UNDERGROUND
SUN.STORAGE

Underground Sun Storage

Storing Sunshine

ENGLISH

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Foreword

Unique research project to investigate underground storage of wind and solar energy

One of the keys to RAG's success over its 80-year history has been the company's commitment to ongoing research and development.
Based on the foundations of our core business, oil and gas exploration and production, RAG is now the fourth-largest natural gas storage operator in Europe.
The importance of large, efficient energy storage facilities to security of supply has become even clearer in light of the rapid expansion of renewable energy in Europe – technologies that we see ourselves as a partner to.
Solar and wind power output is erratic because of changing weather conditions, meaning that generation cannot be adjusted in response to demand as is the case with conventional power stations. In some parts of Europe, such as the north of Austria's Burgenland province, on windy days the amount of power generated by wind farms is already well in excess of demand. With wind and solar generating capacity growing, energy storage is becoming an increasingly pressing issue. And even Austria's pumped storage plants in the Alps are no longer sufficient to meet this need.
Power to gas has been widely discussed as a potential solution to the storage problem for some time. The technology uses surplus solar and wind power to split water into oxygen and hydrogen. The hydrogen can then either be directly injected into the gas grid, or converted into methane – the main constituent of natural gas – by means of a methanation process using carbon dioxide. At present direct hydrogen admixture is still the more economic option, due to its higher efficiency and the shortage of suitable sources of carbon dioxide. However, up to now there has been no research into the effects of hydrogen on the storage capacity employed by natural gas infrastructure – the underground storage facilities.
A consortium led by RAG has addressed this issue, and is carrying out research into underground storage of a mixture of hydrogen and synthetic methane in the test facility that has now opened.

Markus Mitteregger, Chief Executive Officer

Stephan Bauer, Project Manager

The project was designated a lead project by Austria's Climate and Energy Fund after the first call for contributions to the 'e! mission.at 2012' programme.

"Gas can be transported in large quantities safely and out of sight via existing underground infrastructure, and held in environmentally friendly natural gas storage facilities that are also already in place. Austria's geology is ideal for underground storage, so the country is able to make a major contribution to security of supply."

Markus Mitteregger,
Chief Executive Officer, RAG

Underground Sun Storage – storing energy from wind and solar power below ground

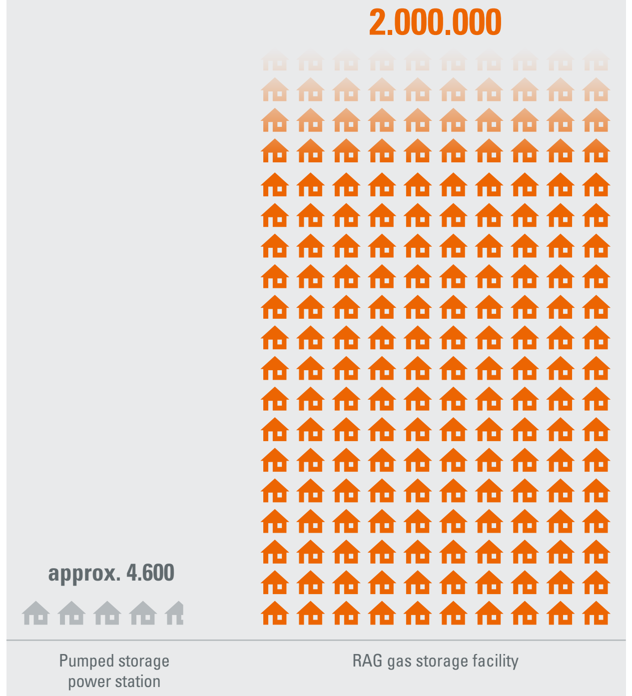
Harvesting, storing and supplying solar energy: an unprecedented pilot project run by RAG is currently testing this groundbreaking approach to energy production and storage.

Storage of hydrogen produced using solar energy is being trialled at a small depleted gas reservoir in Pilsbach, Upper Austria.
Energy from renewable sources that can be retained thanks to storage offers the only straight replacement for conventional energy – and Austria's gas storage facilities provide the necessary infrastructure. The project is being financed by Austria's Climate and Energy Fund.

Project outline

In most cases, energy from renewable sources lacks flexibility. Neither wind nor solar power can be controlled to meet actual energy demand. But the electricity grid cannot store energy, so grid operators have to adjust generation precisely to demand. If it were possible to store large amounts of power and inject it back into the grid when needed, generation would no longer be tied to demand. That is why huge energy storage facilities are essential in a world that relies on renewables. In nature, carbon and hydrogen have evolved as primary sources of energy, and the main substances in which energy is stored. We have taken this process as a model and imitated it with power to gas technology. Using electrolysis, excess energy generated from renewables is transformed into hydrogen, which can be stored in the natural gas network. A range of tests are being conducted to investigate how the natural gas infrastructure tolerates hydrogen. These have already shown that the existing infrastructure seems to cope well with hydrogen content of up to 10%.
Whether underground gas storage reservoirs can tolerate hydrogen is still unclear, and that is the main focus of this groundbreaking project. If the results are positive, the role of such facilities and their enormous storage capacity (more than 8 billion cu m in Austria, equivalent to 92,000 GWh) in the energy system of the future will change significantly, since they can be used to store and balance out supplies of renewable energy. Within this lead project, we are attempting to demonstrate the ability of underground storage facilities to tolerate hydrogen content of up to 10% in gas, so that they do not have to limit the potential of the network as a whole.
To achieve this aim, the project comprises laboratory experiments, simulations and a field trial conducted on an industrial scale at an existing storage reservoir with similar characteristics to Austria's large storage facilities. The tests are being accompanied by a risk assessment, a life cycle assessment, and an analysis of the legal and economic framework conditions. Simulation tools developed in the project will be calibrated by collating the results from the laboratory tests, simulations and the field trial. The goal is to enable similar investigations for many other storage facilities, all over the world.
Finding a solution to the question of storing renewable energy is the key to maximising its contribution to the energy mix and achieving a substantial reduction in carbon dioxide emissions. In terms of the strategic development of energy systems for the future, the results of the pilot will be hugely significant for companies, political decision-makers and public authorities.

Pumped storage vs. Gas storage



At present, the principal method available for storing large amounts of energy in the electricity grid is pumped storage. Austria's pumped storage power stations can store the electricity demand of 4,600 households (based on average annual consumption), and inject power into the grid when needed. The quantity of energy stored in RAG'S gas storage facilities alone is more than 400 times that amount.

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Focus areas

A work plan divided into ten work packages has been developed to formulate and answer the research questions raised by this project.

Work package 1: Project Management

The tasks involved in this work package include managing communications between the various work packages, organising the public relations effort, disseminating the research findings, communicating with funders and reporting on the project.

Work package 2: Geochemistry and Reactive Transportmodelling

This package investigates whether hydrogen admixture would lead to changes in the chemistry of the reservoir rock and fluids. Another research focus is reactive transport modelling. The work will be based on laboratory experiments and simulations.

Work package 3: Microbial processes in Hydrogen exposed Reservoirs

Tests in this work package will deliver insights into microbiological transformations in the natural gas storage facility. Molecular biology techniques will be used to characterise microorganisms in formation water in the reservoir. A variety of gas mixtures (comprising methane, hydrogen, carbon dioxide and sulphur compounds) are being applied to core samples from the reservoirs in lab reactors, with gas components and pressure changes measured at regular intervals. The findings will provide information on the impact of hydrogen content on metabolic processes in microorganisms.

Work package 4: Demixing Natural Gas and Hydrogen

The aim of this work package is to characterise the behaviour of the natural gas-hydrogen mixture under static and dynamic reservoir conditions. Potential demixing processes are being investigated, and here, too, laboratory experiments are employed.

Work package 5: Materials and Corrosion

This work package involves conducting laboratory tests to determine whether admixture of hydrogen results in corrosion of the steel grades typically used in the storage facility under normal operating conditions, and whether there is a possibility of changes occurring in the cementation of the storage wells.

Work package 6: Hydrogen Separation

Work in this package forms the basis for setting up a pilot plant to separate hydrogen from natural gas mixtures using membrane permeation. Numerical models and laboratory-scale experiments will provide support for configuration of the high pressure membrane module, and selection of the right membrane type for the separation process.

Work package 7: Design and Construction of the Testbed

This package comprises the design and construction of a pilot facility for in-situ testing of the storage of hydrogen-methane mixtures at an actual storage reservoir. The planned test facility must also be capable of demonstrating the power to gas principle, including its application to energy storage.

Work package 8: Operation of the Testbed

The objective of this work package is to carry out a field trial of storage of hydrogen-methane mixtures at an actual storage reservoir, located 1,000 m below ground. Gas flow rates and gas composition will be measured throughout the trial and balanced out on withdrawal. Microbial analysis and corrosion tests will also be conducted during the trial, and the membrane module produced by Axiom will be tested under real operating conditions.

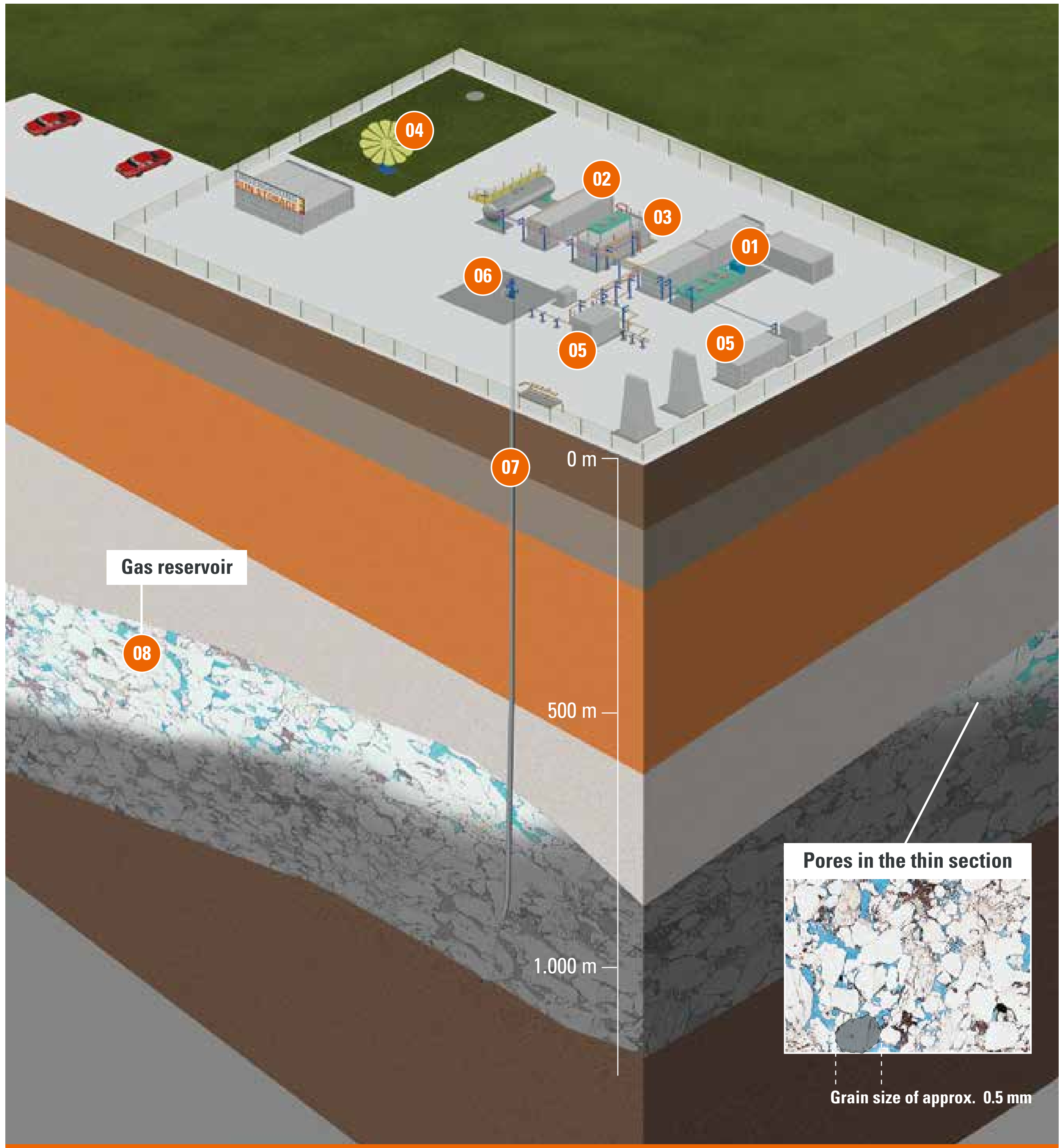
Work package 9: Risk and Life Cycle Assessment

A comprehensive assessment of the risks associated with combined methane and hydrogen storage will be performed, as well as an evaluation of projected economic and environmental performance of the pilot project over its entire life cycle.

Work package 10: Economic and Legal Assessment

The Energy Institute at the Johannes Kepler University Linz is leading this work package, and execute it in cooperation with Verbund and RAG. The economic assessment involves looking at the various potential applications of the storage technology in the context of overall power to gas systems, so as to arrive at a range of different market roles and combinations of business models. The work will also include analysing the existing legal system with a view to identifying obstacles to the technology and proposing future improvements to the legislative framework.

Schematic representation of Underground Sun Storage



- 01 Electrolysis
- 02 Membrane module
- 03 Compressor station
- 04 Solar flower
- 05 Control centre, measurement station
- 06 Wellhead
- 07 Well
- 08 Reservoir

01. Electrolysis

In this process, electricity is used to produce hydrogen. After the well water is purified in the reverse osmosis plant, it is split into hydrogen and oxygen by applying a direct current. The hydrogen is dried and mixed with natural gas, before the mixture is directed to the compressor station. The oxygen is released into the atmosphere as a by-product.

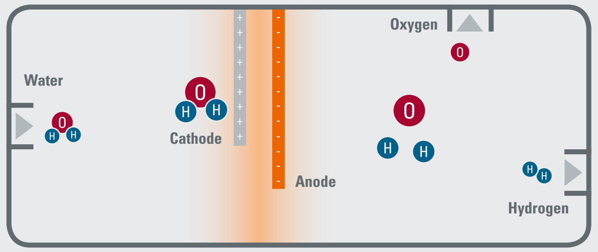
Electrolysis of water comprises two half reactions, which take place at the two electrodes, the cathode and the anode.

At the cathode: $2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH$

At the anode: $6\ H_2O \rightarrow O_2 + 4\ H_3O^+ + 4\ e^-$

The resulting overall redox reaction is:

$2\ H_2O(l) \xrightarrow{electrolysis} 2\ H_2(g) + O_2(g)$



The Underground Sun Storage project uses alkaline water electrolysis, where potassium hydroxide is added to enhance the conductivity of the water and boost process efficiency.

02. Membrane module

Hydrogen and natural gas can be separated again in the membrane plant. The membranes used are about 100 times more permeable for hydrogen than they are for methane. This separation concept enables the natural gas to be conditioned and the hydrogen to be recovered in one step.

03. Compressor station

A compressor station is needed to bring the methane-hydrogen mixture to the required pressure before it is introduced into the storage reservoir. The planned maximum storage pressure is 80 bar.

04. Solar flower

The sunflower-shaped photovoltaic plant provides part of the power required to produce the hydrogen. It is intended to symbolise the fact that storing renewable energy is the main focus of this project.

05. Control centre and measurement station

All information flows to the control centre, where measurement data are processed and dispatched for evaluation. Under normal operating conditions, the facility runs autonomously, and is monitored from RAG's offices in Gampern. Staff are only required on-site for a changeover from injection of gas to withdrawal, or under special circumstances.

06. Wellhead

Gas is conveyed to the wellhead and injected into the natural rock formations via the well.

07. Well

Injection and withdrawal take place via the well.

08. Reservoir

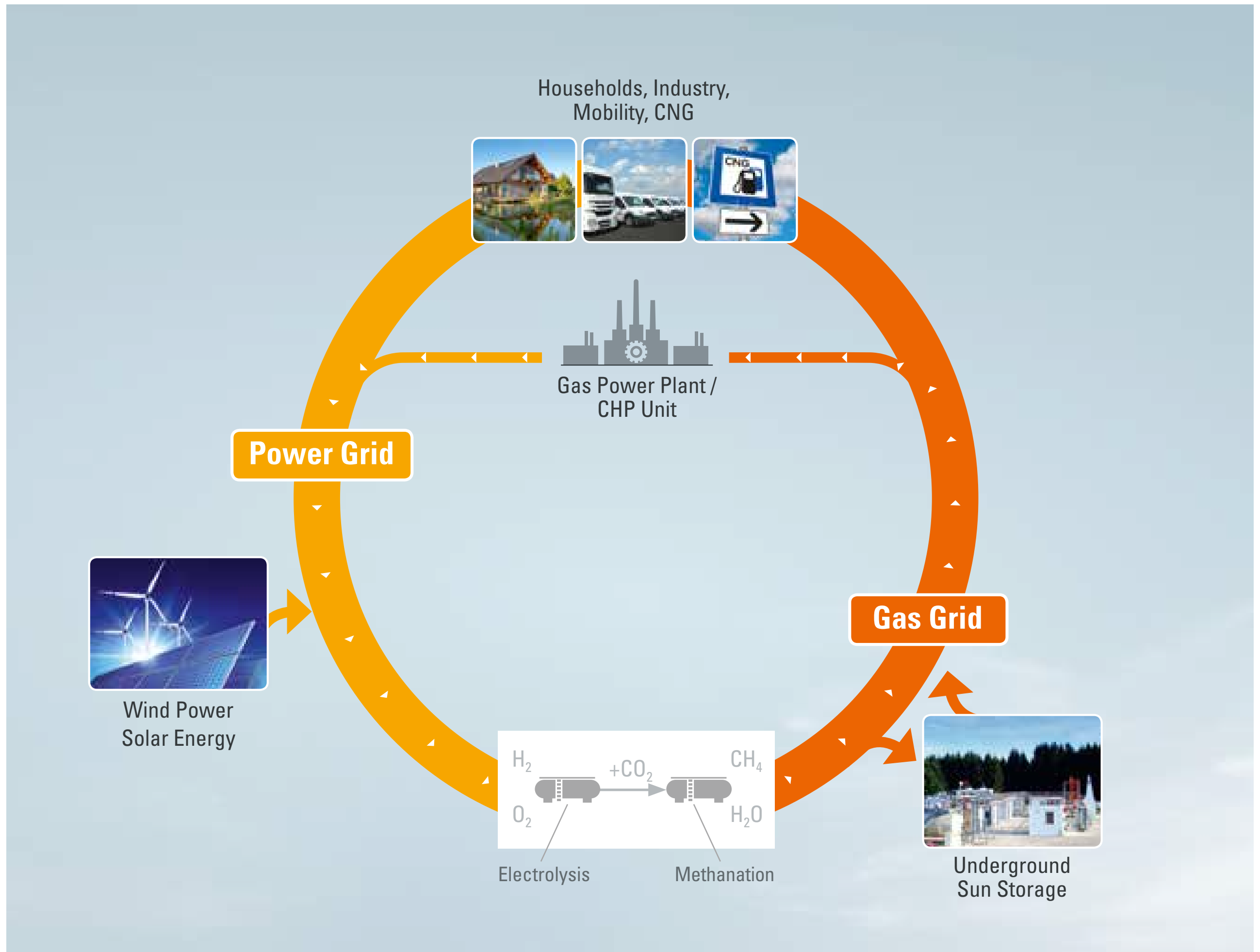
Millions of years ago, natural gas reservoirs formed in the pores of sandstone, sealed beneath layers of clay over 100 m thick. They offer space to store large amounts of energy sustainably, safely and out of sight.

Technical specifications of the facility

Reservoir	
Max. pressure	80 bar
Temperature	34 °C
Depth	1,027 m
Working gas volume	1.8 mn cu m
Reservoir volume	6.0 mn cu m
Electrolysis	
Power	600 kW 120 cu m H_2/h

Wind + Sun = Gas

This is the equation behind power to gas, an innovative technology that forms the basis for the Underground Sun Storage research project.



Power to gas could hold the key to affordable transportation and storage of large quantities of solar and wind energy, making it available around the clock. Sometimes the wind does not blow or the sun goes in, while at other times surplus power is produced. For their share of the energy mix to keep on growing over the long term, renewables need a means of compensating for fluctuations in output.

Huge potential

Intermittent renewable electricity output is not the only problem. Something will also have to be done with all the excess power generated by giant wind and solar parks at times when demand is low. This surplus energy needs to be stored so that it can be made available during peak periods. If we want 100 percent of the electricity generated in Austria to come from renewable sources, we will need storage with capacity over 100 times greater than the potential offered by pumped storage. (Source: Vienna University of Technology, ESEA/EA (ed.): 'Super-4-Micro-Grid', research project final report, Vienna 2011). The combined capacity of pumped storage plants and battery storage used to date is far from sufficient. Additionally, such facilities can only release electricity. The answer is gas. Besides power generation, it can also be used for heating, in vehicles and as a raw material. The gas transportation and storage infrastructure in place has all the makings of a storage system for green power.

Eco-friendly technology

Secure, long-term energy supplies that are economically viable, environmentally sustainable and socially responsible are a high priority on the European political agenda, as is reducing the continually growing dependency on energy imports.
Energy companies and research institutes in Austria and Germany are working flat out on new approaches to large-scale electricity storage. The power to gas strategy is particularly promising. This involves converting renewable electricity into gas and using existing gas infrastructure to transport and store it.

The principle behind this new, environmentally friendly technology could hardly be simpler. Surplus solar and wind power is used to split water into oxygen and hydrogen by means of electrolysis. The hydrogen can then be stored for later use, for example as primary energy in fuel cells. But a further step is also possible: in methanation, the hydrogen is reacted with carbon dioxide (CO_2). The CO_2 can be drawn from the atmosphere or it can come from a biogas or industrial plant. The product of the process is renewable synthetic natural gas.

Methane is the main constituent of natural gas, making up as much as 98% of its content. It can be injected into the gas grid and used in the same way as conventional natural gas to fuel domestic space, for water heating and industrial processes, as a renewable fuel for gas-powered vehicles, or alternatively for gas-fired electricity generation. The process gives rise to no emissions apart from the oxygen released when the water is split. Today the efficiency of the conversion process is already about 60% – a big step forward in view of the fact that surplus electricity is often not used at all owing to the lack of storage capacity, and instead wind turbines are idled or whole wind farms taken off the grid. If the hydrogen can be used directly, the efficiency rate is even higher.

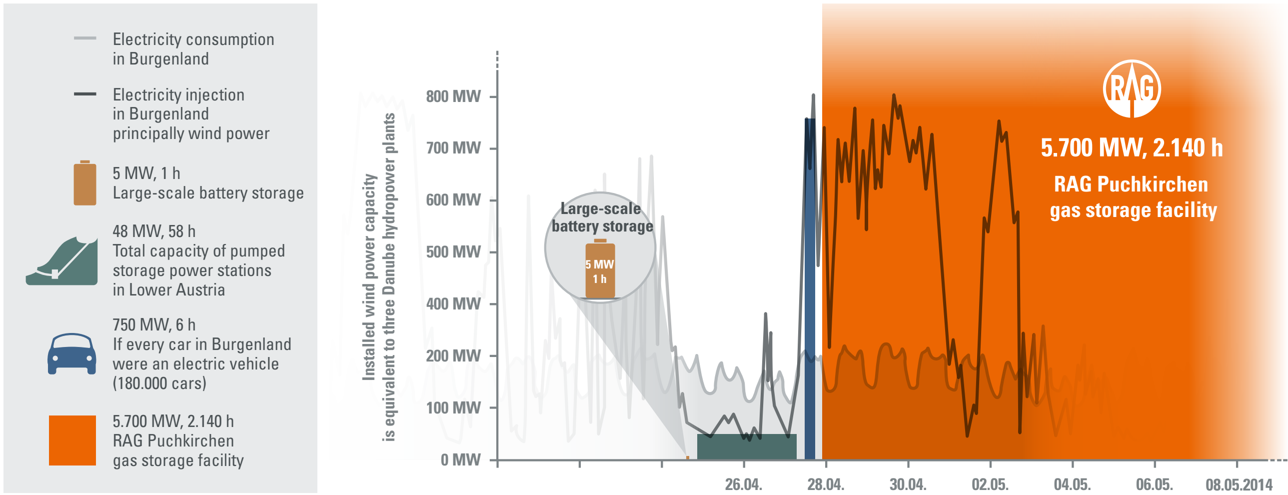
Using existing gas infrastructure

Thanks to electrolysis and methanation, electricity can be converted into hydrogen and into natural gas, making large-scale power storage possible for the first time. The process solves one of the biggest problems posed by electricity storage – shortage of space. It means we can simply turn to existing natural gas infrastructure, in the shape of the pipeline grid and large storage facilities. Instead of developing and rolling out expensive and elaborate new storage technologies, the power would be transformed into synthetic natural gas and stored in depleted gas reservoirs.

"Europe is committed to renewables, but we need reliable energy supplies around the clock. Gas can pull that off. Cutting edge power to gas technology has the potential to make transporting and storing solar and wind energy affordable, which would make them constantly available. The infrastructure is already in place – we have the pipelines and storage facilities to do the job."

Markus Mitteregger,
Chief Executive Officer, RAG

Gas storage facilities are the solution to renewable energy storage



Project Partners

Rohöl-Aufsuchungs Aktiengesellschaft (RAG) is Austria's oldest oil and gas exploration and production company. One of its core business activities is energy storage. RAG has developed and operates its own storage facilities at Puchkirchen and Aigelsbrunn. A joint venture between RAG, Gazprom and Wingas operates the Haidach gas storage facility, and another, with E.ON Gas Storage, runs the 7Fields storage facility. Both facilities straddle the border between the provinces of Salzburg and Upper Austria.

Through its own storage capacity, which now totals about 5.8 billion cubic metres, and its activities as an operator, RAG makes a major contribution to security of supply in Austria and Central Europe as a whole. RAG is currently the fourth biggest gas storage operator in Europe.

The company sees itself as a partner for renewables and also develops geothermal energy projects.

RAG's role in the Underground Sun Storage project: RAG is the lead company and biggest investor in the group that is undertaking this pioneering project. The experienced RAG staff on the Underground Sun Storage project team provide access to the company's extensive expertise in developing and commissioning underground storage facilities.

RAG will mainly be concerned with developing, building and operating an experimental facility for underground storage of renewable energy converted into a mixture of methane and hydrogen. Experts from RAG are also involved in all of the other work packages that make up the project. They are assisting with the provision of test materials, and verification of the relevance of the laboratory tests and simulations to real-life reservoir conditions.

The project is being financed by Austria's Climate and Energy Fund as part of its energy research programme.

Montanuniversität Leoben (University of Leoben)

As the leading academic project partner, the University of Leoben will contribute fundamental research and simulations. It will use laboratory experiments and proprietary simulation software to investigate the geochemistry and model the reactive transport processes concerned. Possibilities for de-mixing hydrogen and natural gas will be tested in long-term experiments on a set of three pressurised reactors filled with porous materials. The influence of the hydrogen-methane mixture on the properties of the materials used in pore storage facilities (cement and various grades of steel) will also be examined in laboratory experiments. In addition, a risk assessment will be performed to identify and evaluate the potential risks of underground hydrogen storage. Finally, a life cycle assessment will determine the environmental impacts of viable hydrogen storage scenarios.

University of Natural Resources and Applied Life Sciences, Vienna
Department for Agrobiotechnology, IFA Tulln
Institute of Environmental Biotechnology

The institute's Geobiotechnology and Chemodynamics working group under Prof. Andreas P. Loibner brings microbiology expertise to the project, offering extensive experience in the scientific description of microbial consortia and their metabolic capabilities. Research is carried out into microbial processes that take place underground, which are then evaluated in terms of their potential commercial use. As part of the Underground Sun Storage project, the group is examining microbial communities in natural gas storage facilities, and assessing microbial changes in the gas and in storage reservoirs following the addition of hydrogen. Insights gained from laboratory experiments (work package 3) will feed into implementation of the field trial (work package 8).

Role of the Energy Institute at the JKU Linz in the Underground Sun Storage project: The Energy Institute is responsible for the economic, systems analysis and legal research related to the Underground Sun Storage project. Legal analysis is required to establish how existing legislation may apply to storing hydrogen underground and, once the findings of the technical tests are available, to draw conclusions as to the need for any changes in the law. The economic and systems analysis is intimately connected with an examination of the technical aspects of the project. This project component will consist of detailed investigations of means of integrating the technology within the existing industrial and economic environment, and an assessment of these options, as well as the likely systemic effects of the technology, based on the outcomes of technical and commercial analyses. A range of alternative solutions will also be considered as part of the economic and systems analysis.

Axiom Angewandte Prozesstechnik was founded in 1992 as a specialist in industrial applications of membrane technology. Besides employing reverse osmosis technology in water purification projects, Axiom carries out intensive research into gas permeation technology, and has secured numerous patents.

In a joint research project with Vienna University of Technology's Institute of Chemical Engineering, Axiom developed new applications for membrane gas separation. These included the recovery of helium and hydrogen, the separation of carbon dioxide from natural gas, as well as biogas treatment. Axiom has steadily extended this area of its expertise, and has applied it with great commercial success, becoming a major supplier for the membrane gas separation process and a leading innovator in the field. Axiom sees membrane technology as one of tomorrow's key technologies.

VERBUND is Austria's leading power company and one of Europe's largest producers of hydroelectricity. The company was established in 1947 in Vienna and has operations in power generation, transmission, trading and sales. Verbund has been a listed company since 1988, and is 51% government-owned.

Approximately 90 percent of its electricity comes from climate-friendly hydropower, making Verbund a reliable supplier of clean energy in Austria and Germany. The remainder of the generation mix comprises wind power and solar thermal installations generating heat and power.

Verbund's role in the Underground Sun Storage project: The energy sector is currently in the throes of a massive transition. Long established structures, based on central generators and decentralised consumers, are disintegrating. Decentralised power generation is gaining ground, at the expense of the traditional business model whereby energy is delivered to consumers. This is affecting the entire energy system, including the power generation mix, the networks that locally produced energy is increasingly being fed into, and the attitudes of consumers, who are becoming keen to produce and store their own energy. Larger-scale consumers, boasting increasingly mature technology, from heat pumps and photovoltaic arrays to local battery storage systems and electric vehicles, are also entering the picture. In collaboration with the Energy Institute at the Johannes Kepler University Linz, Verbund is examining the economic implications of power to gas as part of the Underground Sun Storage project. A range of application scenarios will be explored and assessed.

Cooperation Partners

NAFTA is a modern company with extensive 40-year experience in natural gas storage and underground facility development and, at the same time, it is the Slovak leader in exploration and production of hydrocarbons with this storage capacity currently stands at 2.6 bcm. NAFTA is participating in the "Underground Sun Storage"-project with reactive transport modelling, analysis of impact on subsurface completion, design and supplying of compressor for parts of testbed facility.

Hychico was established in 2006 and its main activities, located in Argentine Patagonia, are power generation from renewable sources and the production of hydrogen and oxygen. The Pilot Project, composed of an Hydrogen Plant and a Wind Park, is currently producing High Purity Hydrogen (120 Nm_3/h and 99,998 % purity), and the Wind Park is selling the energy through the National Wholesale Electric Market through the national grid. Our current challenge is to test the storage of hydrogen in depleted gas reservoirs as a peaking facility to fuel a turbine or gensets also with natural gas and to study possible methanation processes in the well.

It is the central mission of the **DVGW** to advance the gas and water industry in both the technical and technical-scientific context. In pursuing this objective, the DVGW bases its activities on the current requirements of its members, and on the objectives declared in the statutes, i.e. safety, hygiene, and environmental protection.
The DVGW has been working for the gas and water industry as an independent and unbiased technical-scientific association since 1859, the objective being to create a basis for the safe and technologically flawless supply of gas and water. The Technical Rules issued by the DVGW form the core of this basis. These rules have been devised by the various DVGW bodies and enjoy quasi-legal status, which at the same time ensures the self-administration of the industry.

ETOGAS GmbH develops, builds and sells turnkey power-to-gas plants that can be used to convert electricity into hydrogen and/or methane (synthetic natural gas, SNG). The plant engineering firm is based in Stuttgart and has 20 employees. It is a leading developer of power to gas technology. In the Underground Sun Storage project, Etogas is providing the centrepiece of the facility, the electrolyser.

Opening of the Research Facility

Rag and its partners achieved an important milestone with the inauguration of the research facility on the 5th of October 2015. After the opening ceremony in the presence of Federal Minister Alois Stöger and Managing Director of KLIEN Theresia Vogel the research facility was presented to the public.

f.l.t.r.: Project Manager Stephan Bauer / RAG, MD Kurt Sonnleitner / RAG, MD Theresia Vogel / KLIEN, FM Alois Stöger / BMVIT, CEO Markus Mitteregger / RAG, MD Michael Längle / RAG

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Credits

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