Zistersdorf, Ried im Innkreis and Munderfing, too. That it is also possible on top of the facility buildings of the future Gas Storage Facility Seven Fields was already mentioned as well.

Solar panels can be used to increase the temperature of water. A good possibility to use solar energy would be to participate on community projects, like using the solar power to increase the temperature of a fire water pond, which could be used as a public swimming pool by the stakeholders of the facility.

Photovoltaic in isolated operation could be used in a more increased way as already done. Today transmission signals of remote wells are supplied by energy from small photovoltaic panels. On satellite stations also roof areas are available and the demand on low potential voltage current is bigger, because of computers, transmission signals and lightning.

Decentralized Energy Generation in the Field

Decentralized energy production is the production of energy, for example by microturbines or by fuel cells, usually at the place where energy is needed. This is useful in mostly remote areas, where the laying of a power cable is not economic or troublesome. Of course normal production wells do not have a significant power need, but for example when dehydration is needed on site, electricity is needed for the preheating and the regeneration. With the application of microturbines these energy needs could be covered on site.

Image and Public Relations

Why are people happy when a geothermal well is drilled, but have concerns when an E&P Company drills for oil or gas? The process is the same, but the image of these two wells is different. A company which is well known to use green energy and to care about more than the balance sheet will have a better position whenever deals with neighbors and other stakeholders have to be made, which will finally lead into a positive movement of the balance sheet. Of course the core business of an E&P company is to drill for and produce oil and gas, but in a wider view the core business is energy and this also includes improving the energy efficiency of the processes and facilities.

Further there is the possibility to see alternative generation of energy as a future profit driver, with the possibility to gain experiences now and to use it in the future.

Conclusion

Analyzing different possibilities to improve processes and to generate energy in alternative ways showed that although it is worth to save every kilowatt hour of energy in every form, it is not always economically useful to do so. In the following the possibilities are summarized, which are economically promising: (Net Present Value calculated with a discount rate of 7 percent)

ORC at Gas Turbines in Puchkirchen

The best way to use the thermal energy of gas turbines is not to use the energy in its thermal state, but to produce electricity. This electricity is saleable the whole year long or can be used within the own facilities. Because the gas turbines in the UGS Puchkirchen work in the same period of time as the compressors in Haidach do, the electricity can be used to drive the compressors there. Using the electricity in own facilities, even when the electricity has to be transported, is more economic than selling it. Following example is for a single ORC facility, a second is possible and suggested in stage 1 and a third at the new built third string in stage 2.

Total Investment	1.000.000 Euro
OPEX	260.000 Euro/5a
IRR after tax	22,8 %
NPV after tax	1.927.112,4 Euro
Payback Period	3,7 years

Screw Type Expansion Machines in Haidach

The pressure drop during certain withdrawal periods is used to produce electrical energy. To use big volumes three expansion machines can be installed. Screw Type Expansion Machines are at the beginning of development and their performance is supposed to improve.

Total Investment	1.070.000 Euro
OPEX	60.000 Euro
IRR after tax	10,7 %
NPV after tax	462.266
Payback Period	11,5 years

Microturbines at Uneconomic Wells

To make money out of wells, which are not worth to be connected to the pipeline system, microturbines could be used. These turbines are very economic, when the internal gas prize for the gas, which cannot be produced anyway, is set to 0 Euro. The economical numbers are based on the data of well GEO-001.

Total Investment	256.000 Euro
OPEX	77.000 Euro/5a
IRR after tax	14,8 %
NPV after tax	316.501 Euro
Payback Period	7,5 years

Microturbine and Screw Type Expansion Machine at Uneconomic Wells

To increase the efficiency a microturbine could be combined with a screw type expansion machine, which uses the pressure difference between well and microturbine. Again GEO-001 is taken as an example and an internal gas prize of 0 Euro is assumed.

Total Investment	270.000 Euro
OPEX	80.000 Euro/5a
IRR after tax	16.0 %
NPV after tax	346.616 Euro
Payback Period	6,8 years

Microturbine C1000 for own Need Electricity Production

The savings were calculated for on location electrical energy production with a 1 MW microturbine, considering the internal gas price of 20 Euro/MWh. The results are the savings considering that buying 1 MWh electrical energy is 85 Euro.

Total Investment	840.000 Euro
OPEX	722.245 Euro/5a
IRR after tax	8,4 %
NPV after tax	103.350,50 Euro
Payback Period	11,4 years

Photovoltaics

In the scenario described not one big photovoltaic facility is built, but several small ones. This could open the possibility to sell the energy for a higher price, regarding the requirements of the "Oekostromgesetz".

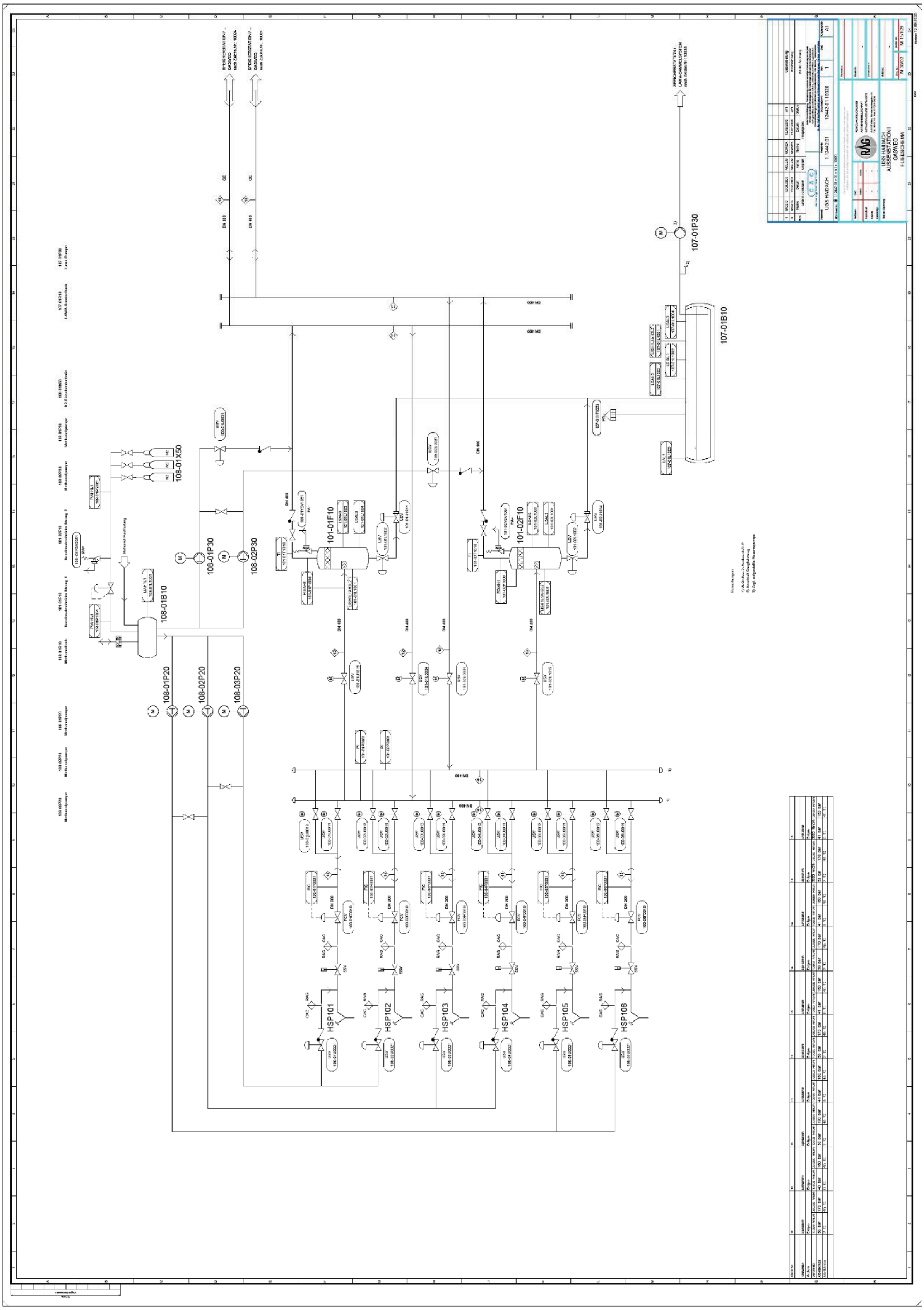
Total Investment	1.525.000 Euro
OPEX	2.000 Euro/5a
IRR after tax	8,3 %
NPV after tax	227.463,8 Euro
Payback Period	16,2 years

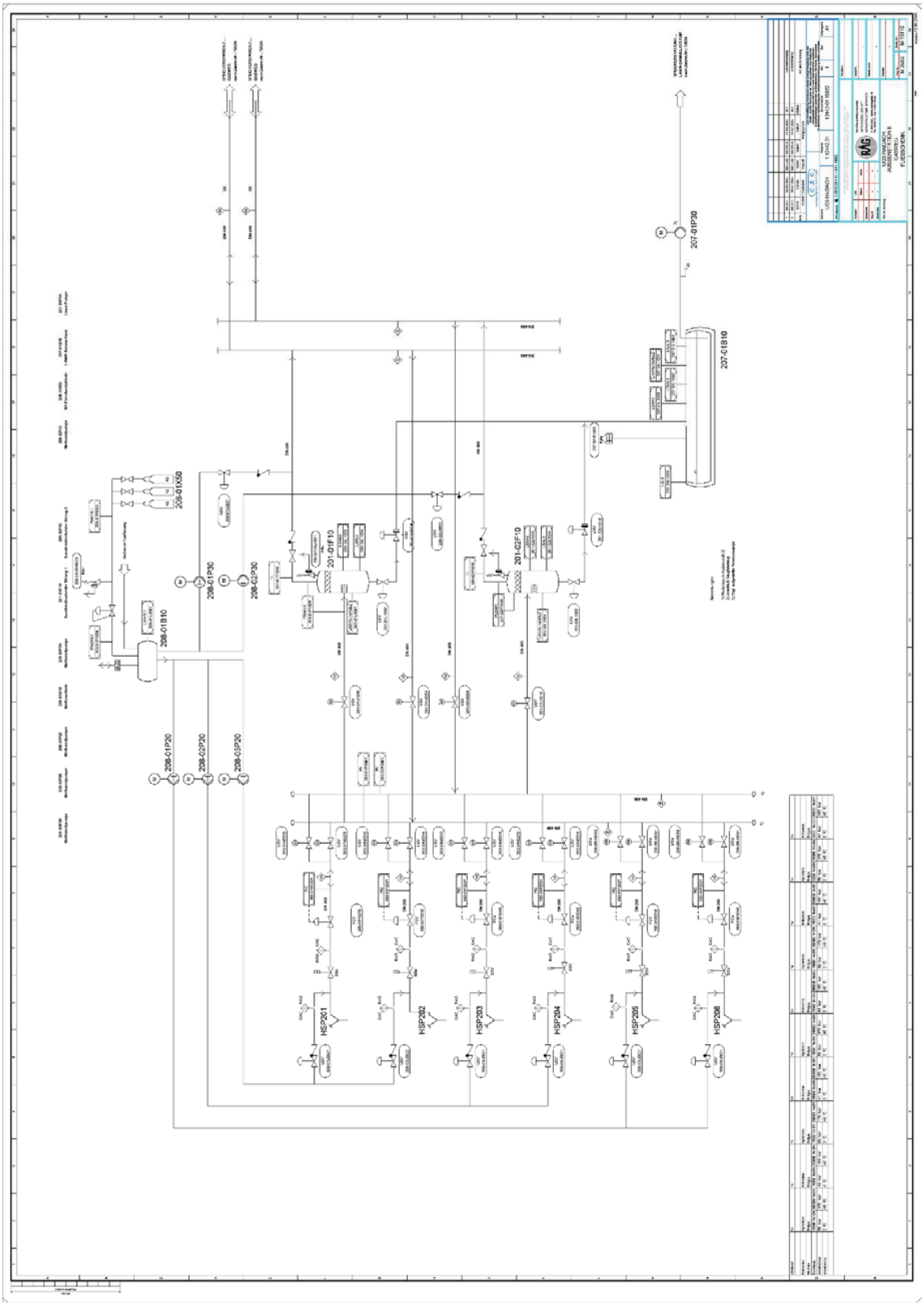
Differential Pressure in the Transfer Pipeline Haidach-Haiming

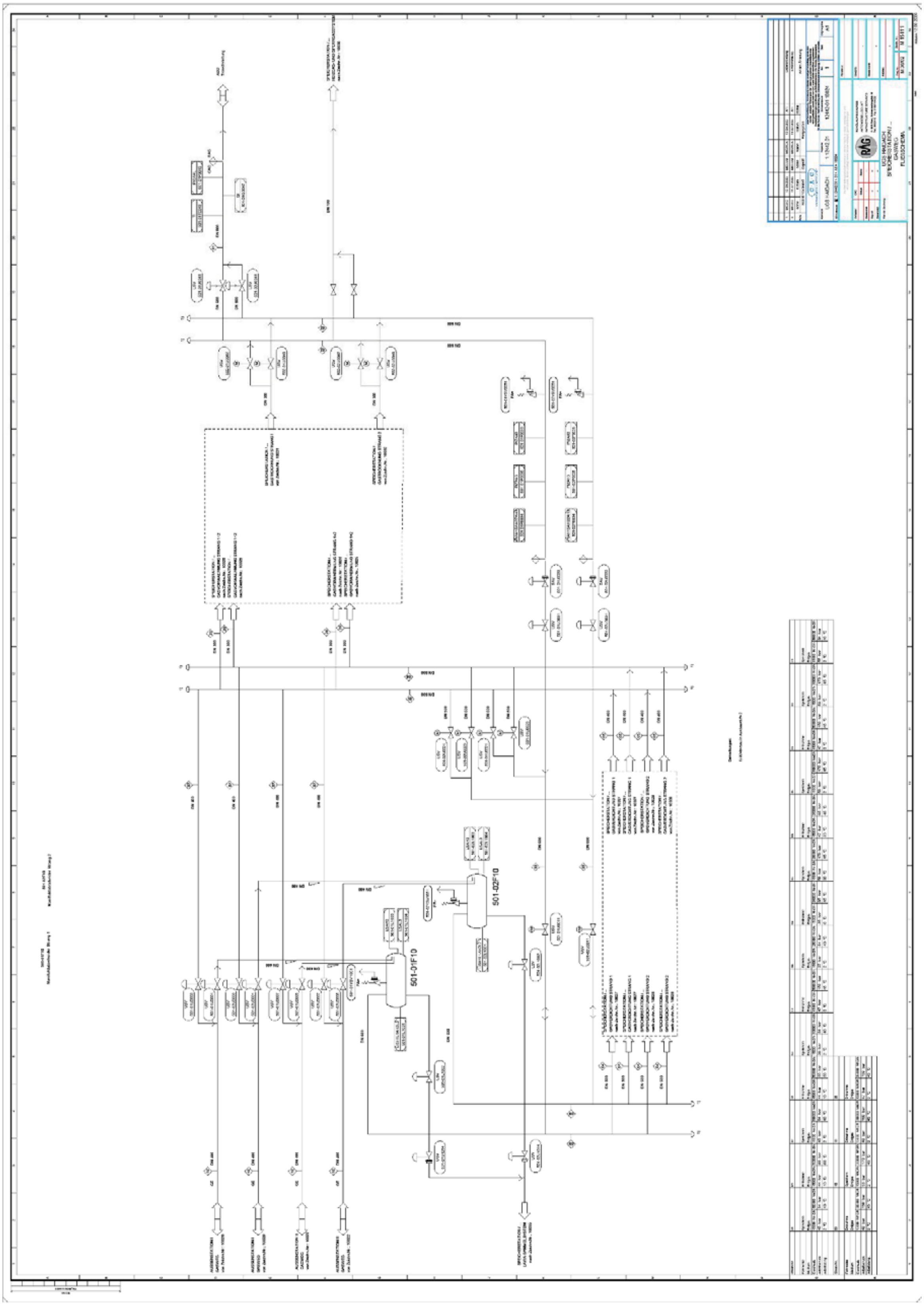
Because for the reason to overcome withdrawal intermittences a minimum pressure difference of 5 bar is tried to be kept in the transfer pipeline. This is not applicable while the withdrawal of big volumes. Taking the year 2008 as an example and assuming to reduce the pressure differences above 3,5 bar by 2 bar whenever the volume of withdrawal with the use of compressors is above 400.000 an amount of 72.292,5 Euro/a could be saved in energy costs.

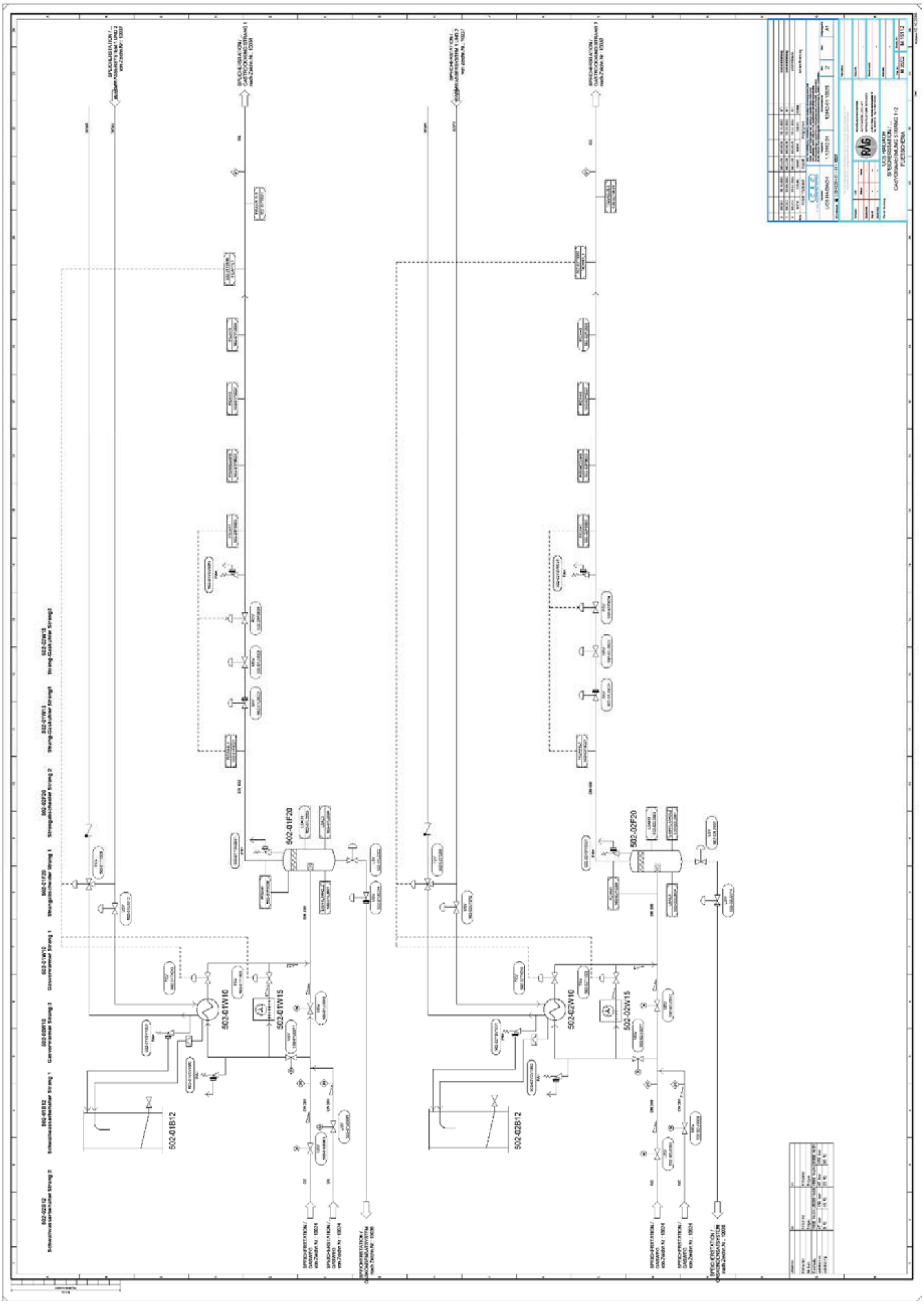
When including governmental aid more projects, which were described and analyzed in this thesis will become economically useful. It can be assumed that with an increasing need to use alternative energy generation systems and to make processes more energy efficient the economical status will be shifted and will become more practical.

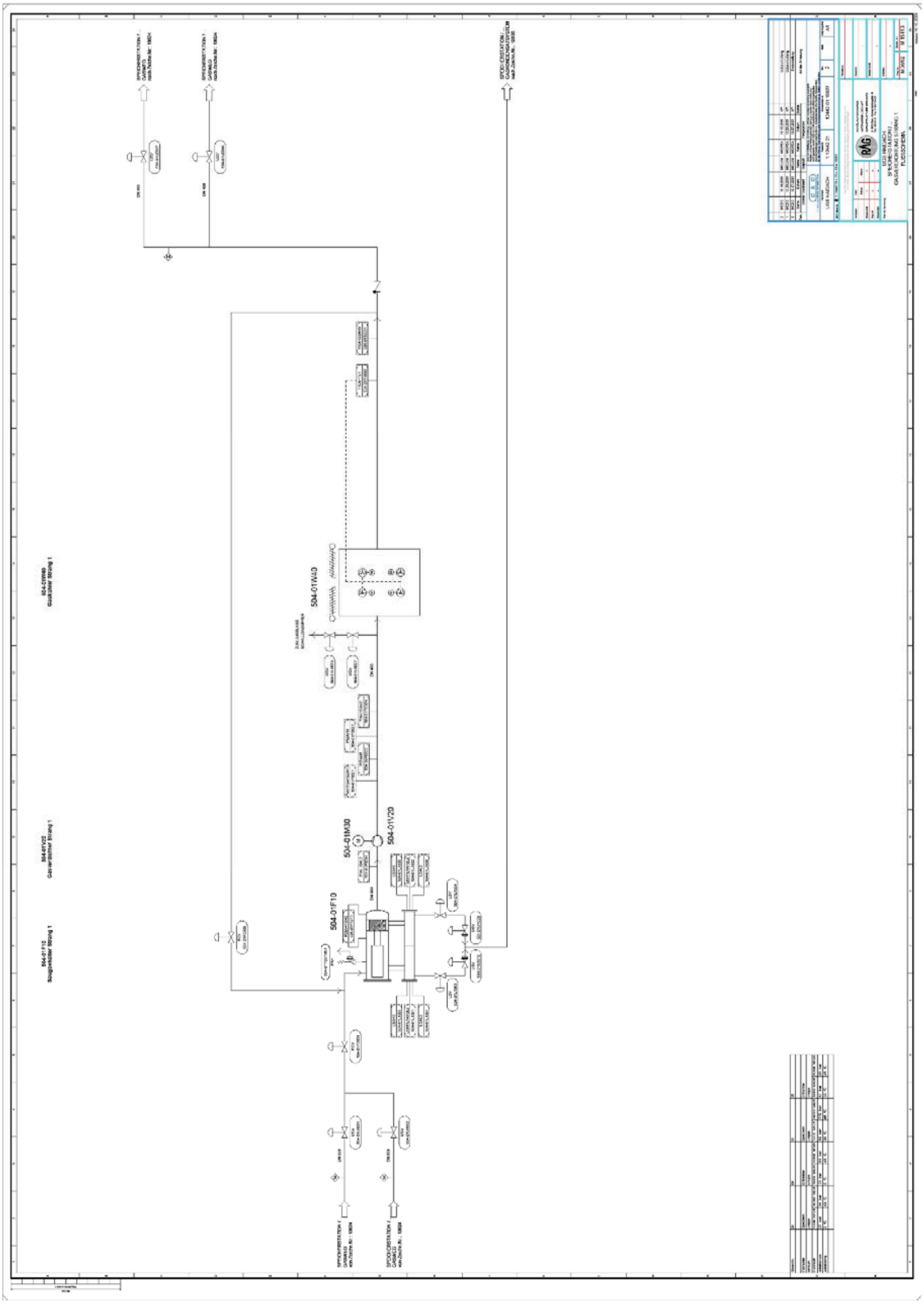
Appendix A

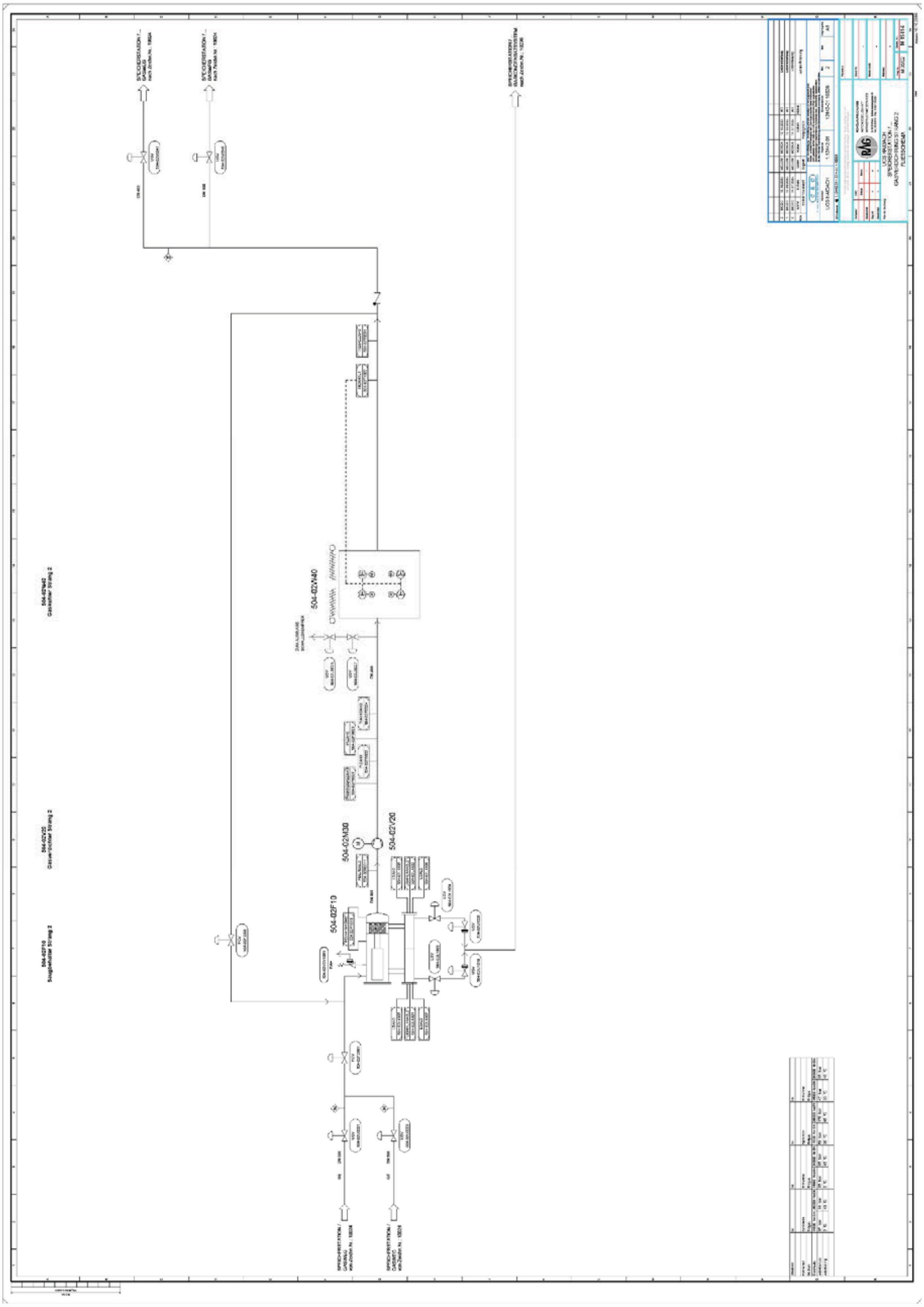

107-01P30
107-01B10
101-01F10
101-02F10
108-01X50
108-01P30
108-02P30
108-01B10
108-01P20
108-02P20
108-03P20
HSP101
HSP102
HSP103
HSP104
HSP105
HSP106
UGS HAIDACH
RAG

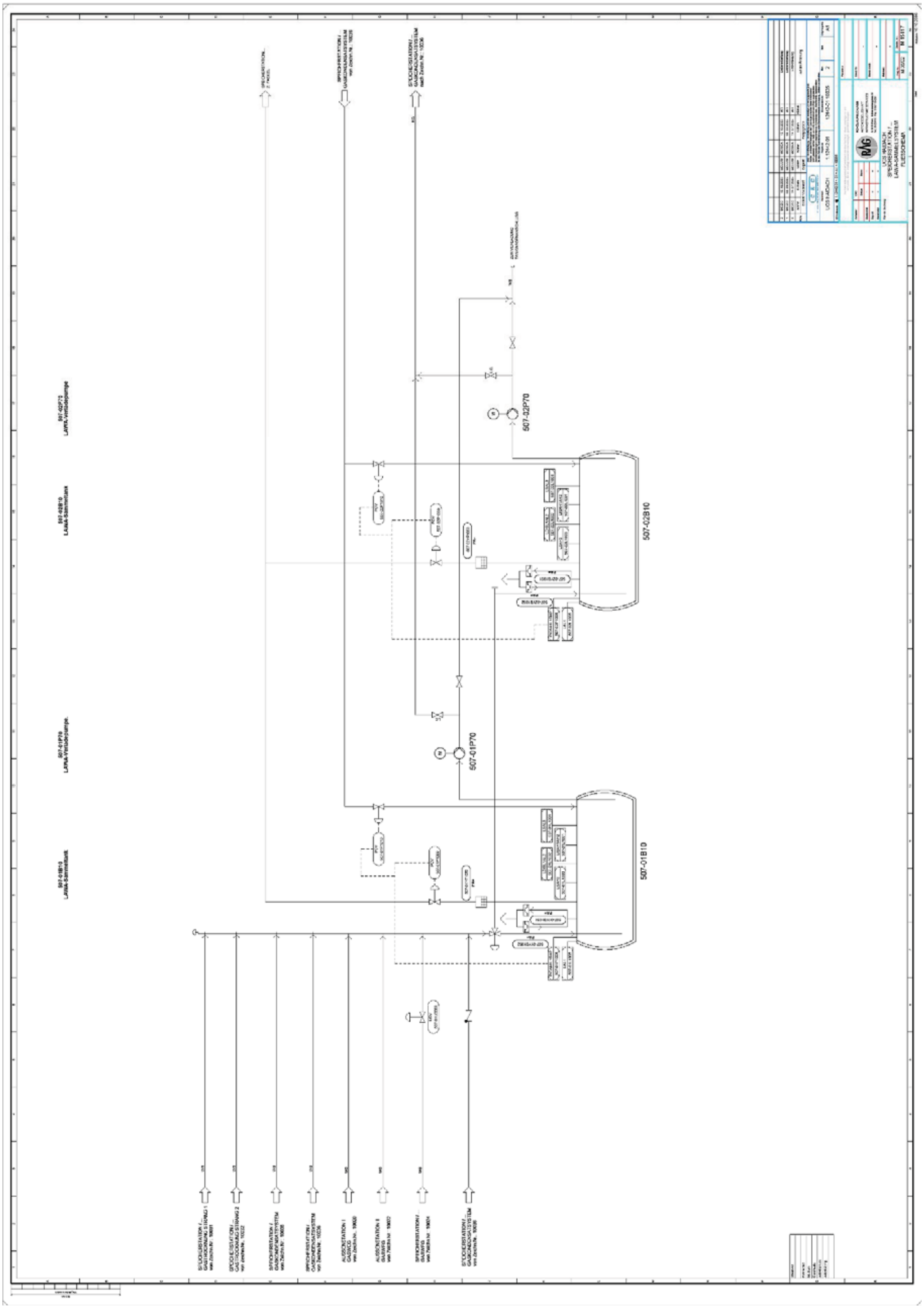

207-01P30
207-01B10
201-01F10
201-02F10
208-01X50
208-01B10
208-01P30
208-02P30
208-01P20
208-02P20
208-03P20
HSP201
HSP202
HSP203
HSP204
HSP205
HSP206
RAG

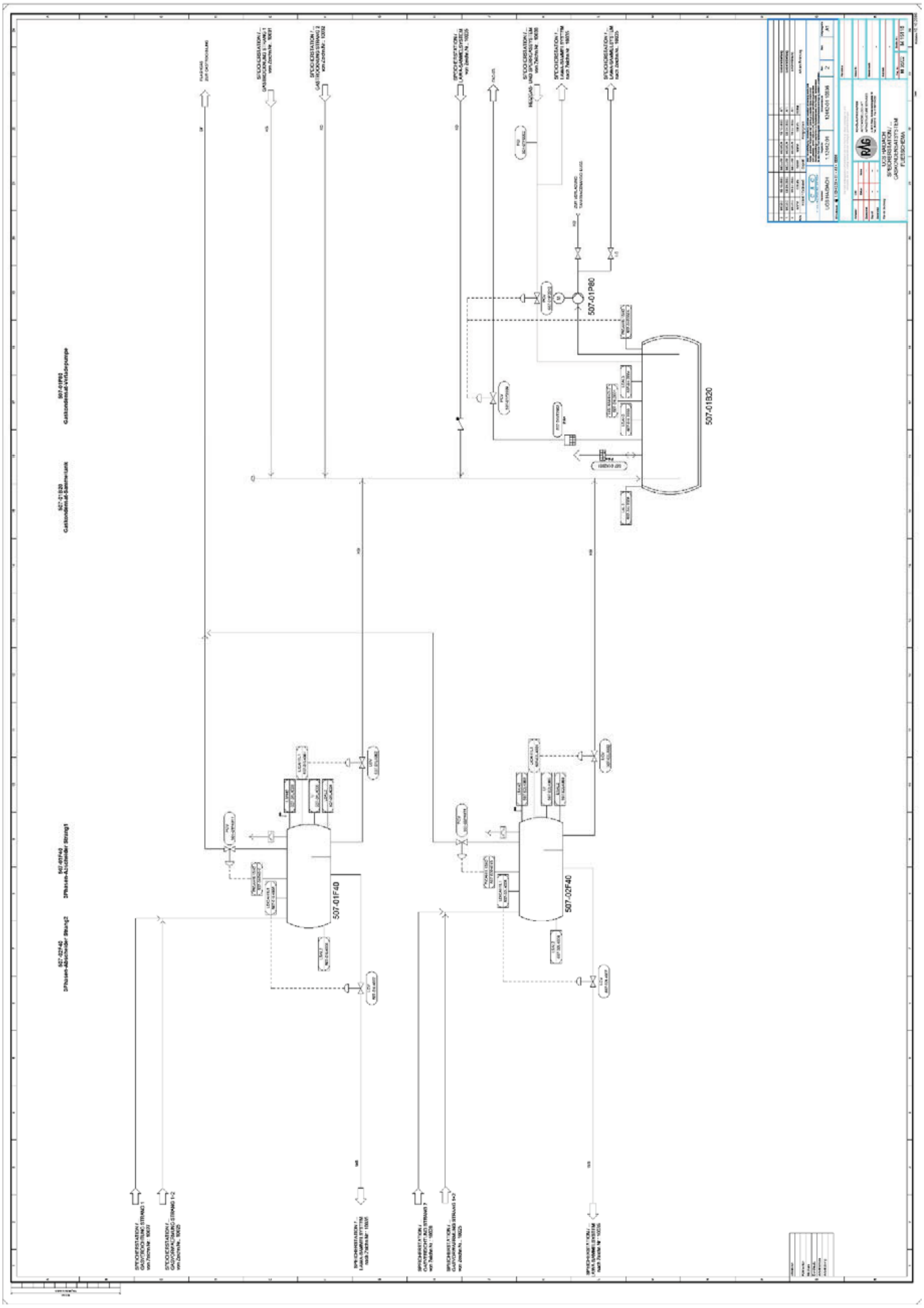

501-01F10
501-02F10


502-01W10
502-01W15
502-01F20
502-01B12
502-02W10
502-02W15
502-02F20
502-02B12
UGS HAIDACH
RAG
FLIESSCHEMA


504-01F10
Saugbehälter Strang 1
504-01V20
Gasverdichter Strang 1
504-01W40
Gaskühler Strang 1
504-01F10
504-01M30
504-01V20
504-01W40
UGS HAIDACH
SPEICHERSTATION 2
GASVERDICHTUNG STRANG 1
FLIESSCHEMA


504-02F10
504-02M30
504-02V20
504-02V40


507-02P70
507-02B10
507-01P70
507-01B10
UGS HAIDACH


507-01P80
Gaskondensat-Verladepumpe
507-01B20
Gaskondensat-Sammeltank
507-01F40
3Phasen-Abscheider Strang1
507-02F40
3Phasen-Abscheider Strang2
507-01B20
507-01P80
507-01F40
507-02F40

Appendix B

Expansion Turbine

Inlet Temp	Outlet Temp	Inlet Pressure	Outlet Pressure	Volume	Electrical Power	Operation Hours in 2008
[°C]	[°C]	[bara]	[bara]	[m3(Vn)/h]	[kW]	[h]
27	4,30	90	64	312.500	2103	64
27	14,70	90	75	312.500	1145	64
40	8,00	90	55	312.500	3035	64
27	4,70	90	64	208.333	1354	1387
27	5,50	90	64	156.250	949	115
27	5,30	90	64	125.000	709	77
27	5,80	90	64	104.167	603	269
27	23,10	68	64	312.500	365	64
27	16,50	75	64	312.500	995	64
27	8,10	85	64	312.500	1769	64

Expansion Turbine Project Evaluation – Economical Analyses

Base Assumptions

Fill in value

Automatic calculation

Parameter		
Full load hours per year	h	2803
Full load hours per year	%	32
Electrical Output	kW	1003
Electrical energy per year	MWh	2812
Perpetual growth electricity sales	%p.a.	2
Electricity retail price per MWh	€	70
Total Investment	€	2.080.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

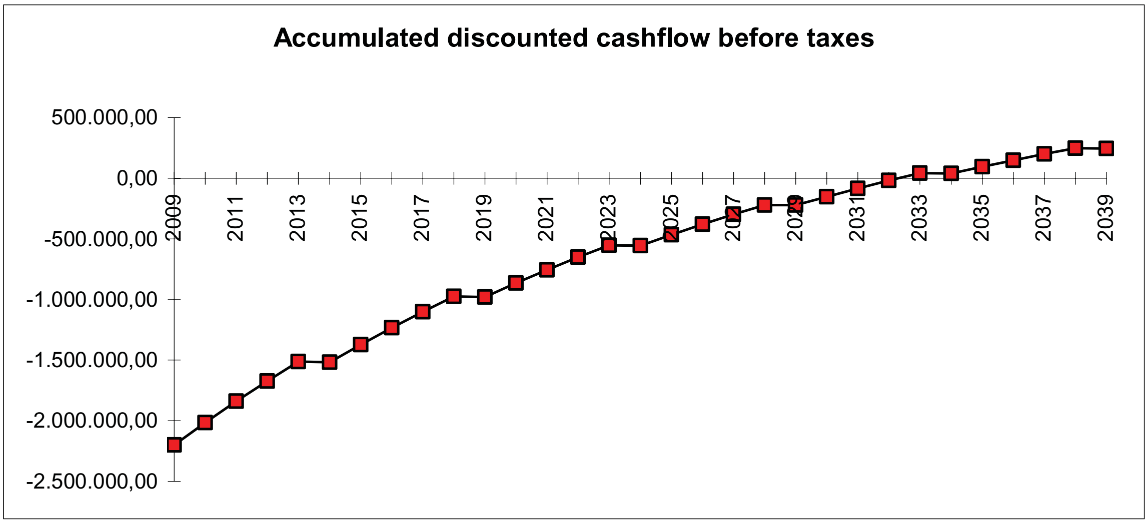
Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Expander	33	€	2.000.000
Civil Work	33	€	10.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	2.080.000

OPEX €

Parameter		
Personnel costs	€	10.000
Maintenance	€	200.000
Total OPEX	€	210.000

Results

Economics after taxes	
Internal rate of return (IRR)	6,4%
Net present value (NPV)	-147.251
Pay back period	0,0



Economics before taxes

Internal rate of return (IRR)	8,0%
Net present value (NPV)	245.454,6
Pay back period	0,0

Economics after taxes

Internal rate of return (IRR)	6,4%
Net present value (NPV)	-147.250,9
Pay back period	23,3
VIR	-0,07
Total Cash Surplus	2.998.323,10
Max. Exposure	-2.200.000,00

Screw Type Expansion Machine at UGS Haidach

Scenario 1

Screw Type Expansion Machine Project Evaluation – Economical Analyses

Base Assumptions

Parameter			Fill in value Automatic calculation
Full load hours per year		H	1051
Full load hours per year		%	12
Electrical Output		kW	600
Electrical energy per year		MWh	631
Perpetual growth electricity sales		%p.a.	2
Electricity retail price per MWh		€	70
Total Investment		€	320.000
Price increase for electricity (or Gas) bought		%p.a.	3
Price increase general costs		%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	10.000
Expander	33	€	250.000
Civil Work	33	€	10.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	320.000

OPEX €

Parameter			
Personnel costs		€	10.000
Maintenance		€	50.000
Total OPEX		€	60.000

Results

Economics after taxes

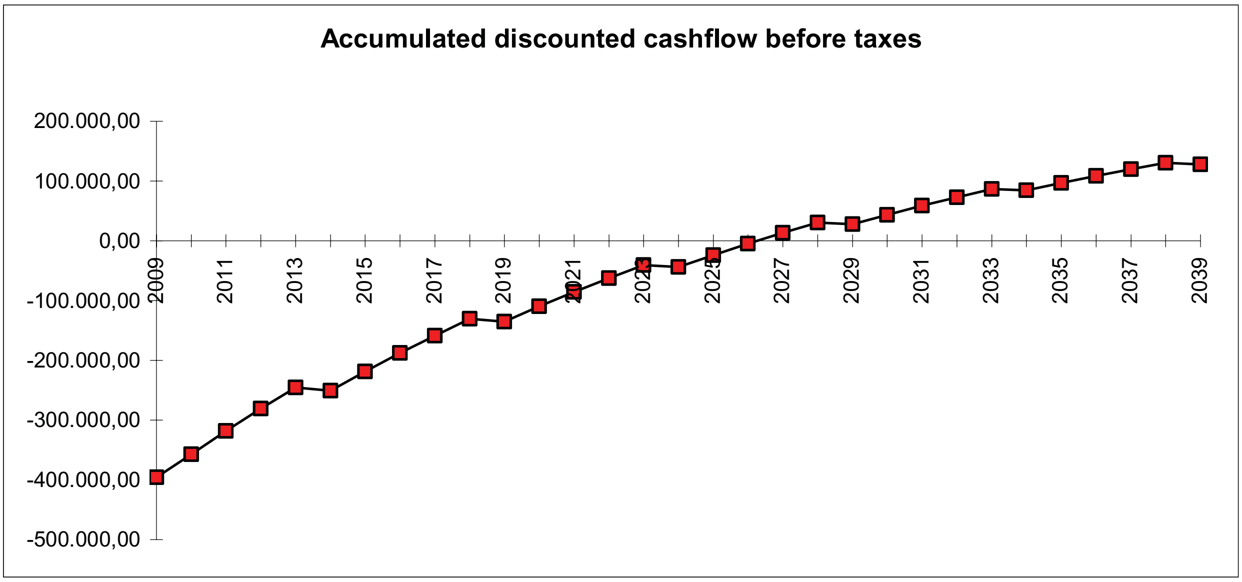
Internal rate of return (IRR)	8,0%
Net present value (NPV)	42.383
Pay back period	17,3

Economics before taxes

Internal rate of return (IRR)	9,9%
Net present value (NPV)	127.900,0
Pay back period	17,3

Economics after taxes

Internal rate of return (IRR)	8,0%
Net present value (NPV)	42.383,4
Pay back period	17,3
VIR	0,11
Total Cash Surplus	691.847,77
Max. Exposure	-395.849,60



Scenario 2

Screw Type Expansion Machine Project Evaluation – Economical Analyses

Base Assumptions

Parameter		
Full load hours per year	H	1051
Full load hours per year	%	12
Electrical Output	kW	1800
Electrical energy per year	MWh	1892
Perpetual growth electricity sales	%p.a.	2
Electricity retail price per MWh	€	70
Total Investment	€	1.070.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	10.000
Expander	33	€	1.000.000
Civil Work	33	€	10.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	1.070.000

OPEX €

Parameter		
Personnel costs	€	10.000
Maintenance	€	50.000
Total OPEX	€	60.000

Results

Economics after taxes

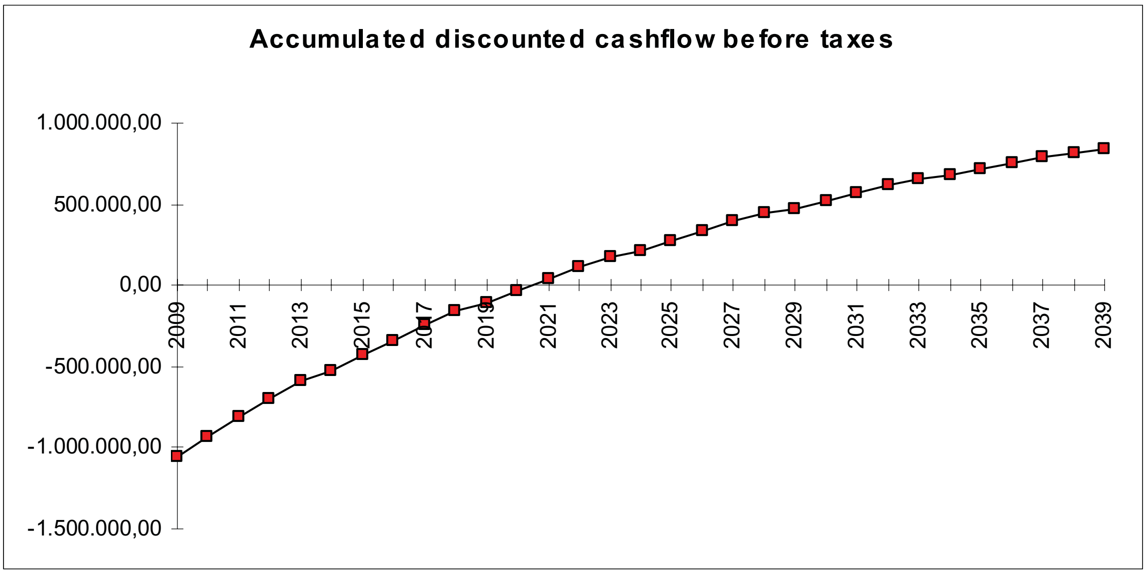
Internal rate of return (IRR)	10,7%
Net present value (NPV)	462.266
Pay back period	11,5

Economics before taxes

Internal rate of return (IRR)	13,4%
Net present value (NPV)	838.903,1
Pay back period	11,5

Economics after taxes

Internal rate of return (IRR)	10,7%
Net present value (NPV)	462.265,8
Pay back period	11,5
VIR	0,44
Total Cash Surplus	2.926.243,59
Max. Exposure	-1.060.661,60



Differential Pressure in Transfer Pipeline

Energy Consumption of one Compressor for Compression from 65 to 75 bar: 4 MW

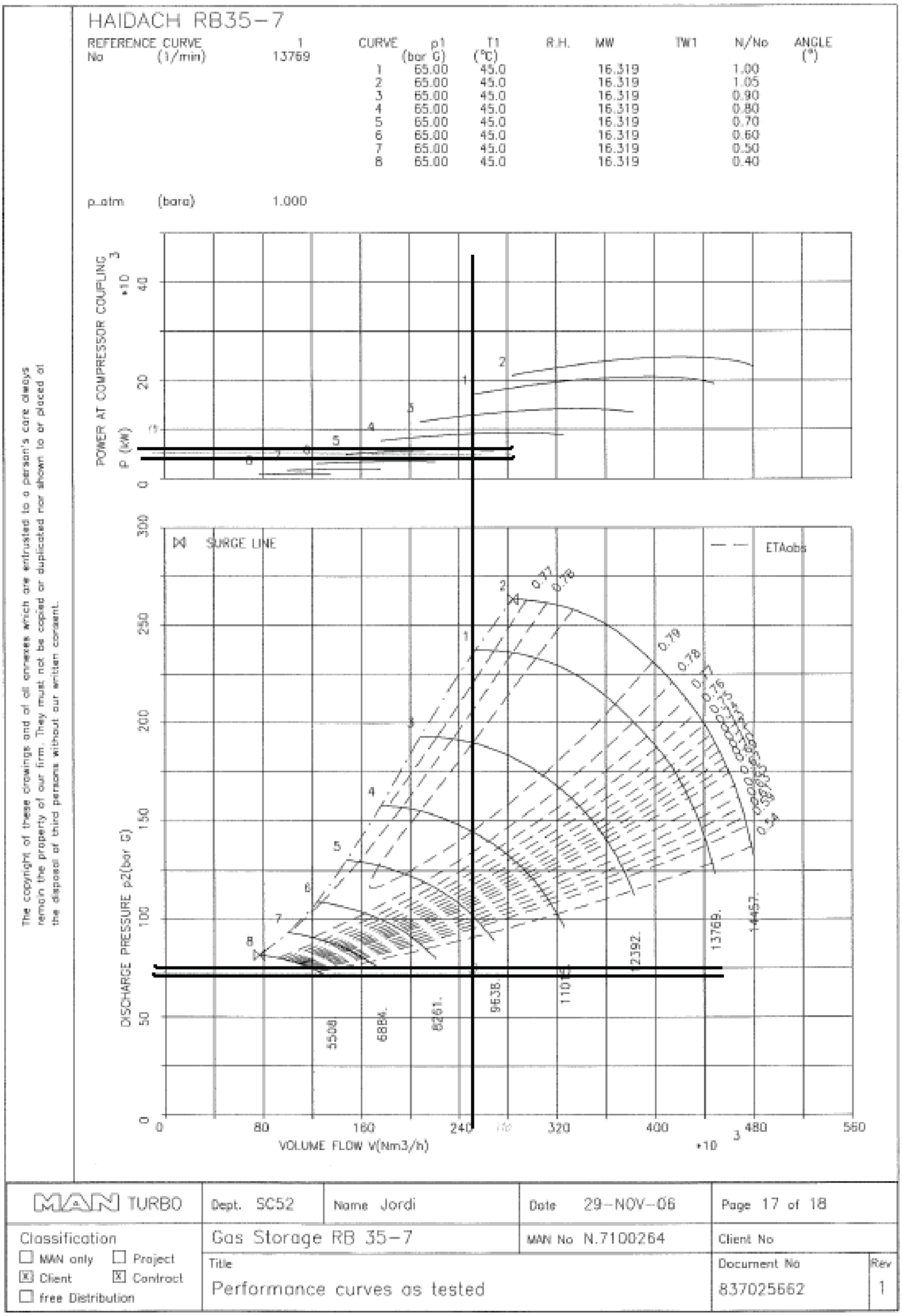
Energy Consumption of one Compressor for Compression from 65 to 72 bar: 3 MW

Total Consumption Savings: 2 MW

Valid for 425,25 h/a (V>400.000 Nm^3/h and Δp>3,5 bar)

Energy Consumption/a: 2 MW * 425,25 h/a = 850.500 kwh/a

Energy Costs: 850.500 kWh/a * 0,085 Euro/kWh = 72.292,5 Euro/a



HAIDACH RB35-7

REFERENCE CURVE 1
No (1/min) 13769

CURVE	p1 (bar G)	T1 (°C)	R.H.	MW	TW1	N/No	ANGLE (°)
1	65.00	45.0		16.319		1.00	
2	65.00	45.0		16.319		1.05	
3	65.00	45.0		16.319		0.90	
4	65.00	45.0		16.319		0.80	
5	65.00	45.0		16.319		0.70	
6	65.00	45.0		16.319		0.60	
7	65.00	45.0		16.319		0.50	
8	65.00	45.0		16.319		0.40	

p_atm (bara) 1.000

MAN TURBO	Dept. SC52	Name Jordi	Date 29-NOV-06	Page 17 of 18
Classification ☐ MAN only ☐ Project ☒ Client ☒ Contract ☐ free Distribution	Gas Storage RB 35-7		MAN No N.7100264	Client No
	Title Performance curves as tested			Document No 837025662 Rev 1

Dehydration Units Puchkirchen

ORC Dehydration Project Evaluation – Economical Analyses

Base Assumptions

Parameter		Fill in value Automatic calculation
Full load hours per year	h	3154
Full load hours per year	%	36
Electrical Power	kW	36
Electrical Energy per year	MWh	114
Perpetual growth electrical sales	%p.a.	2
Electricity retail price per MWh	€	70
Total Investment	€	105.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	5.000
Small ORC Facility	33	€	60.000
Civil Work	33	€	10.000
Project Management	33	€	30.000
Total CAPEX € million	33	€	105.000

OPEX €

Parameter		
Personnel costs	€	1.000
Maintenance	€	5.000
Total OPEX	€	6.000

Results

Economics after taxes

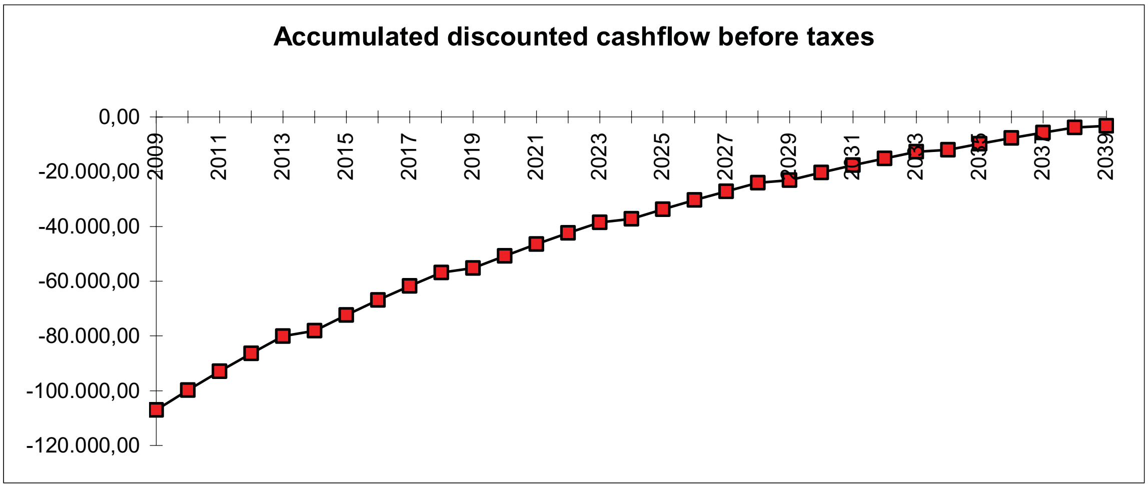
Internal rate of return (IRR)	5,3%
Net present value (NPV)	-18.842
Pay back period	0,0

Economics before taxes

Internal rate of return (IRR)	6,7%
Net present value (NPV)	-3.234,0
Pay back period	0,0

Economics after taxes

Internal rate of return (IRR)	5,3%
Net present value (NPV)	-18.842,3
Pay back period	0,0
VIR	-0,18
Total Cash Surplus	120.319,63
Max. Exposure	-2.572,91


Accumulated discounted cashflow before taxes
0,00
-20.000,00
-40.000,00
-60.000,00
-80.000,00
-100.000,00
-120.000,00
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039

ORC Exhaust Heat

ORC Gas Driven Turbines Project Evaluation – Economical Analyses

Base Assumptions

Parameter		
Full load hours per year	h	2978
Full load hours per year	%	34
Electrical Output	kW	1400
Electrical energy per year	MWh	4170
Perpetual growth electricity sales	%p.a.	2
Electricity retail price per MWh	€	69
Total Investment	€	1.000.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
ORC Facility	33	€	700.000
Civil Work	33	€	20.000
Project Management	33	€	80.000
Total CAPEX € million	33	€	820.000

OPEX €

Parameter		
Personnel costs	€	10.000
Maintenance	€	250.000
Total OPEX	€	260.000

Results

Economics after taxes

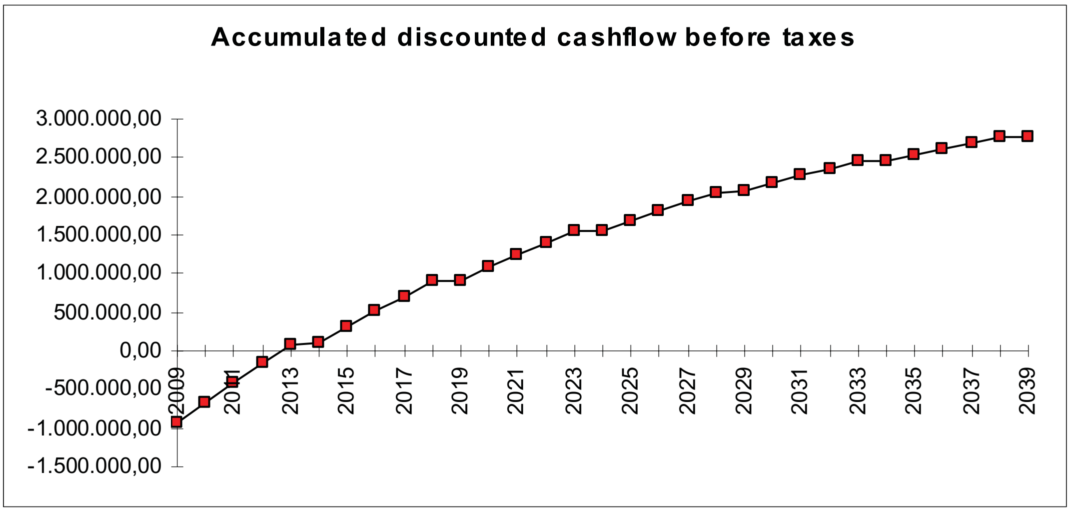
Internal rate of return (IRR)	22,8%
Net present value (NPV)	1.927.112
Pay back period	3,7

Economics before taxes

Internal rate of return (IRR)	29,7%
Net present value (NPV)	2.777.472,7
Pay back period	3,7

Economics after taxes

Internal rate of return (IRR)	22,8%
Net present value (NPV)	1.927.112,4
Pay back period	3,7
VIR	2,06
Total Cash Surplus	6.481.896,56
Max. Exposure	-118.648,37


Accumulated discounted cashflow before taxes
3.000.000,00
2.500.000,00
2.000.000,00
1.500.000,00
1.000.000,00
500.000,00
0,00
-500.000,00
-1.000.000,00
-1.500.000,00
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039

Microturbines

C30

Scenario 1

Microturbine 30 kW project evaluation – Economical Analyses

Base Assumptions		Fill in value
Parameter		Automatic calculation
Full load hours per year	H	8322
Full load hours per year	%	95
Electrical Power	kW	30
Electrical energy per year	MWh	250
Perpetual growth electricity sales	%p.a.	2
Electricity retail price per MWh	€	69
Total Investment	€	81.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Microturbine	33	€	41.000
Civil Work	33	€	10.000
Project Management	33	€	10.000
Total CAPEX € million	33	€	81.000

OPEX €

Parameter		
Gas costs per MWh	€/MWh	20,00
Gas costs	€	21.137,88
Personnel costs	€	5.000
Maintenance	€	5.000
Total OPEX	€	31.138

Results

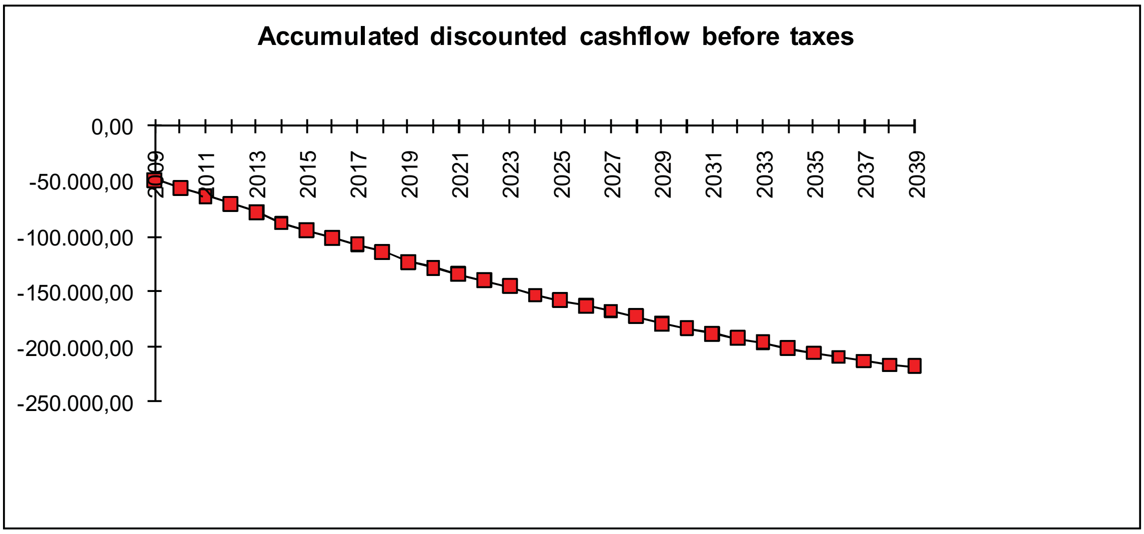
Economics after taxes	
Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-220.605
Pay back period	0,0

Economics before taxes

Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-217.548,6
Pay back period	0,0

Economics after taxes

Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-220.605,3
Pay back period	0,0
VIR	-4,52
Total Cash Surplus	-535.450,44
Max. Exposure	-3.056,64



Scenario 2

Microturbine 30 kW Project Evaluation – Economical Analyses

Base Assumptions

Fill in value

Automatic calculation

Parameter		
Full load hours per year	H	8322
Full load hours per year	%	95
Electrical Power	kW	30
Electrical energy per year	MWh	250
Perpetual growth electricity sales	%p.a.	2
Electricity retail price per MWh	€	85
Total Investment	€	81.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Microturbine	33	€	41.000
Civil Work	33	€	10.000
Project Management	33	€	10.000
Total CAPEX € million	33	€	81.000

OPEX €

Parameter		
Electricity consumption	MWh	10,00
Gas costs per MWh	€/MWh	10,55
Gas costs	€	11.150,23
Personnel costs	€	5.000
Maintenance	€	5.000
Total OPEX	€	21.150

Results

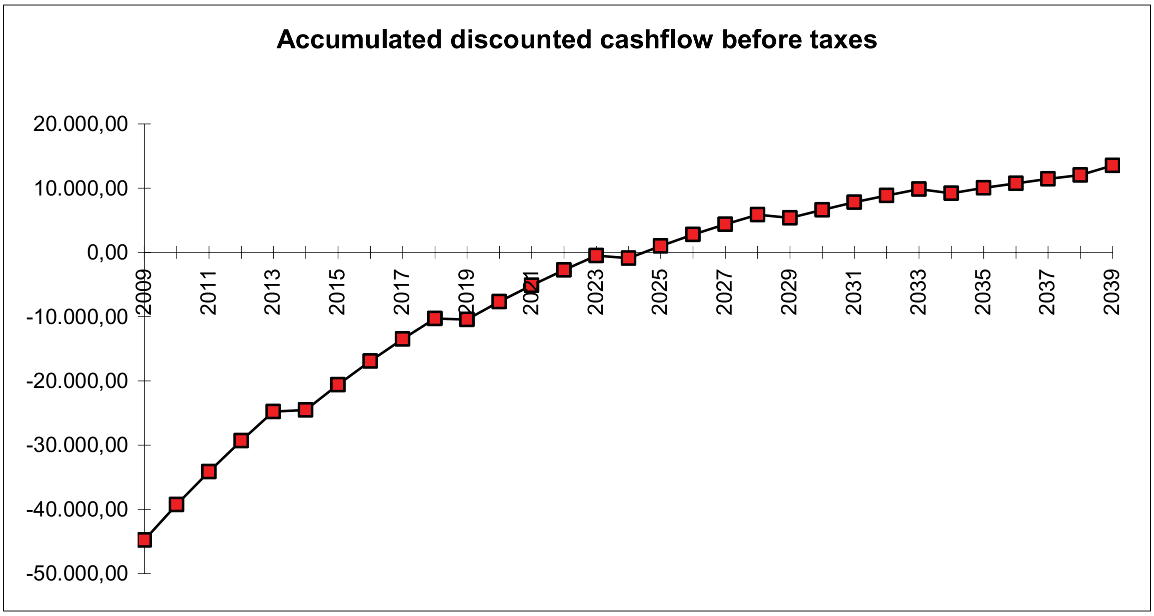
Economics after taxes	
Internal rate of return (IRR)	7,1%
Net present value (NPV)	538
Pay back period	15,5

Economics before taxes

Internal rate of return (IRR)	10,1%
Net present value (NPV)	13.528,7
Pay back period	15,5

Economics after taxes

Internal rate of return (IRR)	7,1%
Net present value (NPV)	538,2
Pay back period	15,5
VIR	0,01
Total Cash Surplus	66.814,64
Max. Exposure	-4.055,28



C200 (Uneconomic Wells)

Microturbine 200 kW Project Evaluation – Economical Analyses

Fill in value

Automatic calculation

Base Assumptions

Parameter		
Full load hours per year	h	8322
Full load hours per year	%	95
Electrical Output	kW	200
Electrical Output per year	MWh	1664
Perpetual growth electrical sales	%p.a.	2
Electricity retail price per MWh	€	45
Total Investment	€	256.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Microturbine	33	€	166.000
Civil Work	33	€	20.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	256.000

OPEX €

Parameter		
Gas Consumption	MWh	0,66
Gas costs per MWh	€/MWh	0,00
Gas costs	€	0,00
Personnel costs	€	10.000
Maintenance	€	67.000
Total OPEX	€	77.000

Results

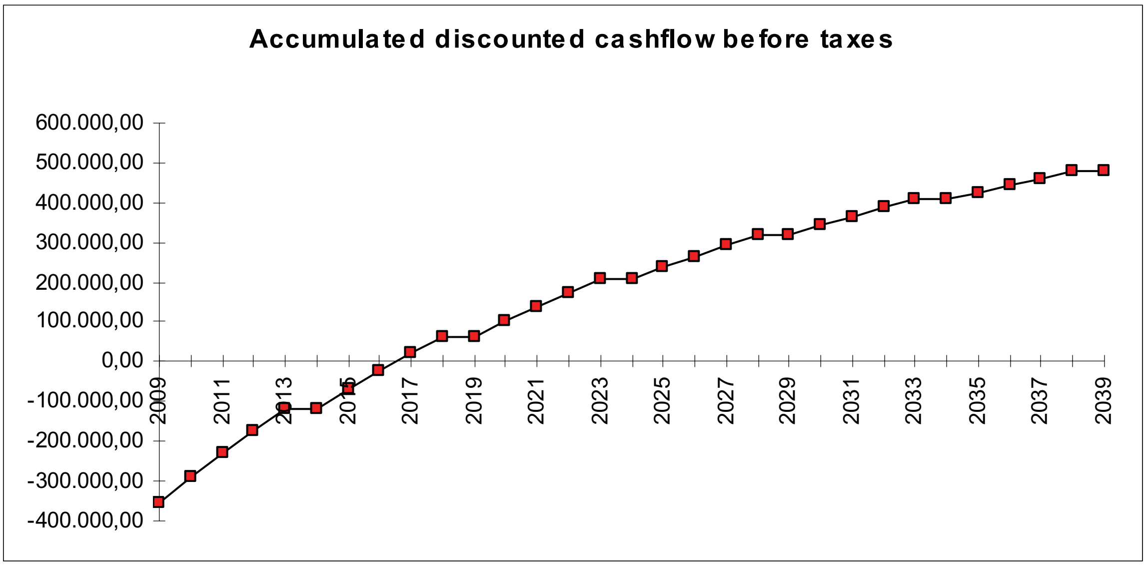
Economics after taxes	
Internal rate of return (IRR)	14,8%
Net present value (NPV)	316.501
Pay back period	7,5

Economics before taxes

Internal rate of return (IRR)	18,0%
Net present value (NPV)	478.680,2
Pay back period	7,5

Economics after taxes

Internal rate of return (IRR)	14,8%
Net present value (NPV)	316.501,2
Pay back period	7,5
VIR	0,89
Total Cash Surplus	1.334.439,46
Max. Exposure	-27.094,78



C400 (Energy Generation Krift)

Scenario 1

Microturbine 400 kW Project Evaluation – Economical Analyses

Base Assumptions	-	Fill in value
Parameter		Automatic calculation
Full load hours per year	H	8322
Full load hours per year	%	95
Electrical Output	kW	**400**
Electrical Output per year	MWh	3329
Perpetual growth electrical sales	%p.a.	2
Electricity retail price per MWh	€	69
Total Investment	€	422.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €	-		
Parameter	***Depreciation term (years)***		
Piping	33	€	20.000
Microturbine	33	€	332.000
Civil Work	33	€	20.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	**422.000**

OPEX €	-	
Parameter		
Gas Consumption	MWh	1,32
Gas costs per MWh	€/MWh	20,00
Gas costs	€	219.700,80
Personnel costs	€	10.000
Maintenance	€	67.000
Total OPEX	€	**296.701**

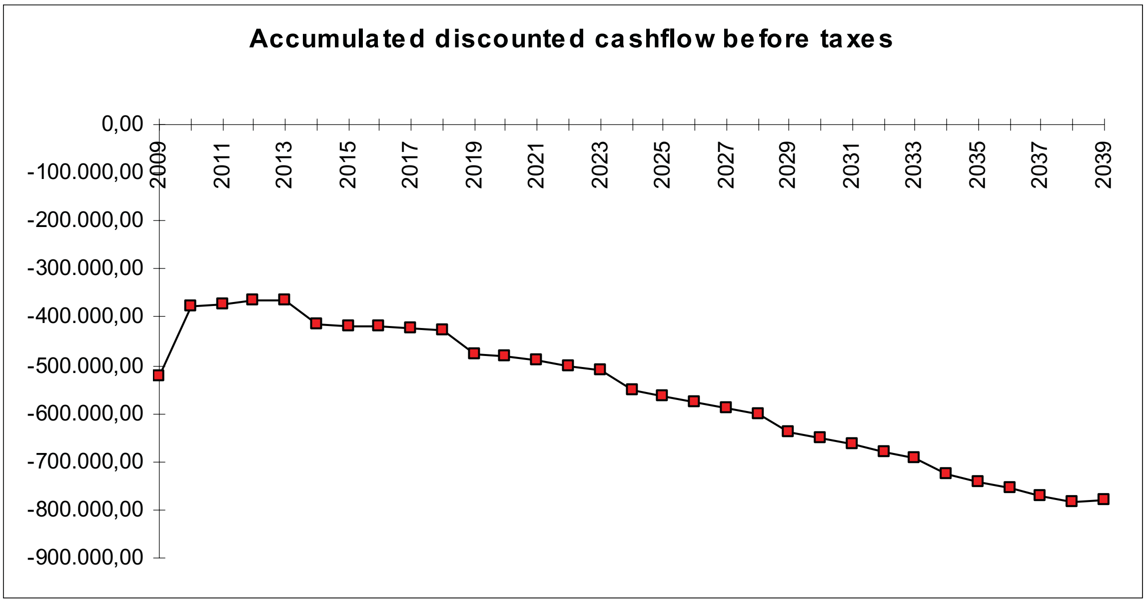
Results	-
Economics after taxes	
Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-790.799
Pay back period	0,0

Economics before taxes

Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-781.199,9
Pay back period	0,0

Economics after taxes

Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-790.799,4
Pay back period	0,0
VIR	-1,51
Total Cash Surplus	-1.832.955,68
Max. Exposure	-10.271,46



Scenario 2

Microturbine 400 kW Project Evaluation – Economical Analyses

Base Assumptions		Fill in value
Parameter		Automatic calculation
Full load hours per year	h	8322
Full load hours per year	%	95
Electrical Output	kW	400
Electrical Output per year	MWh	3329
Perpetual growth electrical sales	%p.a.	2
Electricity retail price per MWh	€	69
Total Investment	€	422.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Microturbine	33	€	332.000
Civil Work	33	€	20.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	422.000

OPEX €

Parameter		
Gas Consumption	MWh	1,32
Gas costs per MWh	€/MWh	15,00
Gas costs	€	164.775,60
Personnel costs	€	10.000
Maintenance	€	67.000
Total OPEX	€	241.776

Results

Economics after taxes

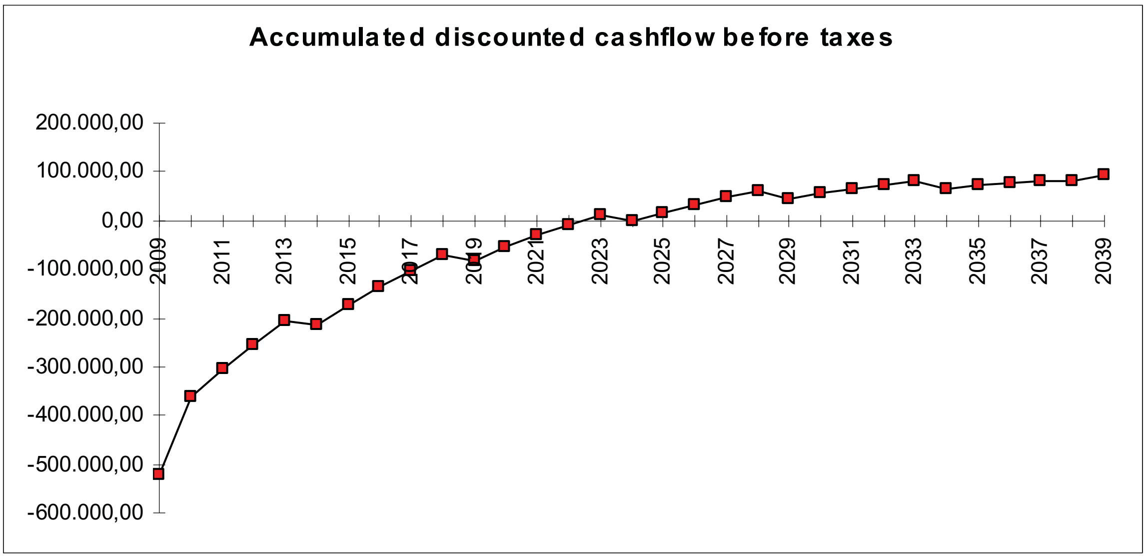
Internal rate of return (IRR)	7,0%
Net present value (NPV)	682
Pay back period	15,0

Economics before taxes

Internal rate of return (IRR)	9,7%
Net present value (NPV)	93.848,7
Pay back period	15,0

Economics after taxes

Internal rate of return (IRR)	7,0%
Net present value (NPV)	682,3
Pay back period	15,0
VIR	0,00
Total Cash Surplus	470.199,87
Max. Exposure	-15.080,16


Accumulated discounted cashflow before taxes
200.000,00
100.000,00
0,00
-100.000,00
-200.000,00
-300.000,00
-400.000,00
-500.000,00
-600.000,00
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039

C1000

Microturbine 1000 kW Project Evaluation – Economical Analyses

Base Assumptions

Fill in value

Parameter

Automatic calculation

Full load hours per year	h	8322
Full load hours per year	%	95
Electrical Output	kW	1000
Electrical Output per year	MWh	8322
Perpetual growth electricity sales	%p.a.	2
Electricity retail price per MWh	€	85
Total Investment	€	840.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Microturbine 1000 kW	33	€	720.000
Civil Work	33	€	50.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	840.000

OPEX €

Parameter

Gas consumption	MW/h	3,33
Gas costs per MWh	€/MWh	20,00
Gas costs	€	554.245,20
Personnel costs	€	1.000
Maintenance	€	167.000
Total OPEX	€	722.245

Results

Economics after taxes

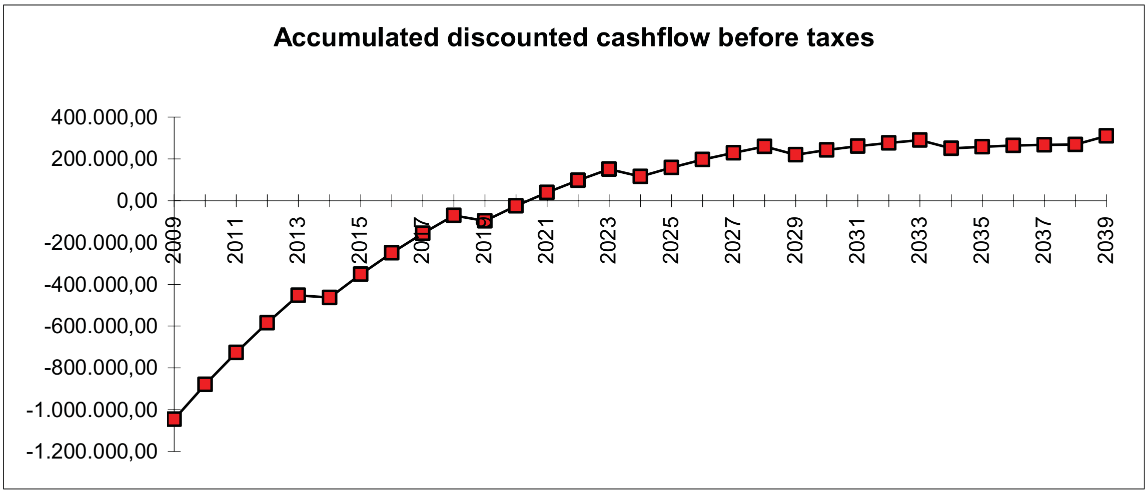
Internal rate of return (IRR)	8,4%
Net present value (NPV)	103.351
Pay back period	11,4

Economics before taxes

Internal rate of return (IRR)	11,0%
Net present value (NPV)	309.364,7
Pay back period	11,4

Economics after taxes

Internal rate of return (IRR)	8,4%
Net present value (NPV)	103.350,5
Pay back period	11,4
VIR	0,10
Total Cash Surplus	1.147.381,52
Max. Exposure	-37.969,39



Combination of Screw Type Expansion Machine and Microturbine

Scenario 1

Microturbine 200 kW +Expander Project Evaluation – Economical Analyses

Base Assumptions		Fill in value
Parameter		Automatic calculation
Full load hours per year	h	8322
Full load hours per year	%	95
Electrical Output	kW	200
Electrical Output per year	MWh	1664
Perpetual growth electrical sales	%p.a.	2
Electricity retail price per MWh	€	45
Total Investment	€	270.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €			
Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Microturbine	33	€	180.000
Civil Work	33	€	20.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	270.000

OPEX €		
Parameter		
Gas Consumption	MWh	0,66
Gas costs per MWh	€/MWh	0,00
Gas costs	€	0,00
Personnel costs	€	10.000
Maintenance	€	70.000
Total OPEX	€	80.000

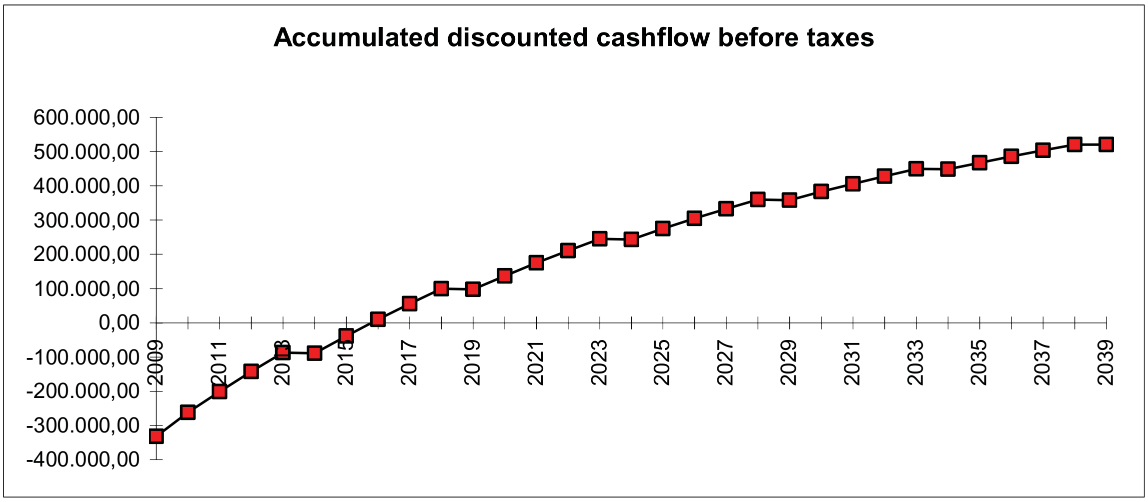
Results	
Economics after taxes	
Internal rate of return (IRR)	16,0%
Net present value (NPV)	346.616
Pay back period	6,8

Economics before taxes

Internal rate of return (IRR)	19,8%
Net present value (NPV)	520.468,6
Pay back period	6,8

Economics after taxes

Internal rate of return (IRR)	16,0%
Net present value (NPV)	346.615,7
Pay back period	6,8
VIR	1,04
Total Cash Surplus	1.379.716,68
Max. Exposure	-27.523,22



Scenario 2

Microturbine 200 kW +Expander Project Evaluation – Economical Analyses

Base Assumptions

Fill in value
Automatic calculation

Parameter		
Full load hours per year	h	8322
Full load hours per year	%	95
Electrical Output	kW	200
Electrical Output per year	MWh	1664
Perpetual growth electrical sales	%p.a.	2
Electricity retail price per MWh	€	45
Total Investment	€	270.000
Price increase for electricity (or Gas) bought	%p.a.	3
Price increase general costs	%p.a.	2

CAPEX €

Parameter	*Depreciation term (years)*		
Piping	33	€	20.000
Microturbine	33	€	180.000
Civil Work	33	€	20.000
Project Management	33	€	50.000
Total CAPEX € million	33	€	270.000

OPEX €

Parameter		
Gas Consumption	MWh	0,66
Gas costs per MWh	€/MWh	20,00
Gas costs	€	109.850,40
Personnel costs	€	10.000
Maintenance	€	70.000
Total OPEX	€	189.850

Results

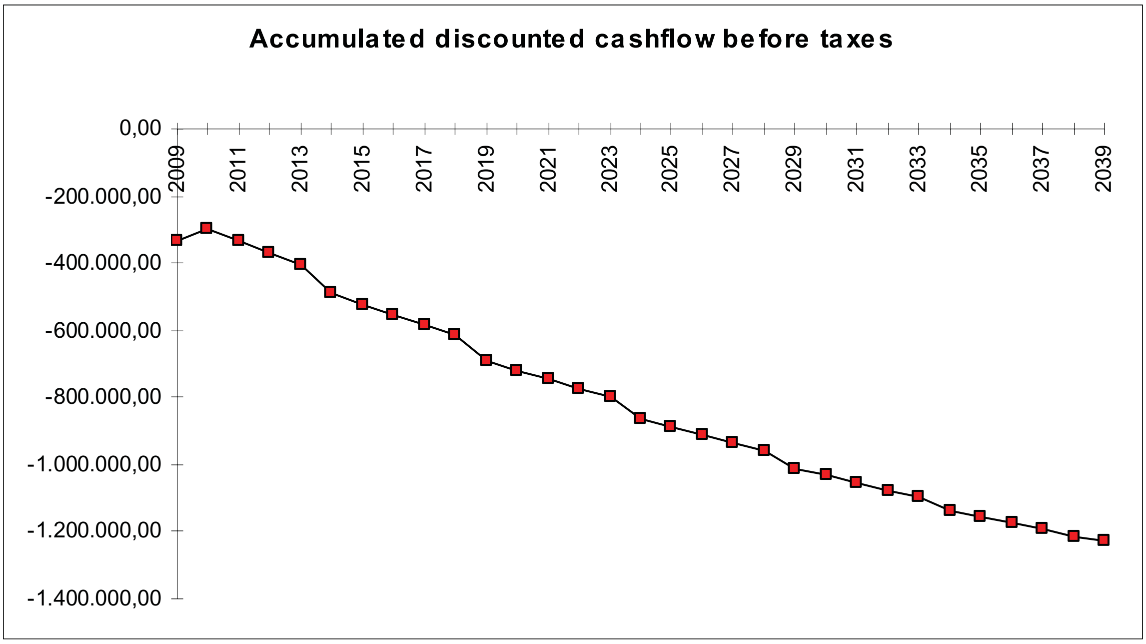
Economics after taxes	
Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-1.229.629
Pay back period	0,0

Economics before taxes

Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-1.229.628,7
Pay back period	0,0

Economics after taxes

Internal rate of return (IRR)	#DIV/0!
Net present value (NPV)	-1.229.628,7
Pay back period	0,0
VIR	-3,70
Total Cash Surplus	-3.074.930,27
Max. Exposure	0,00



Photovoltaic

Scenario 1

Photovoltaic Project Evaluation – Economical Analyses

Base Assumptions	-		Fill in value
Parameter			Automatic calculation
Full load hours per year		h	1034
Full load hours per year		%	12
Electrical Output		kW	295
Electrical Power Output per year		MWh	305
Perpetual growth electricity sales		%p.a.	2
Electricity retail price per MWh		€	300
Total Investment		€	1.525.000
Price increase for electricity (or Gas) bought		%p.a.	3
Price increase general costs		%p.a.	2

CAPEX €	-		
Parameter	*Depreciation term (years)*		
Additional Equipment	33	€	5.000
Photovoltaic Panels	33	€	1.400.000
Civil Work	33	€	20.000
Project Management	33	€	100.000
Total CAPEX € million	33	€	1.525.000

OPEX €	-		
Parameter			
Personnel costs		€	1.000
Maintenance		€	1.000
Total OPEX		€	2.000

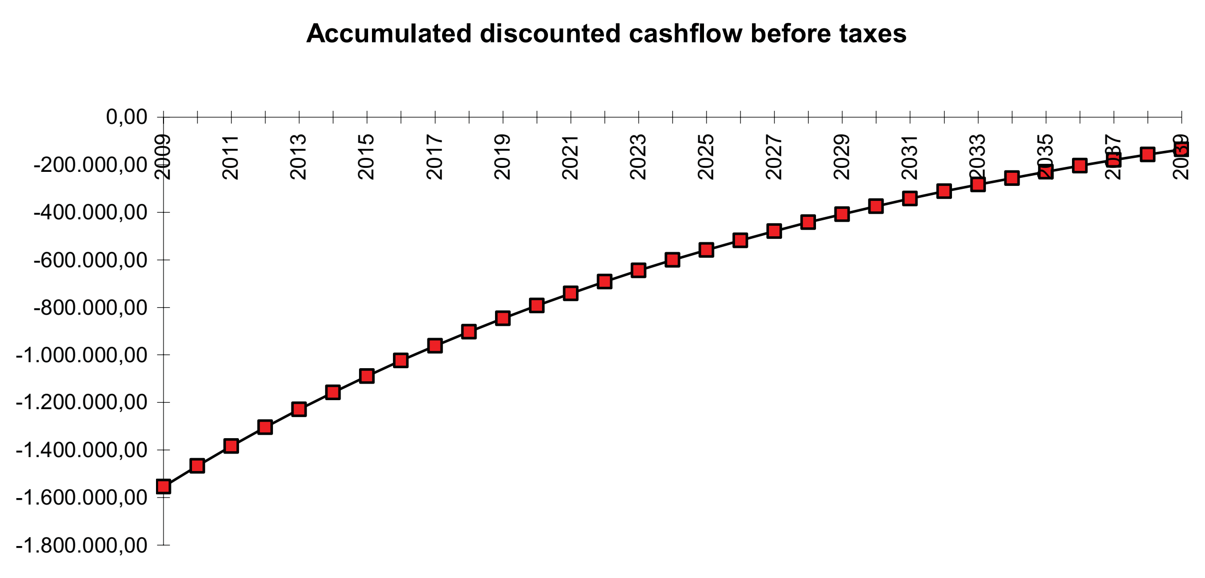
Results	-
Economics after taxes	
Internal rate of return (IRR)	4,9%
Net present value (NPV)	-340.609
Pay back period	0,0

Economics before taxes

Internal rate of return (IRR)	6,2%
Net present value (NPV)	-136.339,2
Pay back period	0,0

Economics after taxes

Internal rate of return (IRR)	4,9%
Net present value (NPV)	-340.608,8
Pay back period	0,0
VIR	-0,22
Total Cash Surplus	1.628.459,95
Max. Exposure	-29.193,86



Scenario 2

Photovoltaic Project Evaluation – Economical Analyses

Base Assumptions -

Fill in value

Automatic calculation

Parameter			
Full load hours per year		h	1034
Full load hours per year		%	12
Electrical Output		kW	295
Electrical Power Output per year		MWh	305
Perpetual growth electricity sales		%p.a.	2
Electricity retail price per MWh		€	450
Total Investment		€	1.525.000
Price increase for electricity (or Gas) bought		%p.a.	3
Price increase general costs		%p.a.	2

CAPEX € -

Parameter	*Depreciation term (years)*		
Additional Equipment	33	€	5.000
Photovoltaic Panels	33	€	1.400.000
Civil Work	33	€	20.000
Project Management	33	€	100.000
Total CAPEX € million	33	€	1.525.000

OPEX € -

Parameter			
Personnel costs		€	1.000
Maintenance		€	1.000
Total OPEX		€	2.000

Results -

Economics after taxes

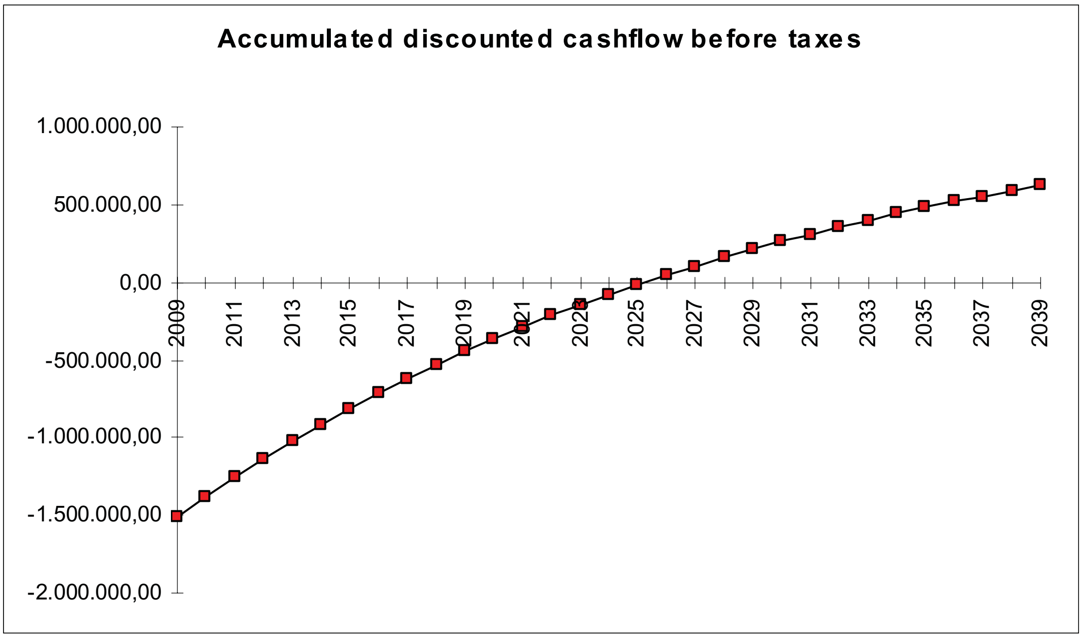
Internal rate of return (IRR)	8,3%
Net present value (NPV)	227.464
Pay back period	16,2

Economics before taxes

Internal rate of return (IRR)	10,4%
Net present value (NPV)	620.469,1
Pay back period	16,2

Economics after taxes

Internal rate of return (IRR)	8,3%
Net present value (NPV)	227.463,8
Pay back period	16,2
VIR	0,15
Total Cash Surplus	3.082.297,47
Max. Exposure	-49.906,93



References

---

[1] http://www.gie.eu.com/index.html (March 2009)

[2] http://rohoel.at (March 2009)

[3] UGS Haidach Projekt Dokumentation; Auftragsabwicklung Verfahrenstechnik; Ausrüstungsliste; 1.12442.01

[4] Notice by Dr. Wolfgang Hahn; Vienna; 22.11.2005

[5] UGS Haidach Projekt Dokumentation; Insturmentenluftsysteme PU 06; Ordner 230; Kaeser Wärmerückgewinnung

[6] http://www.kaeser.de/online-services/toolbox/waermerueckgewinnung/ (March 2009)

[7] http://www.kaeser.de/online-services/toolbox/waermerueckgewinnung/ (March 2009)

[8] Turboden Company Presentation; Doc Code 08A05204; p 2; March 2009

[9] Turboden Company Presentation; Doc Code 08Aß5204; p 6; March 2009

[10] Ingwald Obernberger et al; Desciption and evaluation of the new 1,000 kwel Organic Rankine Cycle process integrated in the biomass CHP plant in Lienz, Austria; Published in: Euroheat & Power; Volume, 10/2002

[11] http://mysolar.cat.com (March 2009)

[12] Correspondency with Gregory Giese, Infinity Turbines, April, 15th , 2009

[13] Prof. Dr. –Ing. Dieter Brüggemann; Infoblatt: Multitalent Organic Rankine Cycle; Uni Bayreuth;2006

[14] Prof. Dr. –Ing. Dieter Brüggemann; Infoblatt: Multitalent Organic Rankine Cycle; Uni Bayreuth;2006

[15] Silke Köhler; Geothermisch angetriebene Dampfkraftwerke; DissertationTU Berlin; Berlin; 2005

[16] The New York Times: Science Times; Steam system may improve power plants; New York; February 4th, 1986

[17] Dr. Manfred Renz; M+W Zander; The new Generation Kalina Cycle; Conference to the topic: Electricity Generation from Enhanced Geothermal Systems; Strasbourg; September, 24th 2006

[18] Corresponcy with Siemens Energy Sector; Albrecht Geissler; April, 16th, 2009

[19] Dokumentation Abwärmeprojekt RAG-Energie AG; Correspondency between RAG and Energie AG; March 9th, 2000

[20] Dokumentation Abwärmeprojekt RAG-Energie AG; Correspondency within RAG; April 22nd, 1999

[21] Corresponcy with Stefan Stich, Zeppelin Österreich GmbH; April, 23rd, 2009

[22] ; G. Beckmann; Paul Viktor Gili; Thermal Energy StorageUniversity of Michigan; 1984

[23] http://www.erdwaerme-zeitung.de/erdwaermeinfo/waermespeichertechnik/index.html (April 2009)

[24] http://www.erdwaerme-zeitung.de/erdwaermeinfo/waermespeichertechnik/index.html (April 2009

[25] Michael Geyer; Concrete Thermal Energy Storage; Deutsches Zentrum für Luft- und Raumfahrt; Presentation at Plataforma Solar de Almeria; Spain; 1999

[26] http://dls.com (March 2009)

[27] Prof. Dr. Ing. Kai Nielsen; Thermal Energy Storage-A State of Art; Report within the research program: Smart Energy Effiecient Buildings; p 8; Trondheim; 2003

[28] http://dlsc.com (March 2009)

[29] http://dlsc.com (March 2009)

[30] Prof. Dr. Ing. Kai Nielsen; Thermal Energy Storage-A State of Art; Report within the research program: Smart Energy Effiecient Buildings; p 6; Trondheim; 2003

[31] Dirk Mangold; Seasonal Heat Storage; Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems; Presentation at PREHEAT; Freiburg; 2007

[32] http://www.bine.info (May 2009)

[33] http://www.bine.info (May 2009)

[34] http://www.rubitherm.com (April 2009)

[35] Peter Schosig; Frauenhofer Institute for Solar Energy Systems; Presentation at the PREHEAT Symposium; 2007; Freiburg

[36] Herbert Zondag et al; Energy Research Center of the Netherlands; Presentatin at the PREHEAT Symposium, 2007, Freiburg

[37] Prof. Dr. Ing. Kai Nielsen; Thermal Energy Storage-A State of Art; Report within the research program: Smart Energy Effiecient Buildings; p 15; Trondheim; 2003

[38] http://www.innovations-report.de/html/berichte/maschinenbau/bericht-107497.html (April 2009)

[39] Dirk Mangold; Seasonal Heat Storage; Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems; Presentation at PREHEAT; Freiburg; 2007

[40] Capstone Turbine Corporation; MicroTurbine; User Manual; 400001-001; 2005

[41] Capstone Turbine Corporation; Information Brochure C1000 Megawatt Power Package; Chatsworth CA; 2008

[42] Capstone Turbine Corporation; Information Brochure C1000 Megawatt Power Package; Chatsworth CA; 2008

[43] Capstone Turbine Corporation; Information Brochure C30 MicroTurbine; Chatsworth CA; 2008

[44] Correspondency with Leopold Berger; Wels Strom GmbH; April, 14th 2009

[45] RMG Technical information brochure MTG; p.5; 2007

[46] General Electrics; Expander/Generator Budgetary Proposal 09-MD-0126-A-B Rev 0 prepared by Jakob Paul; 14.4.2009

[47] Atlas Copco Gas and Process Solutions: Brochure GT and T Engineered Centrifugal Compressors; p 12; 2009

[48] RMG Turboexpander MTG 160 Data Sheet; Kassel

[49] RMG Turboexpander MTG 550 Data Sheet; Kassel

[50] Dresdner Transferbrief; TU Dresden; Dresden; p. 4; 01/2007;

[51] Elektrische Mobilität in Österreich; Energiegespräche; EAEW; Technisches Museum Wien; 7. Oktober 2008

[52] http://www.prefa.at/prefalz-voltaik/ (April 2009)

[53] Sun 4 Energy Infobrochure; Photovoltaik Solarstrom; March 2009

[54] http://www.kvkcorporation.com (April 2009)

[55] Spilling Energie Systeme; Gas Expansion; Hamburg; 2009

[56] http://www.bios-bioenergy.at (April 2009)

---

[57] Dipl. Ing. Gert Hinsenkamp; Berechnung und Optimierung adiabater Schrauben Expansionsmaschinen als Grundlage für den Kennfeldvergleich mit Turbinen kleiner Wellenleistung; Chapter 3.1; P. 13; Karlsruhe 1993

[58] http://www.bios-bioenergy.at (April 2009)

[59] Innovative small-scale biomass CHP module based on a 730 kwel screw-type steam engine; BIOS Bioenergiesysteme GMBH; Hammerschmid Alfred et al

[60] http://fuelcellmarkets.com (April 2009)

[61] The White Paper; Fuel Cell Energy; Connecticut USA; 2009

[62] http://fuelcellsworks.com/Typesoffuelcells.html (April 2009)

[63] DFC 3000 Direct Fuel Cell Applicatins Guide; Fuel Cell Energy; Danbury CT USA; September 2008

[64] Correspondency with Ben Toby; Fuel Cell Energy; April, 28th; 2009

[65] Wels Strom Energie Systeme; Gerhard Berger; Correspondency April; 17th, 2009