Underground Storage of Natural Gas in West Germany

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ABSTRACT

The underground storage of natural gas to cover medium- and long-term fluctuations in consumption is gaining increasing significance within the Federal Republic of Germany.

Porous formations as well as salt caverns are known to be suitable for the underground storage of natural gas. Both of these storage types are to be found in the FRG. There are at present 13 aquifer storages in the FRG with a max. capacity (working gas plus cushion gas) of 3.2 billion standard m^3 corresponding to 110 billion scft. The technology of storage in salt caverns has its origin in a patent of the former Deutsche Erdöl AG of 1916. There are at present 17 caverns in the FRG with a capacity of 0.7 billion standard m^3 corresponding to 24.5 billion scft.

After a brief summary description of the leaching process adopted for the construction of salt caverns several data concerning gas consumption as well as storage capacities in France, Italy, Great Britain and Austria are made. In Denmark and Sweden 2 underground gas storage projects are under design respectively under construction.

INTRODUCTION

With a current population of approximately 60 million in the Federal Republic of Germany (FRG) the present natural gas consumption (1982) is about 50 billion m^3 corresponding to 1800 billion scft., 30% of which is derived from domestic production (Figure 1). The remaining volumes are imported essentially from the following regions: Netherlands (approx. 50%), North Sea (approx. 20%), USSR (approx. 30%).

The percentage of natural gas consumption in the FRG in relation to the total primary energy consumption is approximately 15%. (Figure 2).

The trend of the total primary energy consumption in the FRG over the last few years, as well as the prognosis for the immediate future, can be clearly seen in Figure 2. Here it can be seen that the percentage of natural gas in the total primary energy consumption, currently 15%, is expected to rise to 17%.

To give an estimate of the magnitude of these figures the following has been determined:

- The total primary energy requirement in the USA is 7 times greater than that of the FRG
- The percentage of natural gas in the total primary energy consumption in the USA is 27% (FRG: 15%)
- The total natural gas consumption in the FRG is therefore approximately 8% of the total natural gas consumption in the USA.

A map of the FRG indicating the main natural gas cross-country pipelines is shown in Figure 3. The numbered circles show the centres of domestic gas production with the respective annual production (in billion scft/year). Imported volumes are essentially channeled into the FRG gas network at three points (see arrows, Figure 3) with the respective import rates.

The percentage of natural gas consumption in the FRG for domestic purposes is currently about 35% with a ris-

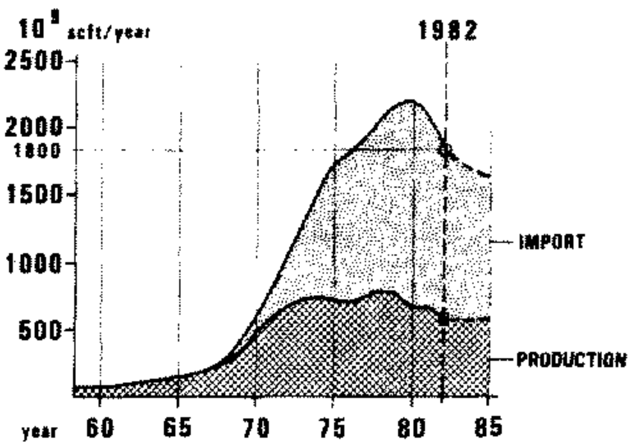

Figure 1. Natural gas in FRG production and import 1960–1982 estimation for 1983–1985.

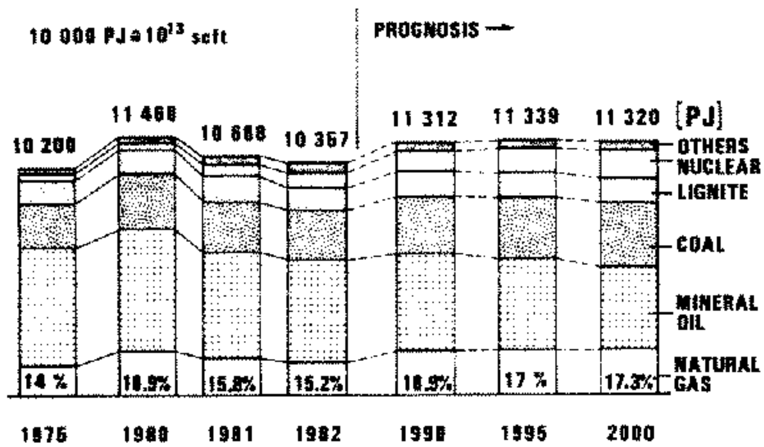

Figure 2. Development of primary energy consumption in the FRG 1975–2000.

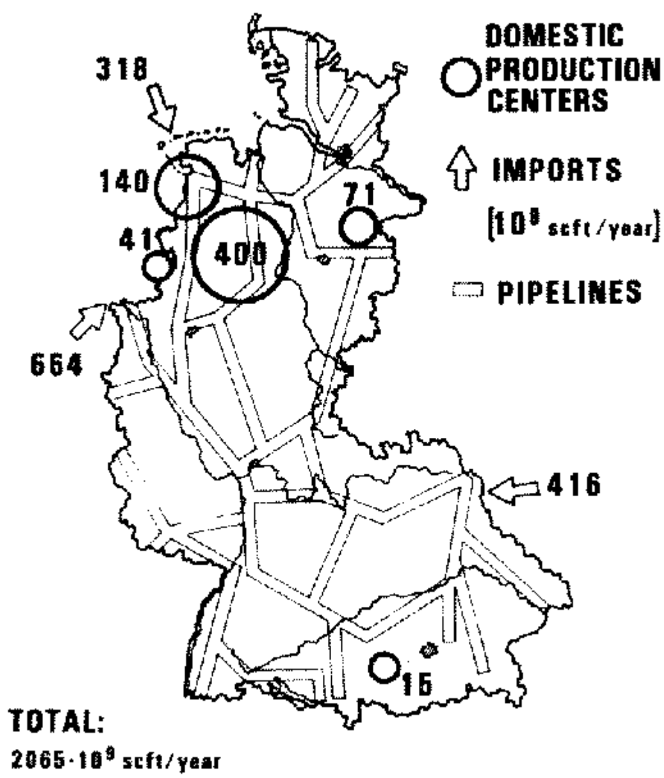

Figure 3. Natural gas in the FRG in 1981.

ing tendency. However, the percentage of users, who consume practically constant gas rates regardless of the season, is falling (e.g. electricity generation, industry). It is therefore anticipated that the ratio of gas consumption in winter to gas consumption in summer will continue to increase (Figure 4).

There will also be a continued rise both relative and absolute in the gas import volumes. Due to contractual conditions the gas volumes imported must be accepted at a practically constant rate. For these reasons underground gas storages have been in existence in the FRG for decades and will increase considerably both in number and capacity in the future.

SUITABLE FORMATIONS FOR GAS STORAGE

Porous formations as well as salt caverns are known to be suitable for the underground storage of natural gas. Both of these storage types are to be found in the FRG.

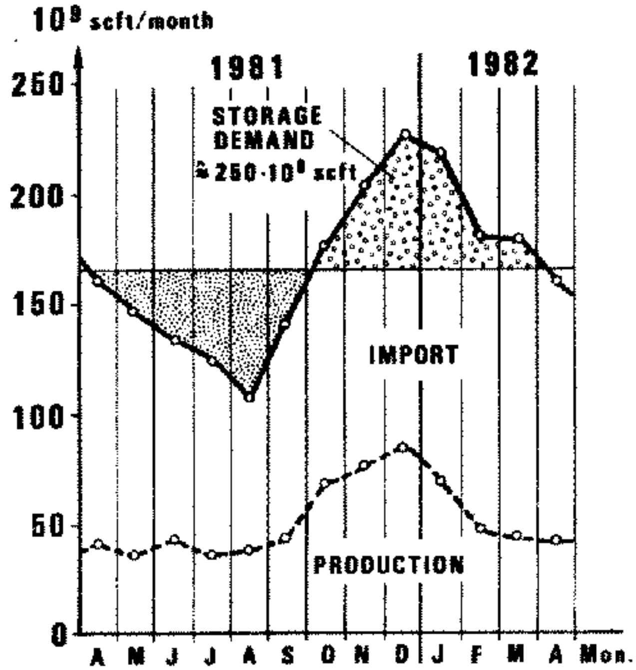

Figure 4. Total gas consumption (FRG) 1981/82 and estimation of theoretical storage demand.

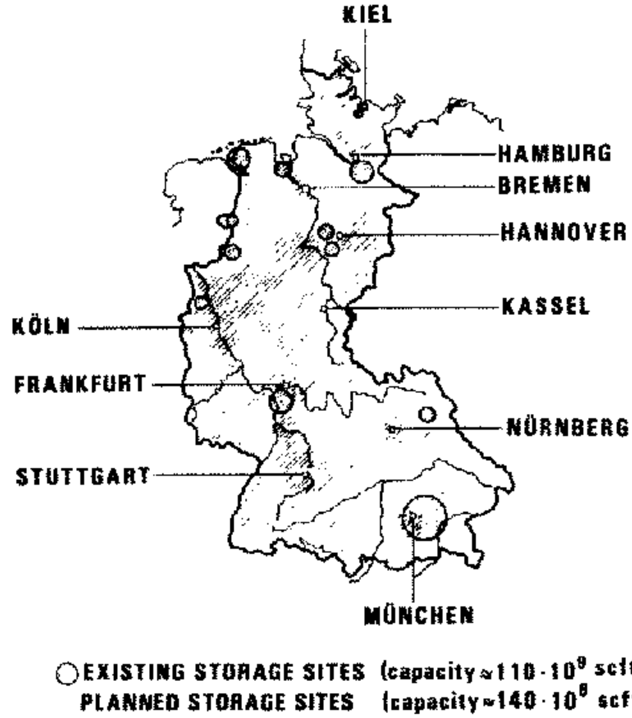

Figure 5. Gas storage in the Federal Republic of Germany.

Experience with gas storage in porous and permeable geological formations has existed in the FRG since about 1940. The oldest systematic planned and developed aquifer storage in Europe is that of Engelbostel near Hanover. This storage has been in operation since 1953. There are at present 13 aquifer storages in the FRG with a maximum capacity (working gas plus cushion gas) of 3.2 billion standard m^3 corresponding to 110 billion scft. These storage facilities are distributed over almost the entire FRG (Figure 5). The depth locations of these storages are between 200 m ≈ 650 ft (Engelbostel near Hanover) and round 3000 m about 10,000 ft (Wolfersberg near Munich). The maximum withdrawal rates fluctuate between approximately 10,000 m^3/h, corresponding to 350,000 scft/h, for smaller storage facilities and as high as 400,000 m^3/h corresponding to 14 million scft/h for the larger storage facilities. Six of the above-named aquifer storages are set up in depleted gas and oil reservoirs. Seven storage sites are developed in aquifer structures. The working gas/cushion gas ratio is on average approximately 1:1. Seven additional aquifer storage facilities are currently being planned or are under construction with an additional capacity of 140 billion scft. Planning, construction and operation of aquifer storages are in accordance with the international status of this technology. The most modern of computer programmes are available in order to predict the storage behavior whilst bearing in mind possible existing geological faults and other inhomogenities of the storage horizon.

OPERATIONAL EXPERIENCE

Generally speaking, the operational and reservoir engineering experiences with these storage facilities can be regarded as positive. In some cases operational problems have arisen because of the secondary formation of H_2S. The subsequent installation of desulfurization plants was therefore necessary. H_2S can either occur as a result of unintentional inoculation of a storage horizon with bacteria (in particular with the so-called sulfate-reducing bacteria *Desulfovibrio desulfuricans*) or even, and this is a relatively new discovery, by hydrolysis of carbonyl-sulfide (COS) percentages in the storage gas.

The storage of natural gas in salt cavern storage facilities is gaining more and more significance in Central Europe and in particular in the FRG. The technology of storage in salt caverns has its origin in a patent of the former Deutsche Erdöl AG of 1916. An initial practical application of this patented idea is known to have been made in the early 1950s in the USA. In the FRG the first salt cavern was set up for the storage of city gas with geometric volume of approximately 40,000 standard m^3 corresponding to 1.4 million scft in 1966.

In the years that followed there was a troubled development in the sector of salt cavern storage sites. At present there are about 1000 salt cavern storages in the Western world with a total geometric volume of approximately 215 million m^3 corresponding to 7.5 billion cft for the storage of liquid and gaseous hydrocarbons. Approximately 10% of this cavern volume is used for the storage of natural gas. The gas volume stored therein is about 2 billion standard m^3 corresponding to 70 billion scft. There are at present 17 caverns in the FRG with a capacity of 0.7 billion standard m^3 corresponding to 24.5 billion scft. The construction of storage caverns in the salt puts certain demands on the geological character of the salt reservoir:

- Sufficient thickness and extent of the salt deposit in depths above approximately 2000 m ≈ 6600 ft
- Wherever possible, homogeneous salt quality which should, for leaching engineering reasons to a great extent, be free of non-soluble or low-soluble components, such as clay, anhydrite and/or dolomite layers, as well as easily soluble components such as potash salts.

The salt deposits found in Europe take the form of salt domes, salt pillows or stratified salts (Figure 6). An enlarged section of Figure 6, namely the North German coastal region and a section of the southern North Sea, is shown in Figure 7. The salts in the North German Main Basin are predominantly in the form of salt domes (Figure 7). In order to construct a cavern in the salt, one well, or even in special cases several wells, are drilled. The drilling technique is completely in accordance with the standard of the oil and gas industry. When drilling through the salt formation a saturated clay-salt water mud or oversaturated NaCl mud must be used. The es-

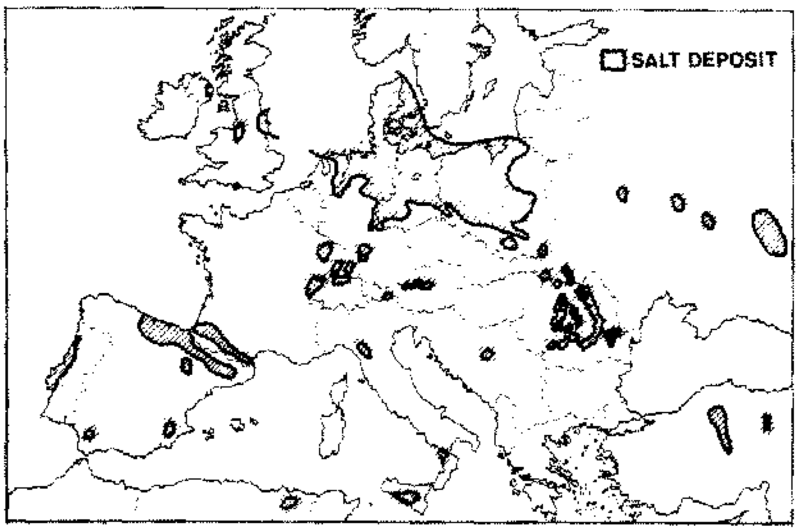

Figure 6. Salt Resources of Europe.

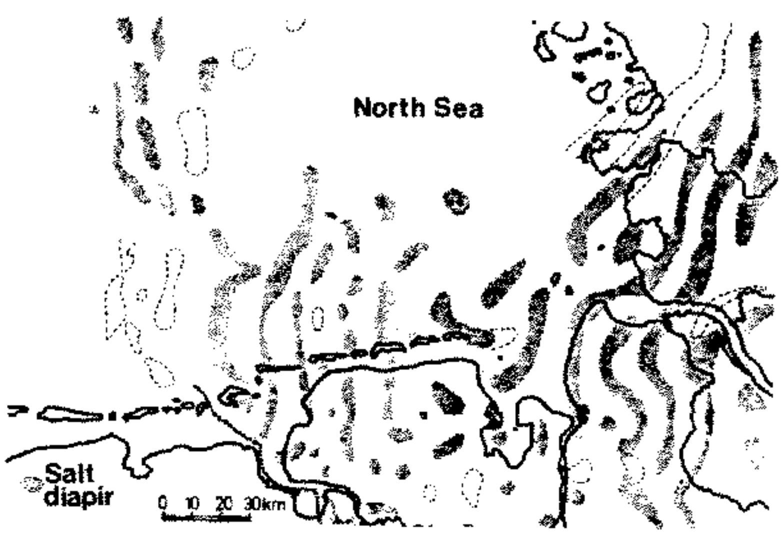

Figure 7. Salt diapirs in North Germany.

sential technical equipment for a leaching process is shown in Figure 8. Fresh water, or water with a slight salt content (e.g. seawater), is pumped into the section to be leached out. The water dissolves salt at the cavern walls and becomes more or less saturated. The fresh water pumped in displaces the brine to the surface and is drafted off. Via the outermost annulus, a protective medium (blanket) lighter than water and non-salt dissolving is pumped into the top section of the cavern in order to limit the leaching process in an upward vertical direction, i.e., at the cavern roof. The depth region in which cavern storage space should be created can be determined by the depth of the brine/blanket interface as well as by the final depths of fresh water and brine strings. The leaching process is planned using a three dimensional finite element computer programme. The growth of the cavern, particularly the control of the geometric development of the cavern, is undertaken at certain intervals by the Sonar survey method. A typical cavern shape with the respective intermediate survey is featured in Figure 9. This cavern has a final volume of 430 000 m^3 capacity, ≙ 15 million cft and with a pressure range of 100 bar ≘ 1420 psi, a working gas volume of 45 million standard m^3 ≙ 1.6 billion scft. Such salt caverns in FRG normally are leached with rates of approximately 300 m^3/h ≘ 1250 gallons per minute. The construction time for such a cavern is approximately 2 years. In practice it is usual to leach several caverns simultaneously.

With this technology the assurance of cavern stability and the minimizing of cavern convergence is of particular importance. For this purpose, extensive laboratory measurements regarding the rock physical behavior of the salt are carried out on the appropriate cores. The mechanical stability of the cavern as well as the long-term

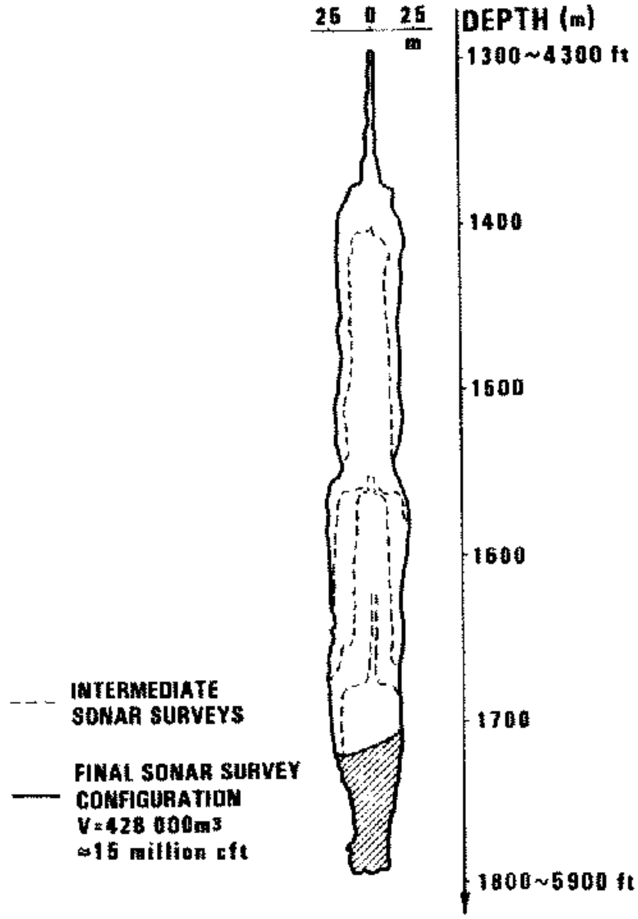

Figure 9. Cavern shape.

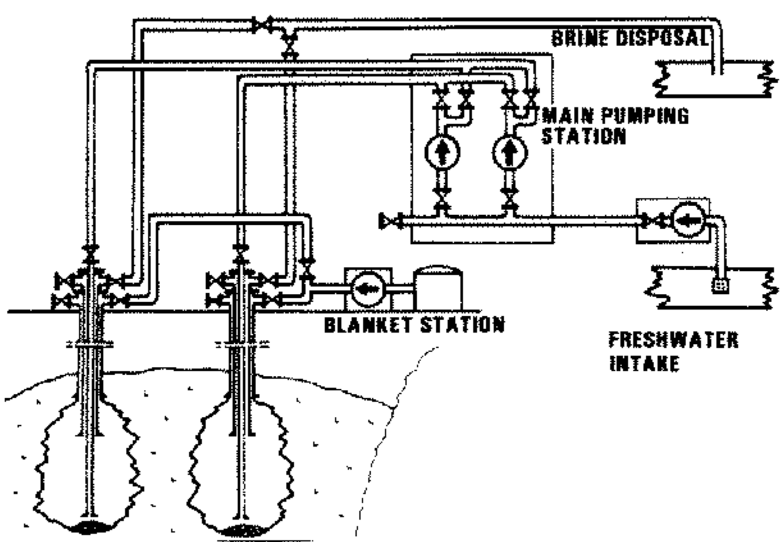

Figure 8. Construction of salt cavities by solution mining.

convergence behaviour is calculated in a finite element computer programme.

In addition to their use of the seasonal storage of natural gas, salt caverns are also particularly suitable to meet peak requirements. Unlike aquifer storage no friction pressure losses occur in the salt cavern; therefore practically unlimitedly high production rates can be withdrawn from the salt caverns with the corresponding dimension requirements of the production string. Peak production rates of up to 1 million m³/h ≙ 35 million scft/h can be achieved without difficulty using a production string diameter of approximately 20". A further essential advantage of the natural gas storage in salt caverns as opposed to aquifer storages would seem worth mentioning.

After overlaying a special fluid on the residual brine at the bottom (sump) of the cavern it is possible (in practice) to prevent a rise in water vapour content and thereby in the water dewpoint of the gas stored. It is then not necessary to install a gas dehydration plant in the case of salt cavern storages, something which leads to considerable economic savings. This KBB patented method is still being tested, the results obtained in practice to date are, however, very promising.

A schematic diagram of a salt cavern gas storage is shown in Figure 10, featuring the following:

1. Main Gas Pipeline
2. Compressor Station
3. After-cooler
4. Separator (Free water knockout)
5. Dehydration plant
6. Glycol Regeneration
7. Methanol Container (Hydrate Protection)
8. Sump overlay.

In the event of a successful sump overlay, the installation of a gas dehydration plant and auxiliary equipment (Items No. 4, 5, 6 and 7 in Figure 10) become unnecessary.

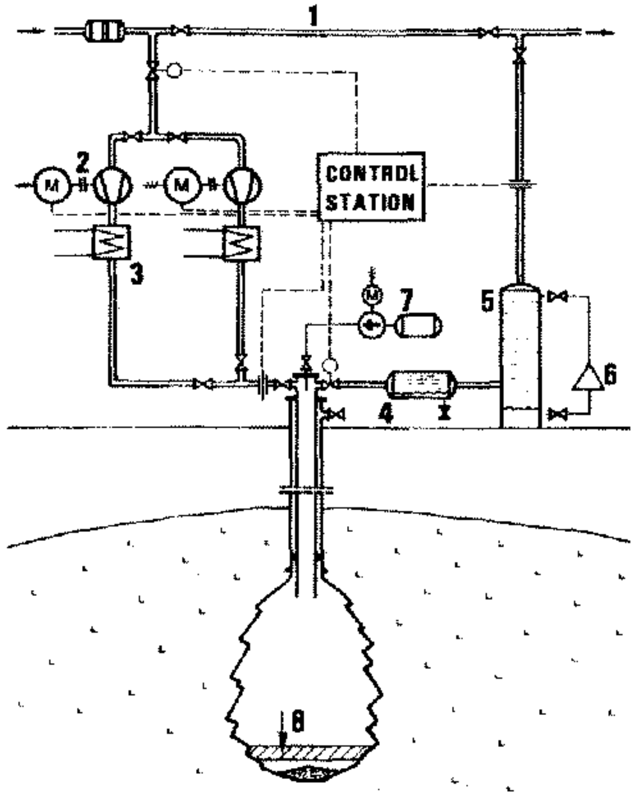

Figure 10. Schematic diagram of a high pressure gas cavern storage.

STORAGE SITUATION IN THE WESTERN EUROPEAN NEIGHBOURING COUNTRIES OF THE FRG

The following is intended to give a brief insight into the natural gas storage situation in some Western European countries neighbouring on the FRG.

The total natural gas consumption in Western Europe was in 1982 $230 \cdot 10^9$ standard m³ ≙ 8000 billion scft. This is approximately 4 times as much as in the FRG, or 30% of the gas consumption in the USA.

The only Western European countries that can meet their own requirements using their own natural gas resources and also export considerable volumes of gas are the Netherlands and Norway. All remaining West European countries import larger gas quantities than the FRG. Apart from the FRG, however, only France (Figure 11) and Italy (Figure 12) have realized larger gas storage capacities.

Although the total annual gas consumption in Great Britain corresponds approximately to the gas consumption in the FRG, there is in the UK at present only one salt cavern storage, which will have a capacity of 5.6 billion scft (working gas volume) in the final stage.

In Austria there are four storages facilities in depleted oil and gas fields with a working gas volume of approximately 80 billion scft.

In Belgium there are two abandoned coal mines converted for the storage of gas. The capacity is currently quoted as being 3–5 billion scft.

Denmark is currently linked up to the European Cross-country pipeline network. At present a salt cavern project is underway in the north of the country with a total capacity of 8.4 billion scft (working gas volume).

In Sweden an aquifer storage is currently under planning with a working gas volume of 3.5 billion scft.

FRANCE

TOTAL GAS CONSUMPTION	1 040 billion scft / year
IMPORTED GAS	700 billion scft / year
STORAGES:	
DEPLETED FIELDS	-
AQUIFERS	7
SALT CAVERNS	2
TOTAL	9
TOTAL WORKING GAS (max.)	156 billion scft
TOTAL CUSHION GAS (max.)	194 billion scft
TOTAL CAPACITY (max.)	350 billion scft
TOTAL WITHDRAWAL RATE (max.)	3.5 billion scft/day

Figure 11. Natural gas data for France.

ITALY

TOTAL GAS CONSUMPTION	1 040 billion scft / year
IMPORTED GAS	500 billion scft / year
STORAGES:	
DEPLETED FIELDS	9
AQUIFERS	-
SALT CAVERNS	-
TOTAL	9
TOTAL WORKING GAS (max.)	115 billion scft
TOTAL CUSHION GAS (max.)	355 billion scft
TOTAL CAPACITY (max.)	470 billion scft
TOTAL WITHDRAWAL RATE (max.)	2.9 billion scft/day

Figure 12. Natural gas data for Italy.

SUMMARY

To sum up, it can be stated that those natural gas storages existing in the FRG respectively West Europe have proven successful, apart from a few cases of operational mishaps. As already mentioned at the start the gas requirement in Europe will continue to increase. This increase can only be covered by a rise in imports. The storage capacity requirement in Europe will therefore continue to grow.