Report of Working Committee 2

TRIENNIIUM 2003 – 2006

Chairperson Sergey Khan

Russia

UNDERGROUND STORAGE OF GAS

June 2006
Abstract

This report is a compilation of three reports issued by the 3 study groups of Working Committee 2 on Underground Storage prepared during the 2003 – 2006 Triennium of the International Gas Union. The Topics covered are a database on underground gas storage (UGS) worldwide and trends in the field of technology efficiency, safety and environmental aspects in UGS operations.

Key words: Underground Gas Storage, UGS, database, operations, safety, environment, efficiency

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Executive Summary, WOC2 within the 2003-2006 triennium

WOC 2 has 48 members (24 delegates, 24 alternates and one associate). The spread over the continents of the Committee is Africa (3), Asia (12), Australia (1), Europe (30), South America (1), North America (1).

WOC2 Chairman – Dr. Sergey Khan (Gazprom, Russia)
WOC2 Vice-Chairman - Dr. Vladimir Onderka (Czech Republic)
Secretary – Elena Sushilina (Gazprom, Russia)

Experts from Russia, Germany, France, Denmark, USA, Italy, Czech Republic, Slovak Republic, Romania, Netherlands, Sweden, Japan, Ukraine, Iran, and Austria took an active part in WOC2 activities.

During the Triennium WOC2 had 7 meetings:

1) 30 September-2 October 2003 in Saint-Petersburg, Russia
2) 1-3 March 2004 in Milan, Italy
3) 16-18 September 2004 in Copenhagen, Denmark
4) 12-14 April 2005 in Moscow, Russia
5) 5-6 October 2005 in Prague, Czech Republic
6) 13-14 January 2006 in Paris, France
7) 20 March 2006 in Vienna, Austria

During the WGC2006 in Amsterdam WOC2 organized two Expert forums and two Committee Sessions on Tuesday 6 June 2006, Wednesday 7 June 2006 and Thursday 8 June 2006.

The first WOC2 meeting held in St. Petersburg brought forward an idea to combine sessions with the workshops on UGS main topics.

So during 2003-2006, WOC2 meetings ran in parallel with 4 workshops:

1. in Milan on UGS deliverability maintenance, with 9 reports from Italy, the USA, Russia, Germany and France presented
2. in Copenhagen with WOC1 and PC A on Greenhouse gases
3. in Moscow jointly with WOC3 on Security of gas supply – interaction between pipelines and UGS, with 6 reports presented from Netherlands, UK, Russia, Germany and the USA.
4. in Prague on Application of Numerical methods in Storage of Natural gas and Reservoir Engineering, 8 reports from Italy, Check Republic, Russia, Austria, South Korea and Spain presented

After each workshop delegates and members received full reports CD versions.

Jointly with WOC2 meetings technical tours were organized to the following UGS facilities:

1. Nevskoye (Russia)
2. Sergnano UGS (Italy)
3. LT. Torup UGS (Denmark)
4. Uvyazovskoye UGS (Russia)
5. Dolni-Dunajovice (Check Republic)
At the technical tours the WOC 2 members could get deep insight in these UGS geological and technical parameters and new technologies applied.

WOC2 included three Study groups:
1. SG 2.1 “Basic activities” headed by Joachim Wallbrecht
   The Basic UGS Activity Study of Study Group 2.1 should be carried on as well in the following trienniums. Because of workload, respectively availability of contributors, support of the study is insufficient. Other ways of working should be considered in the following Triennium, e.g. by cooperation with consultants. Further improvements are proposed for the oncoming Triennium:
   - Continuous completion of database, especially incorporating “new” storage countries and planned projects
   - Incorporation of additional data: split between oil-/gas fields, company shares in individual storage facilities
   - Participation of additional countries and active participants in the study work for data collection and derivation of trends
   - Development of a standard data bank platform on the IGU website
   - Incorporation of the pipeline system in the geo-referenced visualisation
   - Extended incorporation of status and trends of the storage industry on a country basis
   - Development of a more detailed prognosis on storage demand in corporation with institutes/consulting companies incorporating all relevant elements related to gas demand and gas supply variables (LNG-supplies, load, sources of supply and flexibility)
   - Demonstration of best practice operation by examples.

2. SG 2.2 “UGS: Achievements and trends in the field of Safety, Technical efficiency” headed by Dr. Sergey Khan and Dr. Alexander Grigoriev as a sub-leader
   The results of the study show that in general storage industry is a part of the oil and gas industry and uses the same technologies. For the past of 5-6 years the total picture with technologies in underground storage is kept stable, however there are some changes in separate directions.
   From answers follows, that the actual problem of increase in working volume storage gas in a greater degree is solved due to creation of new objects, rather than expansions existing. In spite of the fact that expansion is prove to be more economy. It is connected by that now on many operating objects the opportunity of expansion are close to a limit.
   Problems of safety still take the important place in activity of the companies.

   First place among techniques used to analyze the performance of storage all times occupied by cost target setting and monitoring. The most significant drivers for improvement are costs, legal requirements and market considerations.
   The most popular new techniques in gas storage remain:
   - CO₂ sequestration
   - Storage in lined Hard Rock Caverns
   - Storage in abandoned Mines
   All indicated techniques show the rating growth in time (average 50%), but relatively not many respondents plan to use new techniques now.

   Among the methods used for definition of characteristics of layers still are most popular 3-D seismic and re-interpretation, at falling a role of 2-D seismic. However 4-D seismic, despite of significant prospects now is used extremely seldom.
There is no defined tendency to increasing of maximal allowable storage pressure gradient in perspective. Obviously the upper limit of this parameter is already reached. Only few respondents mark slight growth of this parameter in future.

Similarly to oil and gas production fields, gas storage management requires an accurate reservoir modelling in order to monitor the gas bubble extension and maximize the potential deliverability of the UGS. According to the questionnaire replies, these types of simulation/model are most common.

- Numerical reservoir simulation
- Integrated geological modelling in reservoir simulation
- Integrated surface and subsurface simulation/model

The most important monitoring techniques used to improve geological, technical, operational safety are:

- Real time well performance monitoring (flow, pressure)
- Gas quality monitoring
- Automated gas quality monitoring
- The most dynamically developing perspective technologies are:
- Permanent down hole gauges
- Remote control
- Real time sand production monitoring

UGS operation especially aquifer UGS, is accompanied with partial gas losses which are defined by gas overflows in overlying adjournment and gas losses in the storage volume. Reduction of pressure losses remains the most significant measure to improve the UGS performance. The risk of gas spilling needs to be modelled and reservoir fluid movement and material balance need to be monitored closely. Simulation need to be comprehensive this has fostered the development of real-time instrumentation.

The majority of UGS wells are traditional vertical wells, which in heterogeneous collectors are combined with slanted ones. Horizontal wells, which give additional deliverability and reduce surface environmental impact, used many fewer. The increasing popularity occupy, larger well bores Re-entry (including horizontal leg extensions), extended reach wells. Some potential has Recompletion (larger size tubulars). The most dynamic growth in time marked by coiled tubing drilling.

There are almost no any changes in corrosion management techniques and gas treatment and gas quality management during last time.

The wide spectrum of technologies is used for good UGS safety:

- Safety studies and audits
- Preventive technical installations
- Subsurface safety valves
- Diagnosis of critical operations
- Enhanced monitoring
- Best knowledge of the geological situation
- Periodical gas inventory and control of cap rock tightness
- Preventive maintains
- Accidence analyses

The report is likely to become a standard information tool for specialists, scientists and students too.
3. SG 2.3 “UGS: Achievements and trends in the field of environmental impact” headed by Dr. Sergey Khan and Dr. Gretta Akopova as a sub-leader.

The carried out analysis of legislative base, normative materials and technical decisions can be named comprehensive. An obtained result can be considered representative both by the number of respondents taking part in study and by geographical coverage of the world’s countries operating UGS in gas industry.

- It has allowed gaining some insight of legal and normative regulation, environmental protection activity in underground gas storage facilities of different countries and companies. As a result of the analysis the world community received valuable operating at UGS;
- on existing methods and means for control of pollutant emissions in combustion products;
- on real and/or potential ecological efficiency of technological decisions undertaken at UGS in different periods of time (3-5 years ago, at present and in the near future) etc.

The analysis data shows the similarity of approach to environmental protection in different countries and relative comparability of attitude to development and application of technologies and technical means for enhancement of UGS environmental stability.

The main inference is a system of present-day trends and mechanisms for lowering the man-caused impact on the environment developed on the basis of the survey results. Summing up the world practice in the UGS operation, we can give the key technologies (methods) for enhancement of UGS environmental stability.

This systematized technologies set or separate technologies can successfully be applied on UGS in the further prospect. Technologies allow supporting the status of underground gas storages as the most reliable in the world.

The companies follow to the specified technical and environmental protection norms during all UGS life cycle, in spite of their distinctions in the different countries. In future, the companies will follow new regulating positions even at possible toughening normative base, keeping the status of high technical reliability and ecological stability.
23RD WORLD GAS CONFERENCE AMSTERDAM 2006

5 – 9 JUNE 2006

AMSTERDAM, THE NETHERLANDS

INTERNATIONAL GAS UNION

TRIENNium 2003 – 2006

Working Committee 2

– Underground Gas Storage –

Report
Study Group 2.1 - Basic UGS Activities
Study Group Chairman

Joachim Wallbrecht

Germany

ABSTRACT

This report includes a summary of the work undertaken in the Basic UGS Activity Study Group of WOC 2-UGS - and is part of the WGC report.

The report includes the following sections:

- Underground Gas Storage World Data Bank
- Underground Gas Storage World Map
- UGS Glossary
- Trends in the UGS business.

The major part of the study is built up out of the UGS World Data Bank and the UGS World Map, which allows for a geo-referenced visualisation and fast derivation of UGS data in the world.

The UGS Glossary of the relevant technical storage terms is included.

The report describes Trends in the UGS business with respect to general, legal, environmental and technological issues and trends from a national perspective.
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Introduction

The Basic Activity Study has been established for the first time as part of the IGU Triennium work programme 2000 - 2003. The Study Group 2.1 -Basic UGS Activities- continued this work within the Triennium 2003 – 2006, developing a new improved study. Results are to be presented during the World Gas Conference 2006 in Amsterdam.

Study Group Members

The study has been developed by the WOC 2 Basic UGS Activities Study Group 2.1 consisting of members of 12 countries. The study group included members from Austria, Croatia, Czech Republic, France, Germany, Japan, The Netherlands, Romania, Russia, Slovakia, Spain and USA. Germany was the study group leader. The members are listed in attachment 1.

Objectives and Scope

The objectives of the Basic UGS Activities Study were:

- Statistical survey of existing/planned Underground Gas Storages (UGS) in the world
- Development/update of a database of underground gas storage facilities in the different regions of the world
- Development/update of a UGS World Map
- Development of the UGS Glossary of relevant technical UGS terms
- Summarizing general trends in the storage business.

The study covers the following types of storage facilities in:

Porous rocks
- storage in aquifers
- storage in gas fields
- storage in oil fields

Caverns
- storage in salt caverns
- storage in rock caverns (including lined rock caverns)
- storage in abandoned mines.
Way of Working

The report has been developed mainly from the feedback of a questionnaire, which was sent out to gas associations and storage companies.

The questionnaire was split up into the following parts:

- Data questionnaire for existing UGS in operation and for planned UGS asking for relevant data from individual storage facilities/projects
- General questionnaire asking for trends in the storage business.

Data have been processed and analysed and additional study work, as e.g. the UGS Glossary, was carried out.

Structure of Basic Activity Study

Elements of the Basic UGS Activities Study are:

I. UGS World Data Bank - UGS in operation and planned (status: 2004/05)
II. UGS World Map - geo-referenced presentation of UGS data in metric units and in English units
III. UGS Glossary - Glossary of relevant technical UGS terms
IV. Study Report on Trends in the UGS business
V. Attachments, incl. relevant terms, units and definitions

The database and its visualisation comprise the major part of the study.

The world wide database on UGS facilities, including data about individual storage facilities in the world, and the graphical presentation of these data has been improved further.

The geo-referenced presentation within the UGS World Map is available in metric and for the first time English units, including UGS data from the USA and Canada.

A glossary of relevant technical UGS terms has been developed and trends in the UGS business are discussed in the report in general and from a perspective by nations.

Underground Gas Storage in the World

- UGS World Data Bank
- UGS World Map

Storage facility data were received from companies and gas associations about the following 23 countries in reply to the data request/questionnaire: Armenia, Austria, Canada, Belgium, Croatia, Czech Republic, Denmark, France, Germany, Hungary, Italy, Japan, Latvia, the Netherlands, Poland, Romania, Russia, Slovak Republic,
Spain, Sweden, Ukraine, United Kingdom, USA. The American Gas Association (AGA) gave excellent support, thus resulting in profound data about the important American UGS industry.

In total present data from 584 underground gas storage facilities covering a working gas volume of some $319 \times 10^9$ m$^3$ (incl. long-term strategic reserves) were received. Those data received directly are equivalent to some 96% of the known total working gas volume of $333 \times 10^9$ in operation in the world.

In addition to the data received directly, data from previous studies (Study on UGS in Europe and Central Asia, UN ECE 1999/status: 1996, Basic Activity Study 2003) were available and additional publications were incorporated in the database.

Thus in total an excellent database with the status and actuality of year 2004/2005 has been developed. Multiple pay horizons of a storage facility are reported separately, but are not added up necessarily to the installed max. capacities. Based on the applied definitions, reported storage capacities are related to the installed max. capacities the surface facilities allow for (see Glossary).

The working gas volume capacities of the countries with known underground gas storage facilities in operation, at reference year 2004/5, derived from company information received and from published data and national information, are enclosed in the following table.

<table>
<thead>
<tr>
<th>Nation</th>
<th>No. of UGS Facilities</th>
<th>Total Installed Working Gas Volume of UGS Facilities $(10^6 \text{ m}^3)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>385</td>
<td>100.846</td>
</tr>
<tr>
<td>Russia *</td>
<td>22</td>
<td>93.533</td>
</tr>
<tr>
<td>Ukraine</td>
<td>13</td>
<td>31.880</td>
</tr>
<tr>
<td>Germany</td>
<td>42</td>
<td>19.179</td>
</tr>
<tr>
<td>Italy</td>
<td>10</td>
<td>17.415</td>
</tr>
<tr>
<td>Canada</td>
<td>48</td>
<td>14.820</td>
</tr>
<tr>
<td>France</td>
<td>15</td>
<td>11.643</td>
</tr>
<tr>
<td>Netherlands</td>
<td>3</td>
<td>5.000</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>3</td>
<td>4.600</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>3</td>
<td>4.203</td>
</tr>
<tr>
<td>Hungary</td>
<td>5</td>
<td>3.610</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>4</td>
<td>3.267</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>8</td>
<td>2.891</td>
</tr>
<tr>
<td>Austria</td>
<td>4</td>
<td>2.829</td>
</tr>
<tr>
<td>Latvia</td>
<td>1</td>
<td>2.300</td>
</tr>
<tr>
<td>Romania</td>
<td>5</td>
<td>2.300</td>
</tr>
<tr>
<td>Slovakia</td>
<td>2</td>
<td>2.199</td>
</tr>
<tr>
<td>Spain</td>
<td>2</td>
<td>1.981</td>
</tr>
<tr>
<td>Poland</td>
<td>6</td>
<td>1.356</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>2</td>
<td>934</td>
</tr>
<tr>
<td>Australia</td>
<td>4</td>
<td>820</td>
</tr>
<tr>
<td>Denmark</td>
<td>2</td>
<td>750</td>
</tr>
<tr>
<td>China</td>
<td>1</td>
<td>600</td>
</tr>
<tr>
<td>Croatia</td>
<td>1</td>
<td>558</td>
</tr>
<tr>
<td>Belgium</td>
<td>1</td>
<td>550</td>
</tr>
<tr>
<td>Japan</td>
<td>4</td>
<td>542</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>1</td>
<td>206</td>
</tr>
<tr>
<td>Ireland</td>
<td>1</td>
<td>210</td>
</tr>
<tr>
<td>Argentina</td>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td>Armenia</td>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>Sweden</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>606</strong></td>
<td><strong>333.235</strong></td>
</tr>
</tbody>
</table>

* including long-term strategic reserves

These data are visualized in the following graph.
Clearly the United States of America are operating the highest capacities, followed by Russia, Ukraine and Germany. It has to be noted, that the Russian working gas volume includes long-term strategic reserves.

The countries of interest for UGS were grouped into the following four regions: North America, South America, Asia, East Europe, Middle East and West Europe:

The data are included, apart from some adjustments, +/- as received. The database is still incomplete for some regions. The study does not claim to be complete. Applied units are defined in attachment 5.

Despite clear definitions, some operators did not deliver data consistent with definitions.

The data contained in the UGS World Data Bank differ from cumulative storage capacities of individual countries reported on a national basis. Differences exist between the individual summation of technical storage capacity data about UGS in operation compared to the reported national storage capacity. Thus differences may be due to different reference years, differing use of capacities (installed vs. utilized or available working gas volume) and included long-term reserves as e.g. in Russia, incl. 30 $10^9$ m³ of long-term strategic reserves.
As the Basic Activity will commence in the next trienniums, the existing database will be broadened and updated successively.

Based on the country based data collected in the Basic UGS Activities Study an installed working gas volume of some $333 \times 10^9$ m³ is operated in about 610 storage facilities all over in the world. A withdrawal rate of some $205,000 \times 10^3$ m³/h is provided by some 23,000 storage wells.

A summary of installed capacities and planned capacities in existing and in green field storage projects is given by regions in attachment 2.

The working gas volume of UGS facilities in operation of $333 \times 10^9$ m³ divided by regions is presented in the following chart.

![UGS in the World Working Gas Volume Distribution by regions](chart)

It is obvious, that the major part of the working gas volume is installed in East Europe and in America.

It is evident from the following chart that the greater part of the working gas volume is installed in UGS facilities in former oil/gas fields (82 %), followed by storage facilities in aquifer structures and caverns. Abandoned mines (0,02 %) and rock caverns (0,02 %) are of no great relevance on a world scale.
This distribution of storage types differs from region to region; in West Europe for example more storage capacities are available from aquifers (22%) and caverns (13%) relative to UGS in oil/gas fields (66%).

The ratio of national working gas volume vs. No of UGS facilities has been analysed. As an average, about 500 $10^6$ m$^3$ of working gas volume/UGS facility can be derived just based on the real installed working gas volume without long-term strategic reserves. The specific WGV by nations ($10^6$ m$^3$ WGV/No of UGS) and No of UGS by nations are presented in the following graph. Russia offers specifically the highest ratio, even when excl. long-term strategic reserves.
The database includes, in addition to the UGS in operation, planned UGS facilities and facilities under construction.

The database has to be completed successively in the future, especially on the planned UGS projects which have a more volatile character. As many project plans are coming up and are going it is always difficult to present the recent status.

The detailed information, at reference year 2004/05, is available in the UGS World Data Bank, which is Access based, [WOC 2 UGS database 2006.mdb](#). The data are made available for information purposes and for any further detailed analysis as Access and EXCEL-reports in metric and for the first time in English units.
For the first time, North American storage data are presented in this geo-referenced way in the UGS World Map. Data are accessible just by clicking on the locations on the map as follows.

Key data of the UGS facilities in the world, as in the following graph, are available geo-referenced in the UGS World Map via links on the front page of the report.

**UGS Glossary**

As there are too many different storage related definitions available, mainly E&P and marketing related, a consolidated glossary of the relevant terminology related to the storage of natural gas in underground gas storage facilities was developed. As the technology is similar, the terminology can be
applied for the storage of hydrogen, CO₂, O₂ and other gases. The glossary covers the following terms:

The glossary is included in attachment 4. The enclosed glossary was translated to glossaries in several other languages available via links on the frontpage.

**Trends in the UGS Business**

Based on 16 replies from 9 countries limited feedback on the general questionnaire request was received. Therefore additional sources were utilized to derive some trends in the storage industry business. In general the database was insufficient and does not allow for a comprehensive analysis.

**8.1 Storage capacity and demand trends**

From the data sources the historical development of the installed working gas capacity by regions was derived as presented in the following graph:
The data compilation was carried out very detailed, identifying some data differences to previous years.

From 2000 onwards only gradual increases in storage capacities can be observed.

Contributions received from different countries indicate increasing storage demand (see chapter 9. Trends in the UGS business from a national perspective).

Company comments received in reply to the questionnaire are indicating increasing storage demand with increasing gas consumption. Reported increases of storage demand differ from country to country between 4 % to 18% till 2010 and 30% till 2020. Some companies comment, that sufficient storage capacities are installed for the time being in some countries.

The load factor of gas supplies is expected to rise in Europe, due to higher import volumes compared to a declining indigenous production. Increasing utilization and increasing storage demand may result in increasing capacities, assuming a reliable economic and political environment.

UGS facilities are the essential tools to match supply and demand on a peak and a seasonal basis. The importance for the storage service will grow further as long-distance base-load supply continues to rise. New storage facilities will be developed linked to new big pipeline projects as in China (West-East pipeline), North East Europe.

Due to the ongoing liberalisation process of the gas market the importance of storage capacity in the gas chain is recognised and new products can be made available from underground gas storage facilities. UGS in a liberalised market environment should, in addition to conventional tasks, be used as a trading tool to enhance the value of gas. New business opportunities for UGS are related to the development of gas hubs in Europe. The liberalised gas market in West Europe can be looked at as well as an opportunity for the storage industry by offering in addition to the “old” tasks new storage products as: parking, balancing, loaning and wheeling linked to hubs. In general higher deliverability will be requested. Withdrawal capacity consequently has to be increased.

Discussions about security of supply may trigger additional storage demand.
New developments are underway in the United Kingdom, the Netherlands, Germany, China, Russian Federation, Spain, Turkey and Iran. New projects may come up in Brazil, India, China, etc., especially as two-thirds of the increase in global energy demand will come from developing countries.

As an example for new developments, the United Kingdom is discussed in the following. UK has very limited gas storage facilities, providing less than 4 per cent of annual consumption, compared to normally 18-25% in gas storage developed nations, thus showing the need for more storage developments.

The following table is indicating projects in the United Kingdom currently constructed, respectively in the planning phase. Including the project Saltfleetby 10 new projects are under investigation.

Assuming all the projects are developed as planned, UK working gas volume will more than double till 2010.

Every current forecast of global energy consumption for the next decades concludes that the use of gas will substantially increase.

The World Energy Outlook 2004 of the International Energy Agency (IEA) is stating that the world primary energy demand in their Reference Scenario is projected to expand by almost 60% between 2002 and 2030. The projected annual rate of demand growth, at 1.7% is slower than the average of the past three decades, which was 2%. Among the fossil fuels, demand for natural gas will grow most rapidly. The worldwide consumption of natural gas will almost double by 2030.

According to the International Energy Outlook 2005 of the Energy Information Administration (EIA), natural gas is projected to be the fastest growing primary energy source worldwide, maintaining average growth of 2.3% annually over the 2002 to 2025 period. Total world natural gas consumption is projected to rise according to EIA from 2002 by some 40% till 2015 and 69% till 2025.

Independent from variations in different prognosis, the gas demand will grow and increasing gas consumption will consequently result in a higher storage demand. In addition higher load factors and changes in the demand structure can be expected in mature gas countries, due to higher import volumes compared to a declining indigenous production. Although the demand for storage will grow in the future, the exact timing of that demand growth remains uncertain.

Some reports are indicating a shortage in seasonal storage in Europe.

A comprehensive analysis of the expected storage demand is strongly recommended. Variables has to be included on a national basis as: total primary energy consumption, energy mix, energy efficiency, alternative flexibility energy sources, gas demand by segments (e.g.: gas power plant), population, demand/supply load structure (swing), gas utilisation (e.g.:air condition), import dependency, origin/distance of gas sources, change in the cost of gas and alternatives, interruptible supply contracts, social/political implications, security of supply requirements.

Further details will be presented in the course of the WOC 2 presentations during the WGC 2006.

8.2 General, legal, technological issues

Based on the replies from 16 companies, which were received as feedback to the questionnaire sent out, the following trends were derived with respect to general, legal and technical topics. Further comments are given in chapter 9 - Trends in the UGS business from a national perspective.
**General issues**

Based on the feedback received the following remarks about Third Party Access (TPA) are mainly related to Europe.

**Third Party Access (TPA)** and the liberalisation of the European gas market, looked out for in the Madrid Process by all parties involved, have the biggest impact on the underground gas storage industry. It is essential to secure economic operation of UGS in the liberalised gas market environment.

Despite there was already competition in the storage industry, a further increase of storage capacity demand/requests and competition can be observed and UGS facilities will be the essential tools to match supply and demand on a peak and a seasonal basis.

The role of old storage companies will change in a liberalised market. Security of supply, which may be provided by UGS, is of vital importance in some countries. Nowadays storage system operators (SSO) normally do not have to fulfil security of supply provisions anymore, as this is the task of merchants, but they have to provide availability of storage capacities. There are some exemptions in Spain, The Netherlands and Italy.

The way to fulfil TPA to storage capacities differs from country to country in Europe, mainly by the selected option for access - negotiated or regulated access to storage capacities - and different conditions.

Due to all requirements of the Gas Directive and the Guidelines for Good Practice for Storage System Operators (GGPSSO) corresponding modifications of the storage facilities, systems and conditions have to be carried out. Increasing efforts to fulfil the requirements and inquiries were reported. More efforts due to regulation is expected.

As the consequences of the liberalisation process for the future of the storage business is not totally clear, some storage system operators (SSO) indicated a certain reluctance in the development of new projects. Uncertainties are especially related to potential insufficient regulated tariffs and non-committed storage capacities, due to a lack of long term contracts.

Essential concerns were raised concerning the question, whether the liberalisation process allows for sufficient incentives for new developments and whether the operation of existing UGS can be carried out economically in the future.

In case of mandatory regulated TPA to UGS, together with low uneconomic storage tariffs, a major impact on the UGS industry is expected. New storage capacities will not be developed, shut-in of existing UGS facilities is possible, or withdrawal from the storage business seems to be a realistic option in the future for some operators.

The expected increasing long-term storage demand cannot be fulfilled under these circumstances. As for new storage developments longer lead times will be required in the future, the covering of storage demand will be aggravated.

Future environmental requirements and revamping requirements for existing “old” UGS-facilities is expected to increase operating costs.

Cost cutting initiatives and efficiency improvements are strongly recommended anyhow and necessary in preparation for a more competitive market.

Assuming an economic development environment, adjustments of the existing facilities to new demand requirements offer good business opportunities in the future. This is mainly related to new storage products compared to the historical use of UGS. For example, peak capacities are becoming more important and cycling capacity can be improved by the development of additional injection capacities. The use of an UGS as marketing tool (wheeling, parking, etc.) in connection with a hub seems to be a useful complement.
Asides new products in a liberalised market environment, new projects may offer new business opportunities. But some countries see, related to their local situation, no new opportunities for gas storage developments, as limited possibilities exist in their country. The required storage service may be carried instead in neighbouring countries.

As new business opportunity the use of caverns in combination with wind energy plants is proposed. Compressed Air Energy Storage (CAES) can balance power demand and fluctuating wind power production (s. SMRI, Crotogino et al Oct. 2004, Berlin and following graph).

Further new alternative opportunities for the UGS industry asides the storage of natural gas are limited. The topic of CO₂ storage is under intensive investigation in several countries and is looked at as a promising opportunity midterm. The storage of hydrogen is considered to be a long-term option. Helium storage has only a limited application.

In general SSO’s don’t encounter severe problems concerning legal and environmental aspects. Some SSO’s see increasing environmental protection activities and legal requirements, probably related to some projects. Approval procedures should be streamlined.

Concerning lead times for new storage project developments no clear trend could be observed. About half of all comments indicated no increase in lead times. On the other hand increasing lead times were reported in some countries/companies related to some projects due to the specific project, respectively to the public/local authorities or due to administrative permits as in Spain.

Consequences from CO₂-emissions and the related emission rights may have some impact; in general it is too early to tell.

Further developments of storage capacities is planned in some countries but cannot carried out so far without strengthening the pipeline system (Japan).

Concerns were raised about the level of qualification and expertise of staff in the future which is required for oncoming tasks and to maintain core competences

Legal issues

Third Party Access is the most relevant topic for the storage industry in Europe for the time being. According to the survey, the transformation of TPA to storage is quite advanced in Europe up to the complete access to storage capacities for third parties in many countries.

The basis for the liberalisation of the European gas market was laid by the European Gas Directive in June 2003. Beyond the transformation of the Gas Directive into national law, companies have to transpose the related requirements. This requires as well re-organisation of company structures to some extent because of unbundling requirements.

The Gas Directive allows for regulated or negotiated access TPA, to be opted by the nations dependent on the status of competition.
Since April 2005 the European “Guidelines for Good Practice for Storage System Operators” (GGPSSO), approved by the Madrid Joint Working Group, are in force. Those guidelines are released by the European Regulatory Group for Electricity and Gas (ERGEG) as recommendations. In principle the compliance of the guidelines is voluntary, but the guidelines are expected to be followed by storage system operators (SSO). European regulators monitor the process of liberalisation.

Concerning the storage related aspects of the Gas Directive and the GGPSSO the following elements are essential:

- access to storage capacities for third parties granted on a non-discriminatory, transparent basis
- either regulated or negotiated Third Party Access to storage capacities
- SSO’s have to operate storage facilities based on economic conditions in a safe, reliable and efficient way
- relevant data of UGS facilities and services have to be published as e.g.: installed, booked and available capacities, utilization, conditions, etc.
- confidentiality has to be guaranteed
- SSO’s shall offer bundled storage services and unbundled storage services
- storage services shall be offered with the duration of one year and longer (long term contracts) and short term contracts on a daily respectively monthly basis. These services shall be offered as firm and interruptible capacities
- rules for congestion management
- promotion of the development of a secondary trading market e.g. by bulletin boards, i.e. free trade of storage capacities between storage customers
- close cooperation between SSO’s and TSO’s.

Thus the storage business is influenced significantly by the liberalisation process and the SSO’s had to implement the provisions on access to storage and the publication duties and to adjust there systems (IT, Operations, General Conditions, etc.).

The degree of fulfilment of all requirements, which came up in 2005, has been monitored by corresponding European inquiries (EU Commission, ERGEG). Despite all new complex developments, including requirements of infrastructure modifications, the degree of accomplishment was quite satisfactory.

The Directive about major hazards (Seveso directive) has been applied for storage differently in some European countries but without any problems.

Concerning the approval of new developments, in some West European countries a lack of public acceptance and increasing environmental requirements are observed. For some companies future does not look too promising in this respect.

In some East European countries financial problems are hindering new developments and economical barriers are the main problem for potential investors.

**Technological issues**

**General**
The technological trends derived from the received questionnaire replies are mainly related to four major items:

- **Operation of storage**
Surface facilities of UGS are revamped ensuring their compliance with the latest environmental and safety standards and regulatory requirements: remote control operation of UGS operation, automatization, computer aided expert system.
Special attention was dedicated to the safety of UGS operation and the analysis of the influence of UGS performance on the environment. Regarding this aspect, there is more need for monitoring of “older” underground facilities.

Optimum modes of underground gas storage operation have been developed, together with the development of control algorithms and adequate computer programs.

- **Development of capacities**

  Regarding the development of capacities, the trend is towards the development of huge UGS and small city gate UGS and concerning cavern facilities, as well the development of mega size caverns, where salt conditions allow for.

  The increase of the maximum allowable storage pressure is the preferred measure for increasing storage capacities dependent on detailed engineering studies and the authority approval.

- **Subsurface**

  Concerning subsurface aspects, 3D seismics, new methodologies and software packages are applied to describe as precisely as possible geological reality, i.e. geological structure and its extension and reservoir characteristics. The proof of cap-rock and trap tightness is of great importance.

  Deliverability tests are recommended to characterise productivity parameters of a particular storage well and reservoir behaviour. Data can be used for calibrating reservoir simulation models, thus improving the prognosis quality. Moreover, complex reservoir models are applied to provide a tool to optimise storage processes and forecast different scenarios of its development. One of the main goals of simulation models is to be able to predict and guarantee capacities in the future.

- **Wells**

  There is a strong tendency towards reduction of the number of storage wells, strengthening wells with higher deliverability. The horizontal well technology is applied when appropriate and possible. Wells are re-completed to optimise completion and to install surface controlled subsurface safety valves. Improved well completions are installed for sand control purpose in unconsolidated reservoirs and slightly cemented reservoirs.

**Main topics of interest and for improvements**

Based on all the received questionnaire replies a summary was derived. The following areas of interest and of technological improvement and the main topics for the optimisation of existing storage facilities were summarised as the most relevant topics:

- increase of the operational flexibility and storage performance
- re-design of UGS facilities in order to adapt to new requirements in a liberalised gas market
- increase of cavern size (mega caverns up to a geometrical volume of 1x10⁶ m³)
- welded casing/tubing
- horizontal wells
- multilateral technology to produce several zones from one well
• integrated subsurface/surface reservoir management
  - application of integrated systems, incorporating subsurface and surface models in order to allow for fast system analysis and improved performance prognosis of the storage facility
• subsurface optimisation / performance improvements by:
  - decrease of min. storage pressure in order to increase WGV and to reduce required cushion gas volume
  - increasing of max. allowable storage pressure in order to enhance WGV and storage performance
  - increasing max. withdrawal rates, for example by debottlenecking, increasing velocities, optimising completion, increasing tubing size
  - 3D seismic, seismic reprocessing
  - monitoring of inside/outside casing conditions by casing inspection tools
  - assessment of casing cementation
  - improvement in casing cementation technology especially honouring the specific conditions of storage operation (changes due to load, temperature and pressure).
  - application of smart well technology
• enhancement of surface facilities –
  - new dehydration technology (Vortex tube)
  - online monitoring of wells/facility
  - remote control
  - environmental monitoring
• total facility
  - reliability improvement
  - start up time reduction
  - “unmanned” operation
  - application of HAZOP etc. procedures and validated operational instructions
  - cost reduction.

New requirements/tasks induced by recent market developments are coming up:

• storage developments in combination with hubs
• increased deliverability
• improved technology application - multilateral well technology in storage facilities
• reduction of minimum injection/withdrawal rate
• injection capacity enhancements – resulting in an enhanced cycling capacity
• fast changes of operational mode
• production data management with respect to TPA
• cost cutting analysis of facility
• technology for the application of CO₂ sequestration should be developed.

**Trends in the UGS business from a national perspective**

Direct valuable contributions about the national situation and trends in the underground gas storage business were received from Austria, France, Germany, Italy, the Netherlands, Poland, Russian Federation, Slovakia, Spain, Ukraine and North America. The contributions are included in this report +/- as received.

**AUSTRIA**

**General**

In the year 2004 Austria has imported 5840 10⁶ Nm³, domestically produced 1963 10⁶ Nm³ and consumed 8563 10⁶ Nm³. The difference covers own use for domestic production and movements from / into storage inventories.
Available volumes in UGS and send out capacities in 2004 were $2820 \times 10^6$ Nm³ and $32 \times 10^6$ Nm³/d. The split for the two providers of the gas storage services is presently OMV Gas $2120 \times 10^6$ Nm³ and $25 \times 10^6$ Nm³/d respectively RAG $700 \times 10^6$ Nm³ and $7 \times 10^6$ Nm³/d.

Due to the different locations, OMV has the bulk of its facilities in the eastern part of Austria and RAG has its facilities near the German border.

Both storage operators consider a lack of send out capacity while working gas volume is still sufficient. Additional to the use of storage to balance the seasonal swing as the basis, OMV and RAG see changes in the demand structure leading to new products like unbundled services, i.e. the splitting of the three components of UGS and providing working gas volume, withdrawal rate and injection rate as separate products to the market.

RAG with its centre of E&P activities in the federal provinces of Upper Austria and Salzburg, both located near the German border forecasts an additional demand for storage in the gas markets of Central Europe. For this reason a new storage is under construction in the depleted gas field of Haidach. The available gas volume in 2007 will figure at $1200 \times 10^6$ Nm³ and $12 \times 10^6$ Nm³/d and will be increased to $2400 \times 10^6$ Nm³ and $24 \times 10^6$ Nm³/d in 2011. This new UGS will be operated by RAG.

OMV has its main E&P activities in the federal province of Lower Austria close to the gas hub Baumgarten at the intersection of big pipeline systems coming from the East and leading to the West (West-Austria-Gasline and Penta West), South (Trans-Austria-Gasline and SOL) and South-East (Hungarian-Austrian-Gasline). At this point OMV Gas predicts an additional demand in the future at the latest when Nabucco pipeline will come into operation.

Hence, OMV Gas is working out a pre-feasibility study to investigate a reservoir located directly below Baumgarten in about 3.000 m depth with high permeability. A volume of up to $2000 \times 10^6$ Nm³ with very high deliverability is probable. This study will be presented in 2006.

**Legal**

The gas law from 2002 governs as far as gas storage is concerned the following:

- Access to gas storage has to be granted to producers, traders and suppliers on non-discriminatory and transparent terms.
- Tariff has to be negotiated based on costs and equal treatment. Provable technical and geological risks, together with opportunity costs have to be adequately considered.
- In case tariffs for comparable and equal services provided in EU-member states, are 20 percent above the average, the Austrian regulator E-CONTROL can stipulate by decree cost elements to be used.
- Holders of storage contracts are obliged to present all contracts to the regulator.

Construction and installations related to an UGS is regulated by the Austrian mining law (MinroG Nov 2002) together with other laws as needed. Deviating from EU standards an UGS in Austria does not require an Environmental Impact Assessment (EIA) Report. Commissioning and supervision of an UGS facility is in the hands of the Austrian Mining Authority.

**Environmental**

Since safety and environmental matters are of major concern to the general public it is the good policy of companies involved in Austria’s gas storage activities, to make abundant information available in due time und during all phases of planning, construction and operations to all which might be concerned.

Emission levels of all kinds and treatment of waste are regulated by a framework of laws and supervision and control rests with the Mining Authority or an agency appointed for a specific task by the Mining Authority (e.g.TÜV).
Gas turbines in the UGS compressor stations have been adapted to Low-Nox operation.

Injecting inert gas as cushion gas has been considered but has not yet reached a status to be a viable solution.

**Technical**

As in the past construction of a new, or expansion of an existing facility will always be governed by techniques available at the time.

Recent project works are all based on 3D seismic to allow the drilling of optimum well patterns. But it had to be realised that due to complicated geological conditions drilling of pilot wells cannot be avoided in some instances.

Reservoir simulation studies are worked out to find the optimum location for drillings and concentrate wells in clusters. Horizontal wells have been considered to supplement the existing vertical wells if it is feasible. Recent studies recommend to expand the diameter to 9 5/8”.

Safety valves have been used on all recently completed new storage wells and will be used in all re-completed old storage wells.

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**FRANCE**

**NATURAL GAS IN FRANCE AND UNDERGROUND GAS STORAGE**

**NATURAL GAS IN FRANCE - A QUICK OVERVIEW**

In 2005, the proportion of total French energy consumption accounted for by natural gas is currently about 15% or around 528 10^9 kWh. This represents 34% of the total energy demand for industry and 32% for residential and tertiary sectors. In this last sector, gas represents a less important part than in others main European countries. But the growth is there quite fast, with 3.5% per year in average since 1995.

In 2004, 11 million customers are served by a 174.500 km distribution network.

France is seeing an increasing number of vehicles running on natural gas, more than 1300 bus and 5500 utility vehicles. Nevertheless, consumption of natural gas for cars, around 550 000 kWh, remains low compared to all energies of this sector.

Cogeneration has been expanding during the last years, with a total of 26,5 10^9 kWh of natural gas being consumed.

The natural gas supply policy in France is based on diversification of gas sources, with long-term contracts which maintain security of trade. In 2004, 32% of sales of natural gas came from Norway, with 24,5% from Russia, 16,5% from Algeria, 20% from the Netherlands, 5,5% from United Kingdom and 4% from other sources (Nigeria, spot and short term). Total of imports are of 515TWh. Compared to previous years, part of short terms contracts is growing, representing 20% of the supplies; imports from Netherlands have increased. In 2007, Egypt should provide around 10% of supplies; first deliveries have been received in July 2005.

The national production represents less than 3% of the gas resources. The Lacq field, located in the south west, supplies most natural gas produced in France. At the beginning of the year 2005, the reserves are of 10 10^9m^3 or
100 TWh, which represents five years of production or 3 months of national consumption. End of exploitation is planned for 2010.

**UNDERGROUND NATURAL GAS STORAGE IN FRANCE**

There are 15 underground gas storage facilities in France, comprising:

- 12 facilities located in aquifer layers
- 3 facilities located in salt cavities.

Two facilities are run by Total Infrastructures Gaz France (TIGF) and thirteen by Gaz de France (GDF).

Role of UGS in France has been detailed in the IGU report “Basic Activities” 2000-2003.

In France, a Third Party Access to storages has been implemented since the law from 9th August 2004, on a transparent and non-discriminatory basis; tariffs are ruled on a “negotiated approach”.

The two french operators, Gaz de France and TIGF, therefore elaborated commercial offers for UGS capacities respectively since April and October 2004.

Total Infrastructures Gaz France (TIGF), subsidiary of Total, has been created in January 2005 for the facilities held in Southwest of France.

For Gaz de France, the management of storages is undertaken by a specific division DGI (Direction des Grandes Infrastructures), in charge of the development and the industrial and commercial management of underground storage facilities since 1st January 2005.

<table>
<thead>
<tr>
<th>OPERATORS</th>
<th>STORAGES</th>
<th>TYPE</th>
<th>CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDF</td>
<td>Soings, Céré, Chémery</td>
<td>Aquifer</td>
<td>46 TWh</td>
</tr>
<tr>
<td></td>
<td>Saint-Clair, Germigny</td>
<td>Aquifer</td>
<td>13 TWh</td>
</tr>
<tr>
<td></td>
<td>Saint-Illiers, Beynes</td>
<td>Aquifer</td>
<td>13 TWh</td>
</tr>
<tr>
<td></td>
<td>Etrez, Tersanne, Manosque</td>
<td>Salt Cavity</td>
<td>9 TWh</td>
</tr>
<tr>
<td></td>
<td>Cerville</td>
<td>Aquifer</td>
<td>7 TWh</td>
</tr>
<tr>
<td></td>
<td>Gournay (B gas)</td>
<td>Aquifer</td>
<td>10 TWh</td>
</tr>
<tr>
<td>TOTAL</td>
<td>Lussagnet</td>
<td>Aquifer</td>
<td>2,4 Gm³</td>
</tr>
<tr>
<td></td>
<td>Izaute</td>
<td>Aquifer</td>
<td>2,8 Gm³</td>
</tr>
</tbody>
</table>

*Underground gas storages in France (from Europ Energies Mars 2005)*

Gaz de France UGS facilities are pooled into six storage groups, according to their geographical position, type of gas and physical characteristics:

- Picardie
- Ile de France Nord
- Ile de France Sud
- Lorraine
- Centre
- Salins Sud.

Each group of storages is characterised by the UGS facilities, a point of interface transportation /storage, the number of injection days and the number of withdrawal days.

The commercial offer has been posted on GDF web site on 19th April 2004 and is regularly reviewed: www.stockage.gazdefrance.com.
The offer, which concerns all suppliers for the needs of their customers, reflects the physical constraints of access to storages. In the contract are defined the rules of utilization regarding injection and withdrawal rates, or inventory during the year.

**Gaz de France storage groups**

**THE TRENDS IN THE UGS BUSINESS IN FRANCE**

On the legal point of view, activity of underground storage of gas is submitted to specific rules and laws. Application of rules for safety to UGS facilities now integrate them in the “Seveso 2” regulation.

The main applicable texts are:
- the Seveso 2 directive, which has been transposed into French law for UGS activity in January 2003
- the mining law, with UGS included in law of January 2003, related to gas and electricity markets and public energy service

Some general European directives may also apply to UGS, for example:
- IPPC directive (Integrated Pollution Prevention and Control)
- "CO2 quotas" directive
- other directives, concerning wastes for example, as electric equipments.

The national environmental regulation also concerns UGS facilities:
- general environmental regulation on air, water and wastes
- specific regulation for industrial “risky” facilities: those facilities are subject to an administrative authorisation or declaration before the start of exploitation

The storage facilities are therefore subject to authorisation of exploitation (law of July 1976).

On an environmental point of view, important efforts have been made to develop integrated management systems for the environment protection. The implementation of environmental management system is made on a voluntary basis based on international norm ISO14001. This is also described in European regulation EMAS (Eco-Management and Audit Scheme).
In terms of recognition, the norm allows to obtain international certificate when EMAS allows to be registered on a list held by the European commission.

Gaz de France plans to obtain in 2006 an ISO 14001 certificate for all UGS facilities. In year 2005, seven of the UGS have already obtained the certification.

**NEW DEVELOPMENTS**

In order to accompany the increasing demand in natural gas, France carries on the development and optimisation of its facilities.

It has been for example the case for the storage of Chemery, where development and extension have been undertaken in the last years.

On the other hand, some development or exploration works are carried out for optimising existing facilities or finding possible new sites in salt or aquifer layers. Some projects are almost decided or are at exploration step.

Future developments will depend on the development of the gas market together with a clear understanding of the regulatory environment.

The program of development of capacities will take into account the renovation and upgrading of the existing facilities in order to keep an availability of installations. Related to the average age of storage facilities, large investments will be necessary in the forthcoming years.

**GERMANY**

**General**

In 2004 the primary energy consumption stayed nearly constant compared to previous years. In 2005 a slightly reduced primary energy consumption (PEV) (1%) was observed compared to 2004.

Natural gas, as the second important source of energy behind oil (36.4 %), provides about 22.5 % of the total primary energy. In 2004 about 100 $10^9$ m$^3$ of natural gas were consumed. The significant increases of gas consumption from previous years can not be observed any more.

As Germany is an energy importing country several countries contribute to the supply of gas according to the following shares:

<table>
<thead>
<tr>
<th>Country</th>
<th>Share in %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2003</td>
</tr>
<tr>
<td>Germany</td>
<td>18</td>
</tr>
<tr>
<td>Netherlands</td>
<td>17</td>
</tr>
<tr>
<td>Norway</td>
<td>26</td>
</tr>
<tr>
<td>Russia</td>
<td>32</td>
</tr>
<tr>
<td>Denmark and United Kingdom</td>
<td>7</td>
</tr>
</tbody>
</table>
The storage of gas is looked at as an essential tool within the gas chain, with increasing importance in the future because of declining gas production in West Europe and increasing imported gas volumes via long distance pipelines.

The UGS industry has a long history in Germany. The first UGS was developed in an aquifer near Hannover in 1953 by Ruhrgas AG and was abandoned in 1999 for economic reasons.

In Germany, 42 underground gas storage facilities, operated by some 20 companies, provide a total of 19,18 10^9 m³ of installed working gas volume as shown in the following table:

<table>
<thead>
<tr>
<th>Porous Rock</th>
<th>Caverns</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total installed working gas volume of UGS in operation (10^9 m³)</td>
<td>12,833</td>
<td>6,346</td>
</tr>
<tr>
<td>Total peak withdrawal rate in operation 10^6 m³/d</td>
<td>204,65</td>
<td>272,52</td>
</tr>
<tr>
<td>Number of storages in operation</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>Total working gas volume from planned storage projects (10^9 m³)</td>
<td>0,6</td>
<td>2,7</td>
</tr>
<tr>
<td>Expected total max. working gas volume in operated and planned storage facilities (10^9 m³)</td>
<td>13,44</td>
<td>9,04</td>
</tr>
</tbody>
</table>

Reported new storage capacities are mainly developed in salt cavern facilities as well obvious from the following graph.

In the following graph, the development of working gas volume (10^9 m³) since the beginning of UGS operation in Germany is shown.

Since 1990 the existing working gas volume has more than doubled. About 19% of the total gas consumption is available in UGS facilities. A further increase of installed storage capacities is forecasted.

Due to favourable geological conditions in North and South Germany sufficient additional storage volume can be developed in salt rock (only in N Germany) and porous rock (mainly in depleted hydrocarbon reservoirs in both areas) to meet the needs of future UGS capacities.
Compared to the distribution of storage types in the world major storage capacities are installed in salt caverns. On a working volume basis for salt caverns, 33 % compares to 3,9 % in the world, and more pronounced on a peak withdrawal rate basis, 57% vs. 15%.

**UGS in Germany**

**Working Gas Volume Distribution by Storage Types**

- **Oil-/Gasfield** 57.2%
- **Salt Cavern** 33.1%
- **Abandonded Mine** 0.02%
- **Aquifers** 9.7%
- **Other** 0.02%

Only 5 storage facilities (Rehden, Dötlingen, Epe E.RG, Bierwang, Breitbrunn/Eggstätt) provide about 50 % of the installed working gas volume. Most of the planned volume will be developed in salt caverns in existing storage facilities by leaching additional salt caverns.

Some of the German storage companies are involved in the domestic E&P and in the storage business. The holders of an exploration permit do not implicitly have the right in North Germany to obtain a permit to operate storage facilities. New applications for storage permission ("Betriebsplanantrag") are required independent of existing exploration or production permits. This application and the operation of UGS are subject to regulations according to the mining law.
The acquired subsurface (geological) data are submitted to the geological surveying authorities in accordance with the mineral law ("Lagerstättengesetz"). There is no specific tax on exploration and operational activity at underground storage sites.

**Legal**

The basis for the liberalisation of the European gas market was laid by the Gas Directive in June 2003. In July 2005 the European Gas Directive from June 2003 has been transferred in Germany by the new German energy law (EnWG). Since April 2005 the European “Guidelines for Good Practice for Storage Operators” (GGPSSO), approved by the Madrid Joint Working Group, are in force. Those guidelines are released by the European Regulatory Group for Electricity and Gas (ERGEG) as recommendations. In principle the compliance of the guidelines is voluntary, but the guidelines are expected to be followed by storage system operators (SSO). A new regulatory authority – the Bundesnetzagentur (BNA) - has been established in Germany, which monitors the process of liberalisation.

According to the German energy law Germany opted for negotiated Third Party Access to storage capacities which have to be granted for third party access on a non-discriminatory, transparent basis.

The storage business in Germany, which is built up by a variety of different facilities and operators compared to other European countries, is influenced significantly by the liberalisation process especially as the SSO’s had to adjust there systems (IT, Operations, General Conditions, etc.).

The degree of fulfilment of all requirements, which came up in 2005, has been monitored by corresponding European inquiries (EU Commission, ERGEG). Despite all new complex developments, including requirements of infrastructure modifications, the degree of accomplishment was quite satisfactory in Germany.

**Technology:**

Due to favourable geological conditions (overburden rocks) high operational pressures are run in some UGS. Due to this fact a high standard of monitoring of the technical integrity of the storage wells and the overburden rocks is ensured.

In general approved E&P-technology is applied, which is adjusted for storage requirements. In new cavern projects, installation of welded casing and tubing strings are preferred.

A large number of horizontal UGS wells have been drilled during the last years. In depleted reservoirs with a low reservoir pressure new types of low pressure mud systems are used to prevent formation damage. Generally, drilling of new wells is based on 3-D seismic surveys, followed by comprehensive 3-D modelling and simulation of the storage dynamics. Most of the UGS have installed subsurface safety valves (SSSV).

The trend to leach a higher geometrical volume in salt caverns, thus reducing specific investment, is increasing; e.g. the salt cavern Huntorf K 6 planned for a geometrical volume of 750,000 m³ could be enlarged to 1,1 $10^6$ m³ because favourable geology, shape and rock mechanics allowed for this enlargement.

Several re-leaching projects in existing caverns are planned respectively carried out. In some cases leaching was carried out under gas.

**ITALY**

**GENERAL**
According to storage service demand in terms of working gas and peak capacity, referred to the last winter (year 2004-05) and reasonably also winter 2005-06, storage needs in the short term appear higher than the available storage capacity.

Great interest from gas operators (mostly shippers) in UGS is demonstrated from the attention to the first round of bidding for the development of new gas storages, both depleted gas reservoirs both aquifers. After the evaluation by the Production Activity Ministry (Ministero Attività Produttive) only few projects have been accepted so far.

This interest of shippers in obtaining licences for new UGS is due also by the possibility to dedicate to itself up to 80% of the developed working gas, leaving only the remaining capacity to the regulated market.

In orders to comply with the increasing storage demand, the present UGS operators have provided a short term program to improve mostly working capacity. In thermal year 2005-06, the capacity offered by present operators is about $8 \times 10^9 \text{ m}^3$ of working gas. Within the next 3 years the development of an additional capacity of more than $1 \times 10^9 \text{ m}^3$ is expected.

**Legal**

From the point of view of Italian laws, the gas market is completely liberalised. TPA access to the storage system and transmission system is fully guaranteed.

Nevertheless in UGS there is a dominant position (more than 95% of storage total capacity) of Stogit (ENI Group). Therefore the Electricity and Gas Authority (Autorità per l’Energia Elettrica e il Gas) have regulated the storage system and imposed storage service tariffs.

As required, Stogit has prepared and sent, on 26 September 2005, to the Electricity and Gas Authority its proposal of Storage Code, for the verification process. At the moment this proposal is under discussion between Shippers and is waiting for the final approval of the Electricity and Gas Authority.

In August 2005, the Production Activity Ministry issued a new decree in which are reported new requirements for the storage, mainly related to open access to new operators and give the opportunity to improve the performances of the system, as operating the field at pressures higher than the original pressure and developing other types of UGS (i.e. aquifer).

**Environmental**

It appears that there will be no particular constraints, on present or future UGS, from present or next future environmental laws except for the necessity to comply with the Kyoto Protocol for greenhouse effect emission.

In case of planning and construction of new UGS, special attention must be paid in order to comply with all the requirements regarding in general environmental aspects and impacts finalised to obtain all necessary authorisations.

**Technical**

In order to increase the performances of the storage system, the technical solutions that have been applied or planned are mainly managing the fields at maximum pressure or overpressure, improving horizontal drillings and utilisation of structured packing in dehydration column.

A Low Temperature Separator plant (LTS), that dehydrates the gas by mean of the Joule-Thompson effect instead of traditional glycol system, is already in full operation.

Finally enhancements have been implemented in reliability of static and dynamic models of the reservoirs and in upgrading tools for the optimisation of the fields management.
THE NETHERLANDS

Background

In the Netherlands the so-called "small fields policy" has successfully promoted exploration for and exploitation of new gas reserves since 1974. The main source of flexibility of the gas supply system is provided for by the Groningen system, allowing the "small fields" to produce at a relatively high load factor. The Groningen system consists of the Groningen field (320 wells) and three UGS facilities.

The Groningen gas field is operated by NAM (50% Shell, 50% ExxonMobil) and has an expected ultimate gas recovery of 2881 \(10^9\) Nm³, of which 60% has been produced to date. Currently a 2 \(10^9\) € investment programme is being executed which comprises out of a full facilities upgrade of 22 production clusters and 7 satellite locations, whilst 22 new depletion compressors are being installed (at 23 MW each). The field can ramp-up capacity with 120 \(10^6\) Nm³ in one hour whilst it supplies a maximum 350 \(10^6\) Nm³/d capacity. The Groningen system is designed around a capacity failure criterion of 1 hour per 50 years.

UGS

Of the three UGS facilities, two are operated by NAM (Grijpskerk, Norg) and one is operated by BP-Amoco (Alkmaar). The UGS facilities were built in the mid 90's and can provide a total send out (end winter capacity) of 140 \(10^6\) Nm³/d (5.8 \(10^6\) m³/h). These UGS reservoirs have currently a total working volume of 2.4 \(10^9\) Nm³ at the above stated capacity.

The UGS’s were designed to cater for winter peak demands, to accommodate for the declining reservoir pressure and production capacity of the Groningen field. Relatively small injection capacity was installed, with limited flexibility in order to accommodate gas from small fields in the summer periods. The UGS’s have long-term contracts with Gasunie. Expansion plans are being considered to meet future capacity and work-volume demands.

Legal

As part of the ongoing European liberalisation efforts the Dutch regulator (DTe) has indicated that a substantial part of the Dutch UGS’s should be made available for Third Party Access (TPA). The objective of the regulator is to increase trade and the efficient operation of the UGS by both owners and users whilst creating a healthy investment climate. In order to achieve these objectives the DTe has issued guidelines, which the storage owner should adhere to when offering storage services to the market.

Although the NAM UGS’s have been designed, built and operated for production purposes and therefore do not fall under the Gas Act and under the jurisdiction of DTe, NAM, together with Gasunie, has decided to make a certain amount of capacity available as NAM/Gasunie wish to co-operate with the overall EU liberalisation efforts.

Environmental/social

There is a general trend to increase energy efficiency and to limit the environmental impact of operations as much as reasonably possible (zero impact if possible). This involves a "no flaring" policy, whilst CO2 emissions are minimized. The extension and/or construction of new facilities require involvement of all stakeholders (i.e. neighbouring communities, local government, Dutch mining authority) in the design of facilities (visual impact, safety, noise contours) and landscaping around facilities.
Technical aspects

State of the art technology is employed in the Groningen system in order to maximise operational flexibility and minimise cost. After finalisation of the Groningen Long Term investment project in 2009, the Groningen field can be operated remotely. The UGS’s Norg and Grijpskerk are also designed around a minimal manning philosophy. On the UGS’s, big bore wells have been drilled with 7 5/8” completion strings that deliver typically some 7.5 \times 10^6 m^3/d.

Business

With a gradual decline of available production capacity in a relative mature hydrocarbon province such as The Netherlands, it is expected that – during the coming decades - there will be an increasing demand on capacity provision at both the high-end and the low-end of the Load Duration Curve (LDC), in order to guarantee security of Supply.

At the high-end of the LDC, capacity is provided for by sizeable investments such as cavern UGS’s that deliver peak capacities when required. Such utilities are already being built just across the Dutch border in Germany.

![Load Duration Curve Diagram](image)

Much higher capital investments will however be required to accommodate seasonal modulation of relatively large working volumes at the low-end of the LDC (figure below). These type of investments require long planning and engineering lead times, before such large UGS’s can be taken into operation. At the moment there is a general trend to postpone such investment decisions, given the uncertainty of regulation issues that may be implemented by the European Union and (consequently) the Dutch Government.

The legal framework for the gas industry in the Netherlands is currently under political review. A first step has been taken by the government in 2005, that separates Gasunie’s gas transport network services from the “trade and supply” department. The Dutch Government is also expected to put measures in place that constrain the average volume offtake from the Groningen Field over a number of years.

Attachments
Overview of Dutch Gas Distribution System

**The Groningen Capacity System**

- **Grijskerk UGS**
- **Norg UGS**
- **Groningen Gas Field**
- **Alkmaar UGS**
- **Amsterdam**
- **The Netherlands** (30-40 BCM/yr)
- **Germany** (15-20 BCM/yr)
- **Belgium** (4-8 BCM/yr)
- **France** (4-8 BCM/yr)
- **Italy, Switzerland** (5-10 BCM/yr)

**LEGEND:**
- Purple: Groningen Cal Gas (14% N2)
- Orange: High Cal Gas

**POLAND**

General
One storage concession is required according to geological & mining law and another one regarding to energy law. A fee is 1,51 PLN/1000 m³ of injected gas according to geological & mining law (a fee re. to energy law is unknown). A company which is engaged in turnover of natural gas with foreign company should maintain stock of 3% planned annual import of natural gas.

**UGS**

- **UGS Wierzchowice**
  The first stage of UGS development is planned to be completed after 2006. Working volume will reach $1.2 \times 10^9$ m³. The realisation of the project depends on growth of the gas market and a tariff policy.

- **UGS Mogilno**
  The first stage of UGS development is completed. Working volume is $416.73 \times 10^6$ m³ with the maximum daily withdrawal rate of $20 \times 10^6$ m³ in the withdrawal season 2005/2006. A decision about extension of the UGS will be taken after assessment of the economy and needs of the transmission system.

- Two UGS for low methane natural gas (LMNG) system will be developed in the near future:

  **UGS Daszewo** — planned in oil field for gas of nominal Wobbe index of 35 MJ/m³. It will provide $30 \times 10^6$ m³ working volume and $17 \times 10^3$ m³ withdraw capacity in the first stage. The facility would switch to storage of HMNG after depletion of the local LMNG fields.

  **UGS Bonikowo** — a facility for LMNG gas of nominal Wobbe index of 41,5 MJ/m³; it is planned to have $32 \times 10^6$ m³ working volume and $11 \times 10^3$ m³ withdraw capacity in 2006.

- **Odolanow**
  The nitrogen removal plant in Odolanow, as a regulator for LMNG of nominal Wobbe index of 35 MJ/m³, provides arbitrage between two gas systems: LMNG (nominal Wobbe index of 35 MJ/m³) and high methane natural gas (nominal Wobbe index of 45,0-54,0 MJ/m³).

- So far POGC has not been offering UGS services separately. No UGS tariffs are published so far.

- Some projects for developing independent UGS facilities have been prepared – none seems feasible before real deregulation of the gas market.

**RUSSIAN FEDERATION**

UGS facilities in Russia are currently operated by nine gas transmission and one gas production wholly - owned subsidiaries of Gazprom. Part of Russia’s United Gas Transmission System, the UGS depots help secure reliable gas supply to domestic and foreign customers over the autumn-winter heating season. Today Gazprom owns UGS facilities with a total working capacity of $62.6 \times 10^9$ m³, and over $30 \times 10^6$ m³ stock piled as long-term reserves. As of the beginning of the withdrawal season the UGS’s maximum and average daily send-out capacity over December to February reaches $568 \times 10^6$ m³ and $477 \times 10^6$ m³, respectively. In January 2005 the maximum daily send - out was $493.9 \times 10^6$ m³ and within the 2004-2005 retrieval period the combined maximum daily send out accounted for $537 \times 10^6$ m³.

In 1958 first gas was injected into a depleted gas field and in 1959, into a new water - bearing structure not far from Moscow (nowadays the Kaluga UGS facility). At present Gazprom operates 24 UGS reservoirs including seven and seventeen constructed in aquifers and depleted gas fields. Some UGS facilities are unique by technological and geological parameters listed below:

- The world’s largest depleted gas field-based UGS depot with the $20 \times 10^6$ m³ active capacity
- The world’s largest UGS facility built in an aquifer ($19.0 \times 10^6$ m³ of overall capacity)
- UGS facility constructed in a practically horizontal aquifer
- UGS facility in low-amplitude aquifer traps
- UGS facility in an aquifer with non-hermetic fractures
- UGS facility in fully flooded gas fields with maximum working pressure exceeding initial layer pressure by an up to 1.45 coefficient
- UGS facility with unconsolidated sands
- UGS with an hard water drive
- Other UGS facilities

Gazprom's future projections include developing UGS networks in Russia with a focus to be placed on increasing the UGS daily send out planned to reach 700 10^6 m^3/d over the nearest five-year period. Currently Gazprom is involved in the construction of new UGS in aquifers including two in rock salt caverns, with a string of several more geological structures under survey & scrutiny. An upgrading & an automation program for existing UGS facilities is in a progress. While implementing the intra-corporate policy of dividing its multi profile subsidiaries by business types, Gazprom intends to spin out UGS units from transmission affiliates and consolidate the former within the Gazprom-UGS company. Establishing Gazprom-UGS Ltd will enhance the underground gas storage business efficiency and will bolster better management and economic transparency of Gazprom in general.

**SLOVAKIA**

**General**

Natural gas is an important energy source for Slovakia with a total year consumption amounted to nearly 7 10^9 m^3. Slovakia operates one of the most developed distribution networks in Europe as 94% of Slovak inhabitants have been connected to a gas distribution network in the previous years. Taking that into account, the growing potential for households achieved its limits especially after deregulation of gas prices. Over the next decade, there is estimated only a slight growth of natural gas consumption which is believed to be driven mainly by the sector of combined heat and power generation.

Most of natural gas consumption is covered by supplies from Russia. At the present time, domestic production does not represent a considerable amount and continues to be slightly decreasing. The main transmission system, delivering natural gas from Russia to Western Europe, leads through Slovakia, which guarantees certain security of gas supply for the domestic market. As declared, within a draft of a document of Slovak energy policy, security of supply is to be influenced by UGS capacity and mutual interconnections of gas grids.

UGS facilities are located only in the southwestern part of Slovakia near Slovak-Austrian borders. Thanks to favourable geological conditions of the northern part of the Vienna basin, existing UGS provide sufficient storage capacity for Slovakia. The UGS were originally designed mainly for seasonal balancing of gas consumption; however, during a winter period, they can provide a very responsive tool even for covering fluctuations on daily basis.

**Legal**

Since joining EU, Slovakia has experienced a completely changed environment. New energy legislation speeds up liberalization of gas market and strictly separates gas supply from a process of gas transmission and distribution. Moreover, it strengthens rights of customers and creates conditions for gas market.

The framework of storage business is laid down mainly in two acts: the Energy Act and Regulation Act. The primary legislation is developed by secondary legislation as Gas market rules and decrees issued either by the Ministry of Economy or the Regulatory office.
The Energy Act stipulates rights and responsibilities of parties involved in energy market. Furthermore, the Act puts emphasis on safe, reliable and effective operation of storages with minimum environmental impact. In accordance with the Energy Act, an operator of storage services needs a license.

The access to storage services is negotiated between operator and gas market participants in compliance with Gas market rules. The part of storage capacity is dedicated solely for the distribution system operator for the purpose of a network balancing.

In line with energy legislation, storage operators were obliged to publish their Rules of Operation, which lay down business conditions for access and use of storages and Technical conditions for access and connections to storages specifying minimum technical requirements, parameters and operation of storages.

Environmental

The increase of environmental efficiency is the main focus of all the involved parties. The main reason is to ensure an efficient utilization of energy and prevent it from being wasted. At the moment, there are limited environmental constraints which prevents construction or operation of UGS provided that an operator follows the conditions determined by environmental authorities. Under some circumstances environment impact assessment is required. In line with the Greenhouse gas emission trading Act, UGS operators are obliged to monitor and reduce the amount of produced CO₂ to meet assigned emission quotas. In line with the Air Protection Act, equipment with a prescribed installed power as gas turbines or burners of heaters, re-boilers have to be regularly certified by an authorized company to ensure meeting emission targets. Moreover, the Water Protection Act imposes to revamp storage facilities in order to guarantee a minimal risk of poisonous or hazardous liquids leakage. Pursuant to the Water Protection Act, UGS operators are equipped with filling platforms to ensure capture of potential leakages during loading and off-loading of hazardous liquids from/to a truck. Hazardous liquids as methanol, glycols or reservoir water are stored either in double shell tanks or single shell tanks placed within leakage sump.

Technical trends

Concerning subsurface, 3D seismics, new methodologies and software tools are applied to depict as precisely as possible a geological reality i.e. geological structure, its extension and tightness of reservoir trap. Deliverability tests are involved to characterize production parameters of a particular storage well and reservoir properties and parameters of drainage area. Moreover, complex reservoir models are applied to provide a tool to optimize storage processes and forecast different scenarios of its development.

There is a strong tendency towards reduction of storage wells number and a preference of wells with higher deliverability whereby a special attention is given to the safety of UGS operation. Safety valve systems, including subsurface valves, are deployed in the completion of the storage wells. Surface facilities of UGS are revamped ensuring their compliance with the latest environmental and safety standards and regulations.

**SPAIN**

General Trends:

Spain is an energy importing country with a negligible domestic production. About 22 % of the total primary energy is provided by natural gas.

In 2004 27,5 \(10^9\) m³ of natural gas was consumed, in 2005 the demand increases to about 33,5 \(10^9\) m³ with a contribution of the electric generation of 9,55 \(10^9\) m³ mainly by the 32 combined cycle units, in the year 2010 a total of 90 C.C.-units are planned to be in operation with a gas consumption of about 25 \(10^9\) m³ over a total demand of 43,5 \(10^9\) m³.
Around 40% of this gas comes through the two pipelines from Algeria and France and the rest is imported as LNG from different countries (Algeria, Nigeria, Qatar, Trinidad & Tobago, Egypt, Abu-Dhabi, etc.) and re-gasified in the existing 4 re-gasification plants. Two new pipelines from Algeria and France and three more re-gasification plants are planned or under construction.

Because around 82% of the gas is delivered to industrial users and to power plants and there is a peak demand of electricity in summer due to the air conditioning and the increase of population, the fluctuation in gas demand is much lower than in the rest of Western Europe.

In the next years the storage business is to be regulated by the government. The tariff will be fixed and there will be obligation to provide strategic reserves. As gas demand is increasing the storage business is a growing activity for both strategic and modulation purposes. More companies are expected to enter the Spanish gas market.

In 2005 Spain has 2 underground gas storage facilities in operation with a total maximum allowable working gas volume of 2,12 $10^9$ m$^3$ and a total max. withdrawal rate of around 12,6 $10^6$ m$^3$/day.

Gaviota is a depleted offshore gas field and is operated by Repsol-YPF on behalf of Enagas and Serrablo is a depleted onshore gas field owned and operated by Enagas who is the only UGS operator today.

Other structures are planned to be developed or adapted for UGS:

- Yela deep aquifer structure in development phase by Enagas
- Reus deep aquifer structure in appraisal phase by Enagas
- Poseidon depleted offshore gas field by Repsol-YPF
- Castor offshore oil field by Petroleum Oil Co.

Is also ongoing a feasibility study to increase capacity in Gaviota.

**Environmental Aspects:**

Exploration and operation activities in UGS are subject to environmental impact assessments ("Estudio de Impacto Ambiental") and to public inquiry. The holders of an exploration permit do not implicitly have the right in Spain to obtain a permit to develop storage facilities. The applications for storage permission are required independent of existing development permits. This application and the operation of UGS are subject to regulations according to hydrocarbons act of 1998 ("Ley de Hidrocarburos"), in accordance with this law, the acquired subsurface geological data are submitted to the Ministry of Industry.

**UKRAINE**

Ukraine is operation the third biggest UGS system in the world behind the USA and Russia. 13 storage facilities can provide an installed working gas volume in the order of $32 \times 10^9$ m$^3$.

The basic functions of Ukrainian underground gas storages are:

- Regulation of seasonal irregularity in gas consumption
- Additional gas submission to consumers at extreme decreases in temperature, both in separate days, and during abnormally cold winters
- Creation of long-term reserves of gas at occurrence of unforeseen extreme situations, such as the long-term termination of gas supply as a result of the big failures, acts of God, etc.
- Reservation of gas on a case of occurrence of short-term emergencies in a gas supply system
- Reliability control of export gas transit through the territory.
THE UNITED KINGDOM

THE CASE FOR UNDERGROUND GAS STORAGE (UGS)
Memorandum by British Geological Survey
Dr David Evans, Dr Sam Holloway, Dr Nick Riley, 25 March 2004
Published by The UK Parliament

BACKGROUND

1. In Western Europe, gas penetration in the residential and commercial sectors has now reached about 44 per cent. In line with this trend, United Kingdom gas consumption has more than doubled over the past 10 years, and gas now holds a key position as an energy source, both as a primary fuel (for heating and cooking) and for electricity generation.

2. The gas supply industry has to adjust to very wide seasonal variations in consumption due to rapidly changing electricity, heating and air conditioning requirements.

3. Thanks to its huge reserves of North Sea gas and oil, Britain is the only G7 country other than Canada still largely self-sufficient in energy. The United Kingdom continues to enjoy a high level of diversity and security of supply, but this is changing rapidly.

4. Although the United Kingdom is still a net exporter of natural gas, there are times during peak demand when it has to import foreign gas to meet its needs. In the course of 2000, the United Kingdom imported about 2 per cent of its gas demand of about 97 bcm (billion cubic metres) per year. The Department of Trade and Industry's (DTI) projections are of United Kingdom gas import dependency rising to more than 58 per cent of demand by 2010, and 90 per cent of demand by 2020. National Grid Transco predicts that net imports of gas will exceed domestic production in 2008-09 and will reach 70 per cent by 2014.

5. Our coming reliance on "less secure" external supply sources makes it necessary to be on guard against any risk of supply shortages or major disruption, be it technical as in an accident (such as the explosion at the Esso Longford gas plant in 1998 in Victoria, Australia, which disrupted supplies across the State for nearly two weeks), or political such as following a terrorist attack.

UNITED KINGDOM GAS DEMAND AND LIKELY TRENDS

6. 50 years ago Britain's coal mines supplied almost 90 per cent of our energy needs, with crude oil providing the rest. This changed rapidly with the advent of nuclear power plants in the mid-1950s, and the subsequent discovery of North Sea gas. The "dash for gas" occurred in the power generation sector in the 1980s, when coal-fired power stations were replaced with gas-fired equivalents. There was a continued shift in the balance between gas and coal in the period 1996-2001, due to the abundance of gas supplies from the North Sea combined with low gas prices on international markets.

7. The recent rise in gas prices has led to some generating companies considering the option of mothballing gas-fired plants, and at least one United Kingdom coal-fired power station has been brought back into service. Despite this, gas is, and will remain, an increasingly important fuel for electricity generation. The DTI predict that gas could form the energy source for 70-80 per cent of the United Kingdom's electricity generation needs by 2020. This is not only because it has been cheap and easy to obtain, but also because it is not clear that alternative fuels will be available. Nuclear energy production is predicted to decline over the next 15 to 20 years unless circumstances, including Government policy towards that energy source, change. At present, the significant contribution to energy needs from coal-fired electricity generation will become increasingly difficult to reconcile with the Government's environmental targets for the reduction of carbon dioxide emissions, as well as more stringent European Union Directives which will affect other emissions, such as particulates, sulphur oxides and nitrous/nitrogen oxides, in addition to carbon dioxide.

8. The DTI expects demand for gas, both for electricity generation and for direct (domestic and commercial) use, to rise gradually, from about 108 bcm (90 Mtoe [million tonnes of oil equivalent]) in 1999 to more than 144.6 bcm (120 Mtoe) by 2020, although demand will depend on changes in the cost of alternatives on international markets. On this basis, annual United Kingdom demand is predicted to exceed production capacity on the UKCS by 2005 (two years earlier than National Grid Transco predict), with imports concentrated in the winter months. As indicated above, the DTI
projections are of United Kingdom gas import dependency rising to more than 76 bcm (63 Mtoe), or 58 per cent of demand by 2010, and to 133 bcm (110 Mtoe) or 90 per cent of demand by 2020.

THE NEED FOR MORE UNDERGROUND GAS STORAGE FACILITIES

9. These projections, if realized, will require the creation of an infrastructure capable of dealing with the problem of fluctuating demand and guaranteeing security of supply. France, Germany and Italy each have gas storage capacity in excess of 20 per cent of annual consumption. Compared to these countries, the United Kingdom has very limited purpose-built natural gas storage facilities, providing for less than 4 per cent of annual consumption. What is more, more than 450 surface gas holders ("gasometers"), with a total storage capacity of 24 million cubic metres of gas at low pressure for delivery to domestic and industrial consumers, are scheduled to be phased out over the next 10 years or so, reducing total gas storage capacity.

10. There is currently no statutory requirement for the provision of strategic gas reserves, unlike in the coal and oil sectors. In the past, ready accessibility to United Kingdom gas reserves in our offshore gas fields may have justified the relatively low priority that has been attached to the development of strategic gas storage in the United Kingdom. However, given that the United Kingdom will become a major net gas importer in the near future and to guard against the unforeseen disruption of external supplies, Government, together with the industry, may wish to give serious consideration to the development of strategic storage capability. Among the solutions that might be considered, subsurface geological storage best fits the bill as the most reliable long-term storage option. Underground gas storage is safe, secure and reliable. Some countries, eg Hungary, which has to import all its gas, relies solely on underground natural gas storage to maintain grid supplies and hold strategic reserves. In comparison to liquefied natural gas (LNG) storage, there is little surface expression from the facility, lower fire and explosion risk, and less energy is expended in storage. Underground storage sites are already located within and around cities (eg Berlin and Paris).

UNDERGROUND GAS STORAGE FACILITIES

11. Natural gas is stored at surface in liquefied natural gas (LNG) receiving terminals, and underground gas storage facilities. The latter form strategic reserves and peak-shaving units, which can supply gas at a high rate in the cold season and over a short interval. In 1996-97, there were 580 underground storage sites worldwide, with a working capacity of 262 109 m3. Storage in porous and permeable formations (hydrocarbon reservoirs and aquifers) represents 98 per cent of the working capacity of all the storage facilities in the world.

12. The goal of underground gas storage is to balance gas consumption and resources at all times (seasonal, daily and hourly fluctuations) chiefly in the residential and commercial sectors, where demand is especially sensitive to changes in temperature. In addition, storage makes it possible to meet peak winter demand. The relative peak demand on the coldest day of the year is a very important parameter for the gas industry, because it conditions the size of the gas distribution network. In the United Kingdom the need to meet peak electricity demand accentuates peak gas demand because so much of the United Kingdom's electricity is now generated from gas rather than coal.

UNITED KINGDOM POTENTIAL FOR THE DEVELOPMENT OF FURTHER NATURAL GAS STORAGE FACILITIES

13. There are three types of large-scale underground natural gas storage facilities: salt caverns, depleted/depleting gas or oil fields, and aquifers:

14. Salt caverns. Salt cavities have been used to store liquid petroleum gas (LPG) for many years, but the technique (with respect to salt caverns) is relatively recent for pressurized natural gas. It was first introduced in the United States in 1961. Today, there are 54 storage facilities of this type worldwide, 26 of which are in the United States. This type of storage is developing rapidly and is particularly well suited to shallow underground storage where the need is to meet daily swing demand and intra-day peaks in demand. Caverns are created in the salt by solution mining (pumping fresh or sea water down a well drilled into the salt, dissolving it, and then recovering the produced brine via the well). These caverns can then be filled with pressurised natural gas. Thick natural deposits of salt are found underground in certain parts of the United Kingdom. United Kingdom storage facilities of this type include the caverns operated by Scottish and Southern Energy at Atwick, near Hornsea on the east coast. In the near term there are potential opportunities for further facilities of this type in salt deposits in the Hornsea area, Cheshire, West Lancashire (Preesall and Walney Island areas), Northern Ireland, Teesside, Dorset and possibly North Somerset. The future potential of hydrogen storage in salt caverns is shown by the construction of a cluster of hydrogen production storage and distribution facilities, operated by Huntsman Petrochemicals at Teesside.
15. Depleting or depleted gas or oil fields. Gas storage in depleted fields is the most widespread method in the world and often the least expensive. Along with aquifer storage (see below) they are capable of storing very large volumes of gas and are particularly suitable for strategic storage and storage to meet seasonal demand swings. An advantage of using depleted natural gas, or oil fields, for underground storage is that they are known to be capable of storing natural gas or oil for geological time-scales—in many cases millions of years, and they can require less "cushion gas" (see below) than other underground storage scenarios. Furthermore, they have commonly been well characterized as a result of the gas or oil extraction programme. Today, there are 448 storage facilities located in depleted reservoirs worldwide. United Kingdom storage facilities of this type include Hatfield Moors gas field (Edinburgh Oil & Gas plc), which stores gas 1,800 metres below ground onshore to the East of Sheffield and the Rough gas field off the East Coast (Centrica Storage Ltd) that has been developed to store natural gas 3,000 metres underground. There are plans to develop some of the United Kingdom's onshore oil fields as natural gas storage facilities, eg Star Energy's Humbly Grove oil field, near Basingstoke and the Welton oil field, near Lincoln. These locations will also have the advantage of stimulating further oil production through restoring the oilfield pressure. Further opportunities are likely to exist amongst Britain's onshore oil and gas fields and offshore in the Southern North Sea.

16. Aquifers. Aquifers are porous and permeable sedimentary rocks, the pore spaces of which are filled with water rather than oil or gas. The principle of aquifer storage is to create an artificial gas field by injecting gas into the voids of an aquifer formation. Many deeper aquifers contain saline water that cannot be used for potable water supply or agriculture. Where they are confined beneath cap rocks (impermeable rocks which prevent escape of gas), they have the potential to store natural gas if a trap for buoyant substances, such as gas (such as a dome) is present. Injection and retrieval of the gas would be similar to a facility in a depleted natural gas field. More testing and development may be required than for depleted oil or gas fields. However, aquifers are more widely distributed than oil and gas fields or thick salt deposits, so they may provide opportunities where there is no potential for the other types of storage. There are 76 storage facilities in aquifers in the world today, most of them in the United States, the former Soviet Union and France.

RESEARCH NEEDS
17. The main research needs for developing gas storage in the United Kingdom salt caverns are to more closely locate and characterize thick salt deposits in order to better define areas of potential.
18. The main research needs for gas storage in oil and gas fields are to determine their geological suitability, eg some fields may not have sufficient permeability to allow gas to be recovered at appropriate rates, others may be too large, too small, or too deep to develop economically for gas storage purposes.
19. The main research needs for aquifers are to identify the location of suitable traps for buoyant gases within aquifers, which otherwise have the correct characteristics for gas storage.
20. A further research need is to create a Geographic Information System (GIS) for United Kingdom natural gas storage, which will locate and characterize potentially suitable sites in relation to other elements of the United Kingdom gas infrastructure. This could form an important national decision support tool for use by policymakers, regulators, planners and operators.

BARRIERS TO DEPLOYING UGS IN THE UNITED KINGDOM
21. Public perception is an issue with underground natural gas storage—see for example the web sites: http://www.overwyrefocus.co.uk/gas—storage/gas—articles.htm and http://www.nogasplant.co.uk/. Opposition is likely to be at the local level, given that the main perceived risks are local (eg risk of fire or explosion from a leaking facility, risk of ground movement). It is hard to see why security of energy supply and seasonal peak shaving (the main drivers for underground natural gas storage) could be perceived negatively. However, from a local perspective these benefits may be outweighed, or ignored, especially by property owners, as they are concerned that a new storage facility could impact on the value of house prices (a significant factor in other infrastructure planning such as onshore windfarms). There is no obvious upside to living above, or near, an underground gas storage facility, but neither is there any significant downside, as surface facilities are very unobtrusive, quiet and easily hidden by careful landscaping and/or tree planting. Research into public perception could be commissioned if it is felt that the United Kingdom underground natural gas storage facilities should be expanded.
22. When asked in March 2004 about the development of gas storage facilities in underground caverns formed within deep rock salt deposits, the Secretary of State for Trade and Industry replied that "as Great Britain becomes increasingly dependent on imported gas it will be important that the
market continues to provide sufficient flexibility to meet demand. Gas storage projects help do this. The Government therefore welcomes proposals for new projects. They must, of course, obtain necessary planning and other regulatory consents.

NORTH AMERICA

by Fred Metzger using information from the American Gas Association (AGA) and the United States Energy Information Administration (EIA)

There are over 115 natural gas storage operators in the United States, with over 385 active underground storage facilities in 30 states. These facilities have a working storage capacity of nearly 3,500 Bcf of natural gas, and the capability of maximum daily deliverability of 80 Bcf per day. US storage operators manage about 15,000 injection/withdrawal wells of which about 120 are horizontal. The industry also operates about 3,000 pressure control or observation wells.

The 2004 AGA Storage report indicates that there are 7 natural gas operators in Canada, with over 50 underground storage facilities in 5 provinces. These facilities have a working storage capacity of over 530 Bcf of natural gas, and the capability of maximum daily deliverability of close to 5 Bcf per day. Canadian storage operators manage nearly 500 injection/withdrawal wells of which about 30 are horizontal. The industry also operates about 150 pressure control or observation wells.

Underground Natural Gas Storage Facilities in the Lower 48 States

The first instance in North America of successfully storing natural gas underground occurred in Weland County, Ontario, Canada, in 1915. This storage facility used a depleted natural gas well that had been reconditioned into a storage field. In the United States, the first storage facility was developed just south of Buffalo, New York. The Zoar field was discovered in 1888 and converted to natural gas storage in 1916. It is the oldest continuously operated storage field in North America. By 1930, there were nine storage facilities in six different states.
The development of underground natural gas storage fields grew rapidly after World War II. (See chart above). At the time, the natural gas industry realized that seasonal demand increases could not feasibly be met by pipeline delivery alone. In order to meet seasonal demand increases, the size and deliverability of pipelines, would have to increase dramatically. However, the technology required to construct such large pipelines to consuming regions was, at the time, unattainable and unfeasible. In order to be able to meet seasonal demand increases, underground storage fields were the only option.

The slowdown in the growth of storage field development in the 1990's is a direct result of changes in market requirements and the implementation of Federal Energy Regulatory Committee (FERC) Order 636. Prior to 1994, interstate pipeline companies, which are subject to the jurisdiction of the FERC, owned all of the gas flowing through their systems, including gas held in storage, and had exclusive control over the capacity and utilization of their storage facilities. Following FERC Order 636, jurisdictional pipeline companies were required to operate their storage facilities on an open-access basis. That is, the major portion of working gas capacity at each site must be made available for lease to third parties on a nondiscriminatory basis. Pipeline operators are still able to reserve gas volumes required to maintain system integrity and for load balancing.

Today, in addition to interstate pipeline storage, many storage facilities owned and operated by large local distribution companies (LDCs), intrastate pipelines, and independent operators also operate on an open-access basis, especially those sites affiliated with natural gas market centers. Open access has allowed storage to be used other than simply as backup inventory or a supplemental seasonal supply source. For example, marketers and other third parties may move gas into and out of storage (subject to the operational capabilities of the site or the tariff limitations) as changes in price levels present arbitrage opportunities. Additionally, storage is used in conjunction with various financial instruments such as futures and options contracts, swaps, etc. in ever more creative and complex ways in an attempt to profit from market conditions. Reflecting this change in focus within the natural gas storage industry during recent years, the largest growth in daily withdrawal capability has been from high deliverability storage sites, which include salt cavern storage reservoirs as well as some depleted oil or gas reservoirs. These facilities can cycle their inventories or completely withdraw and refill working gas (or vice versa)-more rapidly than can other types of storage, a feature more suitable to the flexible operational needs of today's storage users. Since 1993, daily withdrawal capability from high deliverability salt cavern storage facilities has grown significantly. Nevertheless, conventional storage facilities continue to be very important to the industry as well.
The State of Michigan has the largest volume of working capacity in the United States. The reason is primarily based on geology, but can also be attributed to the fact that it is in the industrial heartland of the United States and its industry spurred the early development of storage fields after World War II. University of Michigan professor Dr. Donald L. Katz was a pioneer in development of storage field technology, and provided significant consulting to the Michigan natural gas utility and pipeline companies during the rapid growth period of the 1950s to the 1970s.
The principal owners/operators of underground storage facilities are (1) interstate pipeline companies, (2) intrastate pipeline companies, (3) local distribution companies (LDCs), and (4) independent storage service providers. If a storage facility serves interstate commerce, it is subject to the jurisdiction of the Federal Energy Regulatory Commission (FERC); otherwise, it is state-regulated.

Owners/operators of storage facilities are not necessarily the owners of the gas held in storage. Indeed, most working gas held in storage facilities is held under lease with shippers, LDCs, or end users who own the gas. On the other hand, the type of entity that owns/operates the facility will determine to some extent how that facility’s storage capacity is utilized.

For example, interstate pipeline companies rely heavily on underground storage to facilitate load balancing and system supply management on their long haul transmission lines. FERC regulations allow interstate pipeline companies to reserve some portion of their storage capacity for this purpose. Nonetheless, the bulk of their storage capacity is leased to other industry participants. Intrastate pipeline companies also use storage capacity and inventories for similar purposes, in addition to serving end-user customers.

In the past, LDCs have generally used underground storage exclusively to serve customer needs directly. However, some LDCs have both recognized and been able to pursue the opportunities for additional revenues available with the deregulation of underground storage. These LDCs, which tend to be the ones with large distribution systems and a number of storage facilities, have been able to manage their facilities such that they can lease a portion of their storage capacity to third parties while still fully meeting their obligations to serve core customers. These arrangements are subject to approval by the LDCs’ respective state-level regulators.

The deregulation of underground storage has combined with other factors such as the growth in the number of gas-fired electricity generating plants to place a premium on high-deliverability storage facilities. Many salt formation and other high deliverability sites, both existing and under development, have been initiated by independent storage service providers, often smaller, more nimble and focused companies started by entrepreneurs who recognized the potential profitability for these specialized facilities. They are utilized almost exclusively to serve third-party customers who can most benefit from
the characteristics of these facilities, such as marketers and electricity generators.

Most existing gas storage in the United States is in depleted natural gas or oil fields that are close to consumption centers. Conversion of a field from production to storage duty takes advantage of existing wells, gathering systems, and pipeline connections. Depleted oil and gas reservoirs are the most commonly used underground storage sites because of their wide availability and lower cost to operate.

In some areas, most notably the Midwestern United States, natural aquifers have been converted to gas storage reservoirs. An aquifer is suitable for gas storage if the water bearing sedimentary rock formation is overlaid with an impermeable cap rock. While the geology of aquifers is similar to depleted production fields, their use in gas storage usually requires more base or cushion gas and greater monitoring of withdrawal and injection performance. Deliverability rates may be enhanced by the presence of an active water drive.
Salt caverns provide very high withdrawal and injection rates relative to their working gas capacity. Base gas requirements are relatively low. The large majority of salt cavern storage facilities have been developed in salt dome formations located in the Gulf Coast states. Salt caverns have also been leached from bedded salt formations in Northeastern, Midwestern, and Southwestern states. Cavern construction is more costly than depleted field conversions when measured on the basis of dollars per thousand cubic feet of working gas capacity, but the ability to perform several withdrawal and injection cycles each year reduces the per-unit cost of each thousand cubic feet of gas injected and withdrawn.

Many of the carbonate reservoirs are ancient coral reefs. These reefs make excellent storage reservoirs. They have very good porosity and permeability resulting in very high deliverability. Additionally they usually are capped by evaporate deposits such as salt or anhydrite which provide excellent seals and containment.

There have been efforts to use abandoned mines to store natural gas, with at least one such facility having been in use in the United States in the past. Additionally, the potential for commercial use of hard-rock cavern storage is currently undergoing testing. None are commercially operational as natural gas storage sites at the present time.
There are over 19,000 storage facility wells in North America, and many of them are 80 to 100 years old. These wells require continual maintenance and remediation to maintain storage field integrity and deliverability requirements. Throughout the 1990's and up until 2004 the major source of natural gas research and development (R&D) funding was provided by a mechanism imposed by the Federal Energy Regulatory Committee (FERC), but that funding was phased out entirely by 2004. At its peak, the FERC funding program raised approximately $212 million per year. A very small percentage of those funds were used for underground gas storage research. Most of that research was directed by an industry steering committee co-coordinated by the Gas Research Institute (GRI). It was determined by that committee that the primary focus for underground storage research should be on maintaining storage field integrity, storage field deliverability, and on the design and operation of storage caverns.

Important work was completed using the FERC R&D funding mechanism. Studies documented that deliverability decline is a consistent and inherent problem in all types of storage fields. Declines average between 2% and 8% per year depending of the geology and use of the storage formations. Causes of this deliverability decline were identified and remediation technologies studied and demonstrated in the field. Many storage operators have incorporated this important research in their operations and have increased capacity and deliverability of existing storage fields and at the same time abandoned poorer performing high cost fields.

Methods employed presently for deliverability enhancement and maintenance include, but are not limited to:

- Horizontal Drilling
- Acid Stimulations
- Fresh Water Washes
- Delta Pressuring
- Down Hole Remediation
- Coiled Tubing Clean-outs
- Fracture Treatments
- Well bore Enhancement (re-perforating, deepening, under reaming)
- Surface Facility Improvements (compression, processing, gathering lines, safety equipment)
The applicability of deliverability enhancement methods is dependent upon storage facility type and geology. Natural gas storage operators are estimated to have invested at least $1 billion over the past few years for storage facility deliverability maintenance and enhancements.

![Horizontal Wells by Company](chart)

The storage industry began applying horizontal drilling technology in the early 1990’s. This technology has proven very successful in improving both capacity and deliverability. DTE Energy has used this technology in a 50 year old storage field and replaced hundreds of old vertical wells with about 30 horizontal wells. This specific project has improved deliverability, improved storage field integrity and reduced O&M costs.

Current gas storage research activities are coordinated through the Gas Storage Technology Consortium (GSTC). The mission of the GSTC is to assist in the development, demonstration, and commercialization of technologies to improve the integrity, flexibility, deliverability, and cost-effectiveness of the United States’ underground gas storage facilities. Its projects are primarily funded by the US Department of Energy (DOE) with co-funding provided by the storage industry, universities and service companies.

The economics of supply and demand dictate business decisions associated with the development of new storage capacity. New underground storage development requires viable subsurface geologic conditions, incremental market demand, pipeline infrastructure for gas transportation and a corresponding volume of upstream gas supply. As intended in the Federal Energy Regulatory Commission’s (FERC) restructuring of the pipeline system, the market has been and continues to be the driving force for such investments.

New underground storage projects will effectively be built to the extent that committed long-term markets support such investments. According to the Energy Information Administration’s (EIA), September 2004 report, U.S. Natural Gas Pipeline and Underground Storage Expansions in 2003, more than 73 underground natural gas storage projects have been proposed for the period between 2004 and 2008. Twenty-six are new facilities, and 47 are expansions to existing facilities. These projects have the potential to add as much as 346 Bcf to existing working gas capacity and 17 Bcf/d to daily withdrawal capability.
Lessons learned, further improvement and proposals for the next triennium

The Basic UGS Activity Study of Study Group 2.1 should be carried on as well in the following trienniums. Because of work load respectively availability of contributors, support of the study is insufficient. Other ways of working should be considered in the following Triennium, e.g. by cooperation with consultants. Further improvements are proposed for the oncoming Triennium:

- Continuous completion of database, especially incorporating "new" storage countries and planned projects
- Incorporation of additional data: split between oil-/gas fields, company shares in individual storage facilities
- Participation of additional countries and active participants in the study work for data collection and derivation of trends
- Development of a standard data bank platform on the IGU website
- Incorporation of the pipeline system in the geo-referenced visualisation
- Extended incorporation of status and trends of the storage industry on a country basis
- Development of a more detailed prognosis on storage demand in corporation with institutes/consulting companies incorporating all relevant elements related to gas demand and gas supply variables (LNG-supplies, load, sources of supply and flexibility)
- Demonstration of best practice operation by examples.

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e-mail: Joachim.Wallbrecht@BEB.de
### Attachments

<table>
<thead>
<tr>
<th>Attachment 1</th>
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<tbody>
<tr>
<td>Attachment 2</td>
<td>Summary - UGS in the world</td>
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<tr>
<td>Attachment 3</td>
<td>Summary - UGS in the world by nations</td>
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<tr>
<td>Attachment 4</td>
<td>Glossary of relevant technical Underground Gas Storage Terminology</td>
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<td>Attachment 5</td>
<td>Relevant terms used in the Basic Activity Study - Units and definitions -</td>
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**Attachment 1**

**Study Group Members**

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* denotes study leader.
### UGS in the World

#### Summary 2004

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## UGS in the World
### Summary 2004/5 by nations

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### Basic UGS Activity Study

**Region** | **Nation** | **Storage Type** | **No. of UGS** | **Volume** | **Gas Withdrawal Capacity** | **No. of Installed** | **Installed** | **Injection Wells** | **Storage Wells** | **Disposal Wells** | **Planned** | **Undeveloped** | **No. of Working Peak Gas Withdrawal Volume Capacity** | **No. of Working Peak Gas Withdrawal Volume Capacity** | **Total** | **Total** |
---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
Middle East | Total | 7 | 1.725 | 6.120 | 2.062 | 1.611 | 506 | 41 | 1,550 | 475 | 6 | 4,525 | 2,725 | 13 | 12,995 | 5,263 |

**North America**

**Total**

- **Abandoned**
  - Aquifer
  - Oil/Gas Field
  - Rock Cavern
  - Salt Cavern

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**USA Total**

- **Abandoned**
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  - Oil/Gas Field
  - Rock Cavern
  - Salt Cavern

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**South America**

**Total**

- **Abandoned**
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  - Oil/Gas Field
  - Rock Cavern
  - Salt Cavern

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**Uruguay Total**

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## Basic UGS Activity Study

**Region** | **Nation** | **Storage Type** | **No. of Cusion UGS** | **Gas Volume** | **Installed Working Peak Capacity** | **Installed Injection Wells** | **Storage Wells** | **Observation Wells** | **Disposal Wells** | **Planned Working Peak Capacity** | **Undeveloped Working Peak Capacity** | **No. of Green Field Working Peak Capacity** | **No. of Working Peak Capacity** | **Total Working Peak Capacity** | **Total Gas Withdrawal Volume Capacity**
---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---
**South America** Total | | | 2 | 120 | 200 | 122 | 87 | 7 | 12 | | | | | | | |
**West Europe** | | Abandoned | | | | | | | | | | | | | | | |
| | Aquifer | | | | | | | | | | | | | | | |
| | Oil/Gasfield | 4 | 3.355 | 2.820 | 1.445 | 1.279 | 180 | 29 | 1 | 509 | 0 | 1 | 2.637 | 1.300 | | 5 | 5.966 | 2.745 |
| | Rock Cavern | | | | | | | | | | | | | | | |
| | Salt Cavern | | | | | | | | | | | | | | | |
**Austria** Total | | | 4 | 3.355 | 2.820 | 1.445 | 1.279 | 180 | 29 | 1 | 509 | 0 | 1 | 2.637 | 1.300 | | 5 | 5.966 | 2.745 |
**West Europe** | | Abandoned | | | | | | | | | | | | | | | |
| | Aquifer | 1 | 550 | 550 | 525 | 250 | 11 | 25 | 80 | 125 | | | | | | | |
| | Oil/Gasfield | | | | | | | | | | | | | | | |
| | Rock Cavern | | | | | | | | | | | | | | | |
| | Salt Cavern | | | | | | | | | | | | | | | |
**Belgium** Total | | | 1 | 550 | 550 | 525 | 250 | 11 | 25 | 80 | 125 | | | | | | | |
**West Europe** | | Abandoned | | | | | | | | | | | | | | | |
| | Aquifer | 1 | 760 | 400 | 450 | 100 | 12 | 60 | 1 | 800 | 900 | | | | | | | |
| | Oil/Gasfield | | | | | | | | | | | | | | | |
| | Rock Cavern | | | | | | | | | | | | | | | |
| | Salt Cavern | 1 | 300 | 420 | 600 | 165 | 7 | 400 | 600 | | | | | | | |
**Denmark** Total | | | 2 | 1,060 | 820 | 1,050 | 265 | 10 | 60 | 1 | 1,200 | 1,500 | | | | | | |
**West Europe** | | Abandoned | | | | | | | | | | | | | | | |
| | Aquifer | 12 | 13,890 | 10,775 | 7,202 | 4,688 | 391 | 182 | 0 | 0 | | | | | | | |
| | Oil/Gasfield | | | | | | | | | | | | | | | |
| | Rock Cavern | | | | | | | | | | | | | | | |
| | Salt Cavern | 3 | 598 | 868 | 1,721 | 953 | 36 | 0 | 0 | | | | | | | |
**France** Total | | | 15 | 14,488 | 11,843 | 8,923 | 5,641 | 427 | 182 | 0 | 0 | | | | | | | |
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## Basic UGS Activity Study

### IGU - WOC 2 - SG 2.1

**2003 – 2006**

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<td>3.267</td>
<td>2.760</td>
<td>693</td>
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### World

- **Abandoned**: 2
- **Aquifer**: 86
- **Oil/Gasfield**: 453
- **Rock Cavern**: 2
- **Salt Cavern**: 63

### UGS Countries 38

- **Total**: 606

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**Table Dimensions**: 595.2x842.0

**Image Dimensions**: 74x71 to 525x763

**Image Resolution**: 37x281 to 55x303

**Page Number**: 67
### Scope of Glossary

The glossary covers the relevant technical terminology related to the storage of natural gas in underground gas storage facilities. As the technology is similar, the terminology can be applied for the storage of hydrogen, CO₂, O₂ and other gases.

### Glossary of relevant technical Underground Gas Storage Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td><strong>Underground Gas Storage (UGS)</strong></td>
<td>All subsurface and surface facilities required for the storage and for the withdrawal and injection of natural gas. Naturally or artificially developed containments in subsurface geological strata are used for the storage of natural gas. Several subsurface storage horizons or caverns may be connected to one common surface facility, which is referred to as the underground gas storage location.</td>
</tr>
<tr>
<td><strong>Type of Storage</strong></td>
<td>There are several types of underground gas storage facilities, which differ by storage formation and storage mechanism:</td>
</tr>
<tr>
<td>Porous rocks</td>
<td>- Storage in aquifers&lt;br&gt;- Storage in former gas fields&lt;br&gt;- Storage in former oil fields</td>
</tr>
<tr>
<td>Caverns</td>
<td>- Storage in salt caverns&lt;br&gt;- Storage in rock caverns (including lined rock caverns)&lt;br&gt;- Storage in abandoned mines</td>
</tr>
<tr>
<td><strong>UGS in Operation</strong></td>
<td>Storage facility capable to inject and withdraw gas</td>
</tr>
<tr>
<td><strong>Greenfield Storage Project</strong></td>
<td>New underground storage development project, not based on any existing storage facilities</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Storage Capacity</strong></td>
<td>Total ability of a storage facility to provide working gas volume, withdrawal rate and injection rate</td>
</tr>
<tr>
<td><strong>Inventory</strong></td>
<td>Total of working and cushion gas volumes stored in UGS</td>
</tr>
<tr>
<td><strong>Cushion Gas Volume (CGV) or Base Gas</strong></td>
<td>Gas volume required in a storage field for reservoir management purpose and to maintain an adequate minimum storage pressure for meeting working gas volume delivery with the required withdrawal profile. In caverns, the cushion gas volume is also required for stability reasons. The cushion gas volume may consist of recoverable and non-recoverable in-situ gas volumes and injected gas volumes</td>
</tr>
<tr>
<td><strong>Working Gas Volume (WGV)</strong></td>
<td>Volume of gas in the storage above the designed level of cushion gas volume, which can be withdrawn/injected with installed subsurface and surface facilities (wells, flow lines, etc.) subject to legal and technical limitations (pressures, velocities, etc.). Depending on local site conditions (injection/withdrawal rates, utilization hours, etc.) the working gas volume may be cycled more than once a year (see annual cycling capability).</td>
</tr>
<tr>
<td><strong>Withdrawal Rate</strong></td>
<td>Flow rate at which gas can be withdrawn from storage fields and caverns, based on the installed subsurface and surface facilities and technical limitations.</td>
</tr>
<tr>
<td><strong>Withdrawal Profile</strong></td>
<td>Dependency between the withdrawal rate and the withdrawn working gas volume. The withdrawal profile and the time (utilization hours) required for withdrawal are indicative of the layout of an underground gas storage facility. The withdrawal profile usually consists of a constant rate (plateau) period (see ‘Nominal Withdrawal Rate’) followed by a period of declining rates.</td>
</tr>
<tr>
<td><strong>Peak Withdrawal Rate</strong></td>
<td>Maximum flow rate which can be delivered based on the installed subsurface and surface facilities and technical limitations. This flow rate is normally reached when the storage is at its maximum working gas volume, i.e. maximum allowable storage pressure. Also known as ‘maximum design deliverability’</td>
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<td>-------------------------------</td>
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</tr>
<tr>
<td><strong>Nominal Withdrawal Rate</strong></td>
<td>Withdrawal rate representing the deliverability of the subsurface and surface facilities available over an extended period of withdrawal (plateau period). This rate corresponds to the constant rate period of the withdrawal profile</td>
</tr>
<tr>
<td><strong>Last Day Withdrawal Rate</strong></td>
<td>Withdrawal rate which can be delivered based on the installed subsurface and surface facilities and technical limitations when the storage reservoir or cavern is at or close to its cushion gas volume</td>
</tr>
<tr>
<td><strong>Injection Rate</strong></td>
<td>Flow rate at which gas can be injected into a storage field and cavern, based on the installed subsurface and surface facilities and technical limitations</td>
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<tr>
<td><strong>Injection Profile</strong></td>
<td>Dependency between the injection rate and the injected working gas volume. The injection profile and the time (utilization hours) required for injection are indicative of the layout of an underground gas storage facility. The injection profile may include a period of declining rates close to maximum storage pressure</td>
</tr>
<tr>
<td><strong>Annual Cycling Capability</strong></td>
<td>Number of times the working gas volume can be withdrawn and injected on an annual basis</td>
</tr>
<tr>
<td><strong>Undeveloped Storage Capacities</strong></td>
<td>Additional storage capacities which could be developed in an existing underground gas storage, e.g.: by additional gas injection, increase of the maximum storage pressure, decrease of the minimum storage pressure, additional facilities (wells, re-compression) etc.</td>
</tr>
<tr>
<td><strong>Storage Well</strong></td>
<td>Well completed for gas withdrawal and/or injection</td>
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</table>
### Basic UGS Activity Study

**Observation Well**
Well completed for the purpose of monitoring the storage horizon and/or the overlying or underlying horizons for pressures, temperatures, saturations, fluid levels, etc.

**Auxiliary Well**
Well completed for other purposes, e.g. water disposal

**Abandoned Well**
Well permanently out of operation and plugged

**Initial Reservoir Pressure**
Initial pressure conditions encountered in a porous formation before any change due to operation of the reservoir, for example: start of production or injection. The initial pressure is related to a reference depth/datum level. Also known as ‘discovery pressure’

**Maximum Allowable Storage Pressure**
Maximum pressure of the storage horizon or cavern, normally at maximum inventory of gas in storage. This pressure has to be engineered in order to ensure the integrity of the storage field. The maximum allowable pressure is related to a reference/datum depth and normally has to be approved by authorities

**Minimum Storage Pressure**
Minimum pressure of the storage horizon or cavern, normally reached at the end of the decline phase of the withdrawal profile. The minimum pressure is related to a reference/datum depth. The minimum pressure of caverns has to be engineered and approved in order to ensure stability

**Pressure Datum Level**
Reference depth at the porous storage level, normally related to the sea level, used for pressure normalisation and correlation throughout the reservoir. In caverns the depth below surface of the last cemented casing shoe is normally used as the reference level for pressures

**Depth Top of Structure/Cavern Roof Depth**
Minimum true vertical depth from the surface down to the top of the storage formation/cavern roof

**Caprock of a Porous Storage**
Sealing formation for gas overlying the porous storage horizon. Caprock prevents the migration of oil and gas out of the storage horizon
| **Containment** | Ability of the storage reservoir or cavern and the storage well completion to resist leakage or migration of the fluids contained therein. Also known as the integrity of a storage facility |
| **Closure** | Vertical distance between the top of the structure and the spill point |
| **Spill Point** | Structural point within a reservoir, where hydrocarbons could leak and migrate out of the storage structure |
| **Areal Extent of the Storage Structure** | Subsurface area of the storage formation at its maximum gas water contact extent |
| **Cavern Convergence** | Reduction in geometrical cavern volume caused by e.g. salt creeping. The annual reduction of the geometrical cavern volume is expressed by the convergence rate |

Gas volumes are related to temperatures and pressures at normal conditions: $273.15 \text{ K (0°C)}$ and $1,01325 \text{ bar}$
### Data Bank Data/Units

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<th>Metric Units</th>
<th>English Units</th>
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<td>Installed max/planned/undeveloped Working Gas Volume</td>
<td>$10^6\ m^3(Vn)$</td>
<td>(MMcf)</td>
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<tr>
<td>Cushion Gas Volume incl. inj. + indig.</td>
<td>$10^5\ m^3(Vn)$</td>
<td>(MMcf)</td>
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<tr>
<td>Peak Withdrawal Rate</td>
<td>$10^3\ m^3(Vn)/h$</td>
<td>(Mcf/d)</td>
</tr>
<tr>
<td>Nominal Withdrawal Rate</td>
<td>$10^3\ m^3(Vn)/h$</td>
<td>(Mcf/d)</td>
</tr>
<tr>
<td>Last Day Withdrawal Rate</td>
<td>$10^3\ m^3(Vn)/h$</td>
<td>(Mcf/d)</td>
</tr>
<tr>
<td>Injection Rate</td>
<td>$10^3\ m^3(Vn)/h$</td>
<td>(Mcf/d)</td>
</tr>
<tr>
<td>Installed Compressor Power</td>
<td>(MW)</td>
<td>(Horsepower)</td>
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<td>Areal Extent Storage Reservoir</td>
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<td>(acres)</td>
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<td>Minimum Storage Pressure @ Datum Level</td>
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<td>(Psig)</td>
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<td>Maximum Allowable Storage Pressure @ Datum Level</td>
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<td>(Psig)</td>
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<td>Initial Reservoir Pressure @ Datum Level</td>
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<td>(Psig)</td>
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<td>Pressure Datum Level below Surface</td>
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<td>Depth Top Structure/Cavern Roof</td>
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<td>Maximum Depth of Storage Structure</td>
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<td>Net Thickness (metre)</td>
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<td>(feet)</td>
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<td>Porosity (average)</td>
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<td>Permeability (average)</td>
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<td>Reservoir Temperature</td>
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<td>Cavern Height average</td>
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<td>Cavern Diameter average</td>
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<td>Distance between Caverns average</td>
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<td>Convergence Rate of Caverns</td>
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<td>Total Convergence of Caverns</td>
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<td>Remaining GIP before UGS Operation in Gasfield</td>
<td>$10^5\ m^3(Vn)$</td>
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<td>Gasquality $H_{sup}$</td>
<td>(kWh/m³)</td>
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UGS: Achievements and trends in the field of technical efficiency and safety

23rd World Gas Conference, Amsterdam 2006

A. Main author
S. Khan
GAZPROM
RUSSIA

Co-authors:
A. Grigoriev
VNIIGAZ, RUSSIA
ABSTRACT

Underground gas storage has been developing rapidly and is now an integral part of the gas chain providing uniformity and reliability gas supplying.

This paper describes results of the activity of Study Group 2.2 IGU Working Committee 2 Storage during triennium 2003 – 2006. The activity of group 2.2 is devoted to studying of world experience in the field of technology of underground gas storage and to definition of the most perspective technologies and directions providing high competitiveness of this branch. The questionnaire analysis used as a basis for the study. The questionnaire on underground gas storage, covering wide spectrum of technological questions and describing modern conditions and tendencies in development of underground storage, is developed for this purpose. The questionnaire designed on the basis of its previous version triennium 1998-2001. During the 1997 to 2000 triennium, WOC 1 which encompassed E&P, Treatment and UGS, had focused (SG 1.1.) on by then new techniques and practice, likely to promote the efficiency of UGS (“Improving the performance of existing UGS”).

The introducing of the temporary factor is its main difference. It has enabled to conduct comparison of the answers in time and to determine the tendencies in UGS development. The efforts restricted to technology, and avoid sensitive regulatory and economic issues. A review and update of the questionnaire issued in 1997/98 was useful, in particular by investigating if the techniques believed at that time by UGS operators to be the most promising have been implemented by them since, and if the results are meeting their expectation. The questionnaire also encourages publication of effective “case studies”, depicting briefly the use of new technology as an answer to technical challenges, and the improvement achieved.

The expansion of world gas demand will lead to a continuous increasing of storage capacity in future, and many new facilities will have to be constructed to meet future needs. The analysis of data shows that gas storage technologies are being developed that allow the efficiency of UGS creation and operation to be enhanced and new market requirements to be met.
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Introduction

The Working Committee 2 (WOC 2) - Underground gas Storage (UGS) - of the International Gas Union (IGU) is developing within the triennium 2003 - 2006 reports for the World Gas Conference in Amsterdam in 2006 which based on the Study Groups’ work.

In order to investigate the selected topic - Achievements and trends in the field of technical efficiency, environment stability and safety - WOC 2 established the study group SG 2.2.

Members of the Study Group 2.2 are:
- Sergey A. Khan (Russia)
- Alexander Grigoriev (Russia)
- Otto Geier (Germany)
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- Neboja Lemagic (Serbia and Montenegro)
- Leif Hansen (Denmark)
- Pierre Marion (France)

Increasing gas consumption and effective gas supply can be effectively provided only with UGS. Progressive technical methods play an important role for improving the performance of existing and future gas storages. Natural gas is usually stored in natural geological reservoirs such as depleted oil or gas fields or water-bearing sands sealed on top by an impermeable cap rock. For smaller volumes of gaseous storage facilities different types caverns are used:
- Storage in salt caverns
- Storage in rock caverns (artificially developed, including lined and unlined rock caverns)
- Storage in abandoned mines

The existing UGS facilities were developed to balance the gas demand with supply potential (including or not supplier swing) the whole year long, and optimize the utilization of the transportation system. For several countries they also represent strategic reserves in case of supply shortage, thus securing their sustainable development. As can be seen from the above table most of these underground storage facilities are located in depleted fields (around 80% of total volume), the remaining 20% being located in either aquifers or salt caverns.

The development in UGS technologies contributes to improving the efficiency of UGS facilities in optimizing the working volume and the withdrawal rate for a given storage and at minimal cost and under safe conditions. Technologies available to meet this goal include detailed geological reservoir description accompanied by migration simulation allowing optimal management of the UGS reservoir, horizontal drilling to increase deliverability and automatisation of UGS processes to reduce operational costs. These technologies will enable, in particular, to raise the maximum allowable pressure for a given storage.

The developed questionnaire covers various types of storages and integrates different on character and the contents questions in one review. Introduction of the time factor has allowed to lead comparison of answers in time and to determine the main tendencies in UGS development in the world.

Questions are grouped in 5 basic parts:

1. General Aspects
2. Reservoir related
20 answers from 15 countries have arrived were received on the offered questionnaire, including the Europe (12), Asia (1), America (2) that allows relying on imposing appearance of the collected information. Responses represent near 30% of total estimated UGS working volume.

For visualization the arrived answers have been presented in the form of charts on which horizontal axis the offered versions of answers are listed. A vertical axis for the majority of charts - relative frequencies of positive answers. The estimation of importance degree of this or that technology also took into consideration.

1. GENERAL ASPECTS

1.1 What improvements (last 3-5 years) did you carry out on existing gas storages?

**Future trends**

From the questionnaire replies it could be deduced that the first three places in last 3-5 years occupied by following answers:

- Increase working volume of existing facilities
- Improve safety performance
- Improve environmental performance

First three places in future 3-5 years occupied by following answers:
• Increase working volume by expansion (adding new facilities)
• Improve safety performance
• Increase delivery capacity by expansion (adding new facilities)

All types of improvements are presented in answers sufficiently often. Some of respondents have expectancies to improve quality safety in future.

1.2 Which techniques do you use to analyze the performance of your storage?

<table>
<thead>
<tr>
<th>Technique</th>
<th>Relative Rating</th>
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<tbody>
<tr>
<td>Cost target setting and monitoring</td>
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<td>Benchmarking</td>
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<td>3rd party evaluation</td>
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<td>Management judgment</td>
<td>0.6</td>
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<tr>
<td>Key performance indicator setting</td>
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All enumerated techniques are rather often used in practice.

First place in all times occupied by *Cost target setting and monitoring*
Second and third places in last 3-5 years and at present occupied by
• *Management judgment*
• *Key performance indicator setting*

Benchmarking and 3rd party evaluation shows constant growth. This is evidence availability of these techniques.
1.3 What are your most significant drivers for improvement?

All respondents mark Costs and Legal requirements as the main drivers in this point.

First three places at present and last 3-5 years occupied by following answers:

- Costs
- Legal requirements
- Market considerations

In future 3-5 years second-third positions will change their places.

Some or respondents attach importance to Service quality or Opportunity to earn storage related revenue.
1.4 What new techniques do you prefer to use in future?

Relatively not many respondents prefer to use new techniques indicated in this question. The most employed technique at present is CO$_2$ sequestration (16% of respondents use it now). This technique and Lined Hard Rock Caverns also have the most dynamic growth in future.

First three places in future 3-5 years occupied by following items:
- CO$_2$ sequestration
- Lined Hard Rock Caverns
- Abandoned Mines

The least popular answer is Compressed air storage. Only one respondent is going to use it in near future. Nevertheless, all indicated techniques show the rating growth in time (average 50%).

2. RESERVOIR RELATED
2.1 What technologies do you apply for a better geological-structural definition of the trap?

First two places at present and in future 3-5 years occupied by following technologies:

- Re-interpretation
- 3D-seismic

3-D technique is widely used. More 50% companies use this technique. This technique is becoming standard for imaging subsurface structures.

The third place at present occupied by 2D-seismic but in future 3-5 years Seismic attribute mapping will be more preferred. Seismic attribute mapping and Re-interpretation technology are also used for monitoring gas spill point. The most dynamic growth in time (400%) has answer: 4D-seismic (time lapse seismic). But simultaneously this answer remains the most infrequent. Only one respondent use this technique now. 2D-seismic technology loses popularity in time.

Besides indicated techniques, respondents mark such new technologies as:

- Seismic Inversion process
- Integrated Reservoir modeling
- Gravimetry
- Crosswell Seismic +/- 3 m
2.2 How do you determine limits for the maximum working reservoir pressure of your storage?

Maximum allowable storage pressure strongly influence on storage characteristics. This level is an indication of the potential utilization of storage capacities. The limitation in the maximum pressure is connected with the risk of gas spilling. It is known that in many countries exist legislative regimes concerning maximum allowable storage pressure.

The pressure range for the storage operating cycle depends upon (1) the safe upper limit of the reservoir pressure (bottom hole or surface pressure), (2) the flow capacity of the wells, and (3) compression requirements when injecting gas into the reservoir or delivering to market.

The highest-pressure level possible normally will provide the maximum storage capacity and the wells will have the highest flow capacity. Required storage deliverability services (daily or seasonal volumes) need maximum storage pressure and gas-in-place volumes prior to the withdrawal season.

Unfortunately, this question has minimum answers. Among answers there was references to norms (DIN EN 1918).

It was noted that in Aquifer storage: maximum pressure is limited by the need to keep the gas within the structure (avoid gas overriding). In Salt cavern storage: maximum pressure is determined by the max. pressure gradient 0.184 bar/meter.

Obviously there is not alternation to techniques of determination of maximum allowable storage pressure based on capillary threshold theory and fracture pressure. The maximum allowable pressure normally has to be approved by authorities.

2.3 What is the trends for max allowable pressure gradient for your storage?

**UGS in aquifer** the most common value is up to 1.4 times higher than level of initial pressure.

**In Oil&gas field** value of pressure gradient in almost 50% answers is equal to initial level. In rest cases, it is allowable to have up to 1.2 times initial reservoir pressure more. The highest level of pressure gradient for Oil&gas field announced in Spain – up to 1.4 of initial pressure.

**In salt caverns** average level allowable pressure gradient is 1.8 – 1.9 bar 10/m.
There is no defined tendency to increasing of maximal allowable pressure gradient in future. Obviously the upper limit of this parameter is already reached. Only few respondents mark slight growth of this parameter in future.

### 2.4 Which type of reservoir modelling tools do you use?

![Graph showing relative rating of reservoir modelling tools](image)

Similarly to oil and gas production fields, gas storage management requires an accurate reservoir modeling in order to monitor the gas bubble extension and maximize the potential deliverability of the UGS.

First three places in last 3-5 years occupied by following answers:

- Numerical reservoir simulation
- Integrated geological modelling in reservoir simulation
- Analytical (material balance) pore reservoir model

Numerical reservoir simulation has become a necessary requisite for realizing the UGS potential. Integrated multidiscipline design environment approach also has become available in the storage business.

First three places in future 3-5 years occupied by following answers:

- Numerical reservoir simulation
- Integrated geological modelling in reservoir simulation
- Integrated surface and subsurface simulation/model

The last type of model has maximal growth. There are no respondents, who not use any models. Simulation model of gas mixing is used in only a few cases for specific questions or as an isolated study. Separate operators are applying their own developed tools to calculate special modeling issues.
2.5 What monitoring techniques do you use to improve geological, technical, operational safety?

Answers show that all types of monitoring techniques are used during UGS exploitation.

First three places in last 3-5 years, at present and in future 3-5 years occupied by following items, which are most important ones:

- Real time well performance monitoring (flow, pressure)
- Gas quality monitoring
- Automated gas quality monitoring

The most dynamic growth of utilization techniques in time marked by following items:

- Permanent down hole gauges
- Remote control
- Real time sand production monitoring

There is observed decreasing in using following techniques:

- Well testing
• Full shift
• Gas quality monitoring

Well testing is recognized by many operating oil and gas companies to be the most hazardous operation they routinely undertake.

Among others there were marked:
• Check of annulus pressure and visual inspection of surface facilities.
• Caliper measurements

2.6 Which technical measures do you implement to improve the performance of your storage reservoir?

For all type of UGS

First place in past, present and future occupied by Reduction of pressure losses. Residual technical measures encountered in answers with almost equal frequency. The most dynamic growth in time marked by answer Fast change of operational mode. This measure in 3-5 years will occupy second place amongst answers. The answer Minimizing size of cushion gas also has growth in time. This measure in 3-5 years will occupy third place amongst answers.
For pore storages First place in all times hold Techniques of sand control to prevent the reservoir destruction.

Second place in last 3-5 years are occupied by following items:
- Stimulations for skin/scale removal
- Measures used to diminish water influx
- Optimum strategy of forming the projected gas saturated volume
- Infill drilling

At the same time two last of these items are lost their positions at present and will lost their positions in future. The answer Minimize cost of cushion gas (by using alternatives) has high growth in time. But simultaneously this answer remains the most infrequent.
**For caverns** Leaching of new caverns to improve the performance remains the main measure.

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\includegraphics[width=\textwidth]{chart.png}
\end{center}

*Enlarge existing caverns* implemented in 3-5 times rare.

### 2.7 Which measures do you implement to improve the leaching of caverns?

The response in the questionnaire on the leaching item was traditionally poor, signifyce low activity in respect to caverns. Only three responses received on this question for last and at present. Five responses received on this question for future. Therefore, answers may not reflect true situation. Following technique are mentioned among measures to improve the leaching of caverns in future with equal frequency:

- Enlarging existing caverns
- Leaching of lens shaped caverns in thinner salt layers
- Networking of caverns
- Sump sealing Re-use leaching brine

BEB Transport und Speicher Service GmbH implement *Use blanket gas.*

Respondent from this company suppose:

- *Net working of caverns has not to be an improvement.*
- *In case of big salt domes lens shape caverns are not an improvement*
There are no respondents, who not use high temperature leaching and use additives in leaching process.

3. WELL RELATED

3.1 Which kind of well concepts is (will be) used in your company?

Conventional wells hold first place (80%) in all times. Individual operators use this wells combined with slanted wells for heterogeneous reservoirs.

Horizontal wells, which give additional deliverability and reduce surface environmental impact, used many fewer – 40% at present and 50% in 3-5 years.

Extended reach wells to increase drainage area and reach reservoir target from an acceptable surface location, mentioned in 20% responses at present and 40% in 3-5 years – this figure allow to take second place.

Re-entry referred in 30% responses at present and 35% in 3-5 years. Besides re-entry horizontal leg extensions are also used.
Larger well bores are widespread at present – 35% and 40% in 3-5 years. In UGS gas wells, completions with larger OD casing strings are more economical than drilling of additional wells in an existing area.

Recompletion (larger size tubulars) used at present in 25% and in 3-5 years in 20% responses.

Some of respondents use conversion of observant wells to Injection well. Certain of respondents operate wells with already best performances and big size tubulars so it is not necessity to recomplete or enlarge it.

Second place at present hold Open hole completions.

Multilateral wells used relatively seldom dependent on technical development especially ensuring integrity of the well at present – 10% and 30% in 3-5 years.

No one answer point Snubbing drilling and Laser drilling at all. Snubbing drilling will be planed to use in 3-5 years (22%). Laser drilling possible much in the future. Wait for technology to be tried and true and cost effective

Among other well concepts CSG Drilling was mentioned.

The most dynamic growth in time marked by answer Coiled tubing drilling at present – 5% and 25% in 3-5 years. It is speedy and easy to use.

Underbalanced drilling, which prevents formation damage, also is very perspective technology (at present – 10% and 35% in 3-5 years).

The technology pad drilling - multiple individual wellbores from the same surface location also used in several companies.
3.2 Did you experience any problems in implementing new well concepts?

Less than 50% respondents marked any problems in this area. Two main problems as it is evidently from answers Well bore damage is and Cement bond quality. Well bore damage hold first place at present and in last 3-5 years. The problem intensifies when reservoir pressure was less than hydrostatic.

Cement bond quality, which is necessary for safety, hold second place. Bad results in cementation marked in 35% new well concepts problems. Gained experience in Drilling in Fluid Application DIF to reduce well bore damage during workover and drilling activity. Progress in technology conduct to reduction these problems in future 3-5 years.

Hole stability is less trouble problem dependent on location, some enlarged well diameter, due to mud system, change of mud resulted in improvements. Now it mentioned in 10% of new well concepts problems. In 3-5 years, this figure remains the same.

Closely connected with this problem is Sand control it mentioned in 10% of new well concepts problems.
In general, the forthcoming volume of problems to become smaller.
3.3 What techniques do you apply for well completion concepts?

All of respondents answered this point are widely apply all numbered in question well completion concepts.

First three places at present and in future 3-5 years occupied by following items:

- Sand screen technology
- Gravel packs technology
- Monobore completion

Permanent downhole monitoring for knowing real pressure is also remain actual. Gained experiences in quartz gauges application. In the future we need to apply the fiber optics to reduce gauge failure.
3.4 Which stimulation technology do you use for maintain and improve deliverability?

Approximately 50% respondents gave answers this question. Apparently, this topic is confidential enough. It is well known that because of formation damage, individual gas storage wells are prone to deliverability loss at a reported average rate of 5% per annum. Although new wells can of course increase field deliverability, effective stimulation or re-stimulation of existing wells can be a more cost-effective approach for maintaining deliverability.

The question is divided according to two concepts: conventional completion and coiled tubing applications. The answers show there is no difference between two mention concepts.

The most prevalent stimulation technologies to increase gas deliverability in all concepts are:

- Acidizing
- Fresh water treatments
Traditional methods for deliverability maintenance such as blowing the wells, coil tubing cleanouts, reperforating and acidizing account for over 80% of all storage well remediation and generally provide only limited temporary deliverability enhancement. Precipitation of iron during acidizing marked as a possible problems.

Among other technologies there was mentioned:

- Fresh water wash to dissolve salt
- Hydroblast to clean out wellbore fill and scale
- Fresh water jet washing
- EDTA treatments.

The less prevalent stimulation technologies are:

- fracking
- frack packs

Advanced fracture stimulation technology include tip-screen out fracturing, hydraulic fracturing with liquid CO$_2$ and proppant, extreme overbalance fracturing, and high-energy gas fracturing. These new technology in spite of its high potential has not yet wide distribution. It is mentioned some poor performance of polymer frac fluids. Some times the polymer doesn’t mix or break as designed.
3.5 Which new methods are you using to ensure the integrity of subsurface equipment?

The integrity of subsurface equipment is a key factor in maintaining efficiency of the storage.

*Annulus pressure monitoring* has first position. All remaining measures (see below) encountered with almost equal frequency (60-70%).

- Corrosion monitoring
- Kathodic protection
- Annulus fluid level control
- Regular inspection programme

Some operators not use kathodic protection for well tubulars – pipelines only.

Among other technologies there was mentioned:
- Injection of biocide into the annulus
- Investigating check values to allow annulus gas to vent without allowing oxygen into the annulus for Annulus fluid level control
- Microvertilog, D-mag log, Neutron and temperature logs for corrosion monitoring.
The answers show constancy of existing status in time.

4. **SURFACE FACILITIES RELATED QUESTIONS**

4.1 What techniques do you use to avoid hydrate formation?

First three places in last and in future 3-5 years occupied by following measures:
- Methanol inhibition
- Gas heating
- Glycol inhibition

Heat tracing for example electrical heating of withdrawal line just during start up presents in 30% answers. Besides Methanol inhibition also investigating kinetic inhibitors.

Techniques of silicagel drying is the least mentioned.

Frequent pigging to remove free water collection was mentioned as other technology.

Based on the responses it is concluded that improvement on avoiding hydrate is rarely implemented.
4.2 What techniques do you use on corrosion management?

There is almost no any change in corrosion management techniques with time during concerned period.

First two places with rates 60%-75% at present and in 3-5 years occupied by following measures:

- Cathodic protection
- Wall thickness monitoring

Following three places with rates 40% at present and in 3-5 years occupied by following measures:

- Material choice
- Chemical inhibitors
- Coating

Last measure used prior to allowance into transmission system for gas quality requirements.

Stainless steel using marked in 15% answers. This techniques dependent on gas environment and pressures. Corrosion coupons techniques will be used in Spain. About 10% respondents do not use any corrosion management. Promising technologies are using of non-metallic, fibreglass reinforced line pipe.
4.3. What technology do you apply on gas treatment and gas quality management?

Gas treatment and gas quality management are very important for effective gas supply.

First place at present and in future occupied by additional to dehydration and inhibition technology:

- **Mechanical separation**
  
  Design changes to optimize mechanical separation implemented as before.

Following place with rates 40% at present and 50% in 3-5 years occupied by:

- **Automation**
  
  These technology used first of all in gas heating, pressure and flow optimization.

Sufficiently regnant measures remains:

- **Design changes**
- **Facility testing**
- **Utilization of no glycol dehydration**
- **Computer assisted optimisation**

The least factor is availability. High availability of the equipment is necessary to supply reliability. Low place of this factor in used technologies most likely connected with high availability level already achieved. In general, there are almost no any changes in gas treatment and gas quality management during last time.

*Computer assisted optimization and Automation* shows slightly growth popularity.
4.4 What improvements did you carry out on compression performance?

First place at present with slighty lessening in future confidently occupied by measure:
- **Optimization of operation conditions** (capacity, fuel, operating points)

Second places with rates 50% at present essential lessening in future occupied by:
- **Turbines**

In future 3-5 years value of **Turbines** descend to 30% The advantage of turbines over conventional compressors is well known and this lowering can be explained that majority UGS already equipped with compressors.

The meaning of following measures will change in future:
- **Adoption of LoNOx system** – from 35% to 40% - become second-third place
- **New technology for compressor & engines** – from 25% to 40% - become second-third place
- **Use of re-compression** stable 35%
- **Withdrawal expansion** – from 15% to 20%
- **Use for power generation** – from 10% to 15%
- **Heat recovery system** – from 10% to 15%.

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5. SAFETY RELATED

5.1. What techniques do you use on safety?

There are no essential changes in safety aspects. All indicated techniques are widely used by all respondents (exception with H₂S prevention). It is difficult to deterring first places among measures listed below:

- Safety studies and audits
- Preventive technical installations
- Subsurface safety Valves
- Diagnosis of critical operations
- Enhanced monitoring
- Best knowledge of the geological situation
- Periodical gas inventory and control of caprock tightness
- Preventive maintenance
- Accident analysis

By the mid-nineties, maintenance projects (maintenance, inspection, revamp) were carried out on the basis of individual site-related experience taking into account:

- legal regulations, decrees, rules
- manufacturers instructions
• operating experience
CONCLUSION

The results of the study show that in general storage industry is a part of the oil and gas industry and uses the same technologies. For the past of 5-6 years the total picture with technologies in underground storage is kept stable, however there are some changes in separate directions.

From answers follows, that the actual problem of increase in working volume storage gas in a greater degree is solved due to creation of new objects, rather than expansions existing. In spite of the fact that expansion is prove to be more economy. It is connected by that now on many operating objects the opportunity of expansion are close to a limit.

Problems of safety still take the important place in activity of the companies.

First place among techniques used to analyze the performance of storage all times occupied by cost target setting and monitoring. The most significant drivers for improvement are costs, legal requirements and market considerations.

The most popular new techniques in gas storage remain:
- CO₂ sequestration
- Storage in lined Hard Rock Caverns
- Storage in abandoned Mines

All indicated techniques show the rating growth in time (average 50%), but relatively not many respondents plan to use new techniques now.

Among the methods used for definition of characteristics of layers still are most popular 3-D seismic and re-interpretation, at falling a role of 2-D seismic. However 4-D seismic, despite of significant prospects now is used extremely seldom.

There is no defined tendency to increasing of maximal allowable storage pressure gradient in perspective. Obviously the upper limit of this parameter is already reached. Only few respondents mark slight growth of this parameter in future.

Similarly to oil and gas production fields, gas storage management requires an accurate reservoir modeling in order to monitor the gas bubble extension and maximize the potential deliverability of the UGS. According to the questionnaire replies, these types of simulation/model are most common.
- Numerical reservoir simulation
- Integrated geological modeling in reservoir simulation
- Integrated surface and subsurface simulation/model

The most important monitoring techniques used to improve geological, technical, operational safety are:
- Real time well performance monitoring (flow, pressure)
- Gas quality monitoring
- Automated gas quality monitoring
- The most dynamically developing perspective technologies are:
  - Permanent down hole gauges
  - Remote control
  - Real time sand production monitoring

UGS operation especially aquifer UGS, is accompanied with partial gas losses f which are defined by gas overflows in overlying adjournment and gas losses in the storage volume. Reduction of pressure losses remains the most significant measure to improve the UGS performance. The risk of gas spilling
needs to be modeled and reservoir fluid movement and material balance need to be monitored closely. Simulation need to be comprehensive this has fostered the development of real-time instrumentation.

The majority of UGS wells are traditional vertical wells, which in heterogeneous collectors are combined with slanted ones. Horizontal wells, which give additional deliverability and reduce surface environmental impact, used many fewer. The increasing popularity occupy, larger well bores Re-entry (including horizontal leg extensions), extended reach wells. Some potential has Recompletion (larger size tubulars). The most dynamic growth in time marked by coiled tubing drilling.

There are almost no any changes in corrosion management techniques and gas treatment and gas quality management during last time.

The wide spectrum of technologies is used for good UGS safety:
- Safety studies and audits
- Preventive technical installations
- Subsurface safety valves
- Diagnosis of critical operations
- Enhanced monitoring
- Best knowledge of the geological situation
- Periodical gas inventory and control of cap rock tightness
- Preventive maintains
- Accidence analyses

The report is likely to become a standard information tool for specialists, scientists and students too.
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23rd World Gas Conference, Amsterdam 2006

UGS: Achievements and trends in the field of ecological stability

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ABSTRACT

Study “Achievements and modern tendencies in the field of Underground Gas Storage safety and ecological stability” of the Triennium work programme 2003 - 2006 is the Working Committee’s 2 (WOC 2) Study Group-2.3 (SG) Activity, which has been established for the first time.

The report of SG 2.3 was based on 3-years study of WOC 2 - underground gas storage (UGS) members and on the questionnaire “Enhancement of UGS Environmental Stability”, which was performed as an essential document for data collection and basic structure of information.

The questionnaire on the SG 2.3 WOC 2 activity “Enhancing environmental stability on UGS” includes the basic sections that specify a normative-legal base for UGS operation including technical and technological aspects directed to the environment protection.

The report contains analysis of data relating to the subject “Enhancement of UGS environmental stability” obtained from 20 studies (20 countries and organizations) as responses to the questionnaire. The gas volume of countries taking part in the discussion accounts for about 90% of world underground gas storage volume.

The main goal of study is development of key proposals and recommendations for world community on enhancement of underground gas storage environmental stability.
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1 Introduction

Study “Achievements and modern tendencies in the field of Underground Gas Storage safety and ecological stability” of the Triennium work programme 2003 - 2006 is the Working Committee’s 2 (WOC 2) Study Group-2.3 (SG) Activity, which has been established for the first time.

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2 Basic concepts

2.1 The goal and methods of study

**The goal** – creation of a “good ecological potential” for efficient exploitation of underground gas storage facilities.

**Tasks:**
- retrieval and analysis of information aimed at ensuring of rational exploitation of UGS facilities in compliance with environmental protection and conservation of resources norms and requirements;
- definition of normative and legal UGS exploitation support levels (legal and normative environmental protection documents);
- list of best technologies and means for creation of ecological stability in UGS operation;
- development of proposals and recommendations for enhancement of UGS environmental stability;
- determination of trends allowing companies to enhance the UGS operation efficiency.

**Method of study** – the work was based on the search and analysis of information for database creation on technologies, methods and means of enhancement of UGS environmental stability.

2.2 List of countries which have conducted studies of the questionnaire «Enhancement of UGS environmental stability» (Table 1).

<table>
<thead>
<tr>
<th>№</th>
<th>Country</th>
<th>№ of surveys</th>
<th>Company</th>
<th>№</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Argentina</td>
<td>1</td>
<td>Repsol YPF</td>
<td>1</td>
<td>Croatia</td>
</tr>
<tr>
<td>2</td>
<td>Croatia</td>
<td>1</td>
<td>INA-NAFTAPLAIN</td>
<td>2</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>3</td>
<td>Czech Republic</td>
<td>1</td>
<td>RWE Transgas Net.</td>
<td>3</td>
<td>Germany</td>
</tr>
<tr>
<td>4</td>
<td>Denmark</td>
<td>1</td>
<td>DONG</td>
<td>4</td>
<td>Hungary</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>1</td>
<td>Gaz de France</td>
<td>5</td>
<td>Netherlands</td>
</tr>
<tr>
<td>6</td>
<td>Germany</td>
<td>3</td>
<td>VNG-VerbundnetzGas AG, BEB Transport, WINGAS GmbH</td>
<td>6</td>
<td>Norway</td>
</tr>
<tr>
<td>7</td>
<td>Italy</td>
<td>1</td>
<td>STOGIT S.p.A.</td>
<td>9</td>
<td>World Health Organization recommendations</td>
</tr>
</tbody>
</table>
2.3 Bodies regulate and monitor the environment

2.3.1 Legislative and normative environment protection basis is directed on maintenance:

- Stability and reliability (safety) of all systems of underground gas storages objects functioning
- Safety of the personnel and working conditions
- Prevention of accident rate
- Technical efficiency
- Ecological stability

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THERE ARE 4 RELATIVE THE MOST IMPORTANT REGULATION LEVELS IN THE LEGAL PRACTICE: INTERNATIONAL, STATE, REGIONAL AND LOCAL [2].

In all countries should exist 3 the most important regulation levels – the state, regional and branch, which should determine the frequency of environmental monitoring. The frequency of monitoring depends on the requirements of various legislations, and regimes of its performance (regular, as required, annually or less frequently) do not depend on the kind of regulation.

2.3.2 International standards are used when developing normative documents

ISO standards of series 9000 and 14000 jointly or separately are usually used in the most countries, and in the nearest future will be used more active.

The use of ISO standards of series 9000, 14000 and 18000 testify to the harmonic approach of the enterprise to manufacturing high quality products.

The development of one integrated system, instead of two or more systems, will decrease costs of management (functioning, certification, audit etc.) since it includes product quality management, labor protection (health) and safety management, and environmental management in a generalized form [1].

2.3.3 Ecological standards for UGS equipment

In the majority of countries there are norms for pollutants in emissions from the surface equipment and during operation of underground constructions. Ecological norms for the surface equipment operating at UGS the are in the most surveys; the norms apply to nitrogen oxides, carbon oxide, methane in emissions from energotechnological equipment (gas turbine unit, gas engine compressor unit).

Ecological norms for underground constructions (boreholes, pipelines) are established in 12 surveys. Quantity indicators are related to specific gas losses in the gas transportation system and UGS facilities.
2.3.4 Frequency of conducting ecological audit and monitoring of processing facilities emissions and environmental objects

The ecological audit and monitoring of emissions of technological equipment and natural environment are carried out by the majority of UGS facilities, with the frequency of such measures having a certain periodicity, and less frequently they are conducted as a necessity.

Ecological audit and monitoring are carried out in compliance with ISO standards, as well as with the industry’s normative and methodical documents.

This issue seems to be of a great importance to the UGS environmental protection activity, since all respondents share intentions and actual deeds in conducting audit and monitoring.

2.3.5 Emission sources of hazard factors in environment

A general review of the basic sources of emission of pollutants formed at stages of construction, normal operation or temporary violations in operation of surface UGS facilities is given in Table 2.

<table>
<thead>
<tr>
<th>Construction and operation of UGS surface equipments</th>
<th>Pollutant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas pumping units</td>
<td>NOx, COx, Methane</td>
</tr>
<tr>
<td>Compressors</td>
<td>Methanol, Glycol</td>
</tr>
<tr>
<td>Boiler unit / Fire heater</td>
<td>Lubricating oil</td>
</tr>
<tr>
<td>Flare</td>
<td>Hydrocarbon condensate</td>
</tr>
<tr>
<td>Vent pipe</td>
<td>Formation water</td>
</tr>
<tr>
<td>Drying units</td>
<td></td>
</tr>
<tr>
<td>Valves</td>
<td></td>
</tr>
<tr>
<td>Separator stations</td>
<td></td>
</tr>
<tr>
<td>Stock reservoir</td>
<td></td>
</tr>
<tr>
<td>Building technology / motor transport</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Emission sources of hazard factors in environment

2.4 Technologies and methods to reduce the impact of hazardous factors on the environment

The importance of technologies and methods in decreasing the impact of hazardous factors on the environment is evaluated for three time periods by five-point system.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Assessment (by five point mark)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Past</td>
</tr>
<tr>
<td>Reduction of vented gas</td>
<td>4,7</td>
</tr>
<tr>
<td>Reduction of flared gas</td>
<td>4,7</td>
</tr>
<tr>
<td>Reduction of effluents</td>
<td>4,7</td>
</tr>
<tr>
<td>Water disposal</td>
<td>4,3</td>
</tr>
<tr>
<td>Noise reduction</td>
<td>3,4</td>
</tr>
<tr>
<td>UGS territory arrangement</td>
<td>2,6</td>
</tr>
<tr>
<td>Methods and means of reduction of physical and mechanical factors</td>
<td>2,8</td>
</tr>
<tr>
<td>Effluents and emissions measuring procedures</td>
<td>2,2</td>
</tr>
<tr>
<td>Technology and methods of natural gas burning</td>
<td>2,2</td>
</tr>
<tr>
<td>Reduction of emissions</td>
<td>2</td>
</tr>
<tr>
<td>Closed cycled systems</td>
<td>1,2</td>
</tr>
</tbody>
</table>
Table 3. Technologies and methods to reduce the impact of hazardous factors on the environment

The data presented in Table 3 were obtained by using an indirect indicator - average meaning of the point marks sum divided by responses number for every of the three time period. Cautiously, one may say that technologies and methods of “Reduction of vented and flared gas; Reduction of effluents; Water disposal; Noise reduction; UGS territory arrangement; Methods and means of reduction of physical and mechanical factors” are always highly assessed by the respondents.

Technologies and methods of “Reduction of vented gas; UGS territory arrangement; Effluents and emissions measuring procedures; Closed cycled systems” are higher assessed for the future use.

2.5 Enhancement of environmental reliability of UGS operation. Has the company received (or will receive) any economic benefits after improving environmental situation at UGS?

The analysis of answers to this question has allowed to reveal the important tendency of decrease negative attitude to the possibility of gaining economic benefit from enhancing environmental situation at UGS.

Improving of an ecological situation has direct or indirect influence on economic efficiency of UGS facilities in the following directions:

- Development of legislative and normative-methodical basis on the environmental protection and technological aspects;
- Capitalization increasing (equity value, information receiving);
- Yield increasing (reduction of payments);
- More precise calculations: of pollutants concentration (NOx, CH4); the sizes of a sanitary-protective area of facility;
- Creation of modern UGS facility image

2.6 Atmospheric air pollution, methods and means of control

Atmospheric air pollutants control means allow: 1) to identify the pollutants emission sources; 2) to check the observance of sanitation norms.

If such measures are not carried out, there is a danger of uncontrolled pollutants impact on the personnel and population.

Monitoring of pollutants in the atmospheric air
Atmospheric air pollutants monitoring at UGS sites is carried out by “legal requirements and facility’s rules”. Monitoring of settlements is carried out by “air quality control and air modeling”.

Technical means of control
The atmospheric air control is carried out by stationary and mobile means. The requirements, methods and means of control are listed in the Table 4. The frequency of control is determined either by the legislation requirements, or by the facility’s rule, or on the annual basis. Systems of continuous monitoring of CO, CO2, NOx are used in four countries in compliance with the legislation requirements.

No surveys mention remote atmospheric control.
IGU - WOC 2 - SG 2.3

UGS: Achievements and trends in the field of ecological stability

2003–2006

Monitoring of pollutants in the atmospheric air

<table>
<thead>
<tr>
<th>Industrial zones (working area)</th>
<th>Outside the industrial zone (settlements)</th>
<th>Technical means of control</th>
<th>Systems for continuous monitoring CO, CO₂, NOₓ, SO₂, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal requirements</td>
<td>Air quality control and air modeling</td>
<td>Legal requirements; Facility’s rules; Continuous; Oxidation catalysts; Low emission; Combustion/oxidation; Catalyst/thermal; (WINTERGAZ type, ASH type); - Cleaner burning engines;</td>
<td>Legal requirements; Facility’s rules; -Measurements 1 per year; -SEWERIN type Chemiluminescent gas analyzers</td>
</tr>
<tr>
<td>Facility’s rules</td>
<td>- Gas analyzers; CEMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous measurement at emission sources (chimney and heaters); - Stack testing of emissions and air modeling; - Gas detectors; - Gas analyzers; CEMS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Atmospheric air pollution, methods and means of control

2.7 Regulations for sewage water, brine, wastes of production and consumption

Regulation for sewage water implemented at the state level (national standards), according to technical rules and industry’s documents.

Industrial sewage. Industrial sewage treatment facilities exist according to surveys. Treatment is carried out mechanically with use of oil removers, sedimentation tanks, filters, separation systems and biological means.

Utilization of industrial sewage is carried out with use of water gathering reservoirs, by returning it into a loss circulation horizon, into thermal absorption towers, by gathering it in reservoirs prior to injection into the loss circulation horizon, in one case – by thermal neutralization (as an extreme measure).

The brine treatment is carried out by neutralization methods, and by returning it into a loss circulation horizon.

The wastes of production and consumption are regulated at the state (national) level technical rules, industry’s documents and other requirements.

There are special grounds for wastes storage.

2.8 Norms of natural gas leakages from equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>mg/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>(experimental data)</td>
<td>- Less then 1,5 % of all connections</td>
</tr>
<tr>
<td>- Locking and regulating</td>
<td>With diffuse emission measurements;</td>
</tr>
<tr>
<td>- Flange connections</td>
<td>1,83 - 5,83</td>
</tr>
<tr>
<td>- Safety valves</td>
<td>0,08 - 0,20</td>
</tr>
<tr>
<td></td>
<td>24,45 – 37,78</td>
</tr>
</tbody>
</table>
compressors shaft sealing | 31.95 – 33.34
pump gland sealing | 38.89

Table 5. Norms of natural gas leakages from equipment

Information on the natural gas leakage is submitted by 5 countries. These data have resulted from experimental research and represent levels from lower than 1.5% (of all connections) to actual values of leakage rate (in mg/sec) from various types of equipment. Several surveys report of the absence of natural gas leakage due to observance of technical requirements (Table 5).

2.9 Measures and means companies use to decrease gas losses for own needs and gas losses in a gas field and compressor stations

Measures and recommendations on the decrease natural gas losses for technological needs relate to many aspects of the gas storage technological process: from lowering gas consumption to technical innovations such as installation at gas pumping unit (GPU) of gas utilization units, enhancement of gas burners efficiency, well plugging etc. Undoubtedly, all these measures are efficient in maintaining the UGS environmental stability.

About 70% of surveys contain responses to the question on the lowering gas losses in gas fields and at compressor stations. A whole complex of measures is proposed including various methods of decreasing losses, comprising the following main groups: monitoring and control of the bleeding gas, pressure decrease, maintenance of sealings, optimization of GPU operation modes, replacement of equipment etc.

There is only one case of using of stationary gas utilization units (mobile unit are not used, evidently, because of no necessity).

Cutting-in under pressure technology is used according to 5 surveys. Saved gas amounts to 1.5 to 50 mln m³/yr. According to 8 surveys, this technology is not used because of use of the blocking and bleeding of excess pressure technology with releasing of minimum gas volumes.

2.10 Norms of emissions from fuel-consuming facilities and control devices

2.10.1 World practice of gas-transport system operation shows the technical and economic feasibility of gas turbine units using. At the same time gas turbine units are the basic sources of pollutant emissions in environment [3]. Therefore following to normative base takes into account specificity of fuel-consuming equipment operation and simultaneously guarantees ecological safety.

The norms of pollutant emissions of the equipment exhaust gases cover practically all types fuel-consuming equipment operated of the gas industry (GTU, GECU, boiler units, etc) (Table 6).

The most significant pollutants are nitrogen oxides (NO+NO₂) and carbon oxides (COₓ) having the highest toxicity.

1. Gas turbine units with indicated capacity in the range 2.6-30 MW:

emissions of nitrogen oxides vary in great limits – from 20 to 500 mg/m³;
emissions of carbon oxide – from 21 to 470 mg/m³

2. Gas Engine Compressor with capacity from 0.7 to 5.5 MW:
emissions of nitrogen oxides – 460-3500 mg/m³;
emissions of carbon oxide – 200 – 2000 mg/m³

3. Boiler units with capacity from 0.12 to 10 MW:
emissions of nitrogen oxides – from 42 to 785 mg/m³;
emissions of carbon oxide – 58 – 100 mg/m³

4. Fire vaporizers:
emissions of nitrogen oxides 58 – 200 mg/m³;
emissions of carbon oxide - 75 mg/m³

5. Flares with capacity 1 MW: emissions of nitrogen oxides -1940 mg/m³

Table 6. Norms for emissions from fuel consuming equipment according to surveys

2.10.2 Methods and means of quantitative control of emissions in combustion materials

The components concentrations are determined by calculation method, indirect methods for measuring gas consumption with emission data processor, accurate measurements with use of electrochemical method, oxidation catalyst method etc. To this end, flue gas analyzers, both stationary and mobile, are used; periodical or continuous control is carried out.

Both unification and complexity of pollutants emissions control methods in combustion products are ways of enhancement of ecological stability UGS.

2.10.3 Do you apply charges (tariffs) for NOx, CO, CO2, SO2 emissions? (Table 7)

Negative factors impact on the environment during UGS construction and operation is currently compensated by some economic mechanisms. Russian legislation on the atmospheric air protection releases the principle “guilty pays”. It consists of payments for pollution depending on the volumes and a kind of pollutant.

The payment for pollution represents the form of compensation of economic damage from pollutants emissions and effluents to the environment. This measure is constraining function of environmental contamination.

Payment emissions norms in atmospheric air by stationary and mobile sources are established for 225 substances, of pollutant effluents in water objects - for 142 substances [4].

It is taken into account the class of waste danger for the environment at the establishment of payment for accommodation of waste production and consumption.

<table>
<thead>
<tr>
<th>Matter, euro per one tone</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Croatia</td>
</tr>
<tr>
<td>25,6 X (192 kn/t + corrective factor)</td>
</tr>
<tr>
<td>Denmark</td>
</tr>
<tr>
<td>0,03 (tax: 0,2 DKK/m³)</td>
</tr>
<tr>
<td>France</td>
</tr>
<tr>
<td>45 (not for all sites)</td>
</tr>
<tr>
<td>Germany</td>
</tr>
<tr>
<td>No or a little bit. But more, in case we</td>
</tr>
</tbody>
</table>
2.11 Ecological, sanitary and other norms for pollutants monitoring at environmental objects

(Atmospheric air, soil, water bodies of the following usage drinkable, household-drinkable and cultural-domestic fishery).

Normative materials on the regulation of environment-anthropogenic systems in different countries have been carefully analyzed, systematized, resulted in uniformity units and indices.

Seven countries in various volumes and different forms took part in the preparation of the information concerning the state of the normative base for the environment pollutants. The largest quantity of information is presented on atmospheric air.

Table 7. Practice of payment for pollutants emissions (NOx, CO, CO2, SO2) exists in several countries

<table>
<thead>
<tr>
<th>Country</th>
<th>NOx 2003</th>
<th>CO 2003</th>
<th>CO2 2003</th>
<th>SO2 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>1.8</td>
<td>0.02</td>
<td>No</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>(62.4 ruble)</td>
<td>(0.7 ruble)</td>
<td></td>
<td>(48 ruble)</td>
</tr>
<tr>
<td>Ukraine</td>
<td>12.7</td>
<td>0.5</td>
<td>12.7</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>(80 grn.)</td>
<td>(3 grn.)</td>
<td>(80 grn.)</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>NOx 28</td>
<td></td>
<td>28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(35 $)</td>
<td></td>
<td>(35 $)</td>
<td></td>
</tr>
</tbody>
</table>

2.12 The most effective technological decisions on improving UGS environmental situation

On the basis of responses from majority countries are maid the list of technological decisions influence the enhancement of UGS environmental stability, but their priority and efficacy are determined by each facility subject to problems it faces (Table 8).

<table>
<thead>
<tr>
<th>Trend</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGS management</td>
<td>Optimization of UGS operation</td>
</tr>
<tr>
<td></td>
<td>Facilities lay-out</td>
</tr>
<tr>
<td>Reduction of atmospheric emission</td>
<td>Exchange of gas turbines in order to meet the regulation requirements</td>
</tr>
<tr>
<td></td>
<td>Up-to-date controlling methods of NOx, CO2, CO, SO2, CH4 atmospheric emissions from all equipments (GPU, boilers and flares included)</td>
</tr>
<tr>
<td></td>
<td>New plans for reduction of flared gas emissions</td>
</tr>
<tr>
<td></td>
<td>New technologies of well drilling</td>
</tr>
<tr>
<td></td>
<td>- Drilling of horizontal wells</td>
</tr>
<tr>
<td></td>
<td>- Wells drilled with electrical rig</td>
</tr>
<tr>
<td>Application of new technologies and methods of natural gas burning</td>
<td>Adjustment of gas turbines to DL NOx Technique and compressor efficiencies enhancing</td>
</tr>
<tr>
<td></td>
<td>Reduction of CH4, emissions to eliminate leakage</td>
</tr>
<tr>
<td></td>
<td>Reduction of vented gas</td>
</tr>
<tr>
<td></td>
<td>DEG &amp; TEG regeneration</td>
</tr>
<tr>
<td>Noise reduction (Creation of noise-reduced gas-pumping units as the compromise between technical opportunities and economic feasibility)</td>
<td>Acoustic improvement of noise occurrence source (rotary superchargers)</td>
</tr>
<tr>
<td></td>
<td>Modular means of noise-killer</td>
</tr>
</tbody>
</table>
Development of Water Use System
- Reduction of effluents
- Effluent measuring procedures
- Water disposal
- Closed cycled systems

Wastes
Reduction of liquid and solid wastes impacts

Methods and means of environment pollutants neutralization
Technologies of impact reduction:
chemical; physical - radiation, electromagnetic;
biological; thermal; mechanical-solid and liquid wastes, rubbish, etc.

UGS territory arrangement
Land reclamation
Land compression in the areas of technological installations releasing pollutants due to asphalting or concreting

HIGH EFFICIENCY OF WORK
Reducing visual impact

Table 8. Key technologies of UGS environmental stability and operation efficiency

Conclusion

The carried out analysis of legislative base, normative materials and technical decisions can be named comprehensive. An obtained result can be considered representative both by the number of respondents taking part in study and by geographical coverage of the world’s countries operating UGS in gas industry.

- It has allowed to gain some insight of legal and normative regulation, environmental protection activity in underground gas storage facilities of different countries and companies. As a result of the analysis the world community received valuable operating at UGS;
- on existing methods and means for control of pollutant emissions in combustion products;
- on real and/or potential ecological efficiency of technological decisions undertaken at UGS in different periods of time (3-5 years ago, at present and in the near future) etc.

The analysis data shows the similarity of approach to environmental protection in different countries and relative comparability of attitude to development and application of technologies and technical means for enhancement of UGS environmental stability.

The main inference is a system of present-day trends and mechanisms for lowering the man-caused impact on the environment developed on the basis of the survey results. Summing up the world practice in the UGS operation, we can give the key technologies (methods) for enhancement of UGS environmental stability (Table 16 and the diagram).

This systematized technologies set or separate technologies can successfully be applied on UGS in the further prospect. Technologies allow supporting the status of underground gas storages as the most reliable in the world.

The companies follow to the specified technical and environmental protection norms during all UGS life cycle, in spite of their distinctions in the different countries. In future the companies will follow new regulating positions even at possible toughening normative base, keeping the status of high technical reliability and ecological stability.

Summary

What resume and guidance to action on the enhancement of the UGS ecological stability does the world community receive according to the study?
Following to key technological decisions results to:

- Reduction of emissions, effluence, waste of production and consumption
- Enhancing of ecological safety
- Ecologically focused technologies
- Extension to sustainable development of underground gas storages
- Further development of research in lines of energy- and resource-efficient and environmental protection in the next WOC triennium

REFERENCES

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Table 3. Technologies and methods to reduce the impact of hazardous factors on the environment
Table 4. Atmospheric air pollution, methods and means of control
Table 5. Norms of natural gas leakages from equipment
Table 6. Norms for emissions from fuel consuming equipment according to surveys
Table 7. Practice of payment for pollutants emissions (NOx, CO, CO2, SO2) exists in several countries
Table 8. Key technologies of UGS environmental stability and operation efficiency