UNDERGROUND SUN.CONVERSION

Underground Sun Conversion

Renewable gas produced to store solar and wind power

ENGLISH

Unique research project

Underground conversion and storage of wind and solar energy

RAG Austria AG is Austria's largest gas storage company – making it the country's biggest energy storage provider – and one of Europe's leading gas storage facility operators.

For years, RAG has been dealing with the decarbonisation and transformation of energy systems. At the same time, with the increasing expansion of energy from renewable sources, the demand for large-volume and seasonal storage will increase, compensating for the seasonal fluctuations in energy harvest (summer sun) and energy demand (winter) and providing the usual level of security of supply. It is a service that cannot be provided by pump storage plants or batteries. Gas storage can provide the solution. RAG Austria AG has therefore been making considerable efforts in research and development for years to evolve storage solutions for structuring the supply of renewable energy as required. We see ourselves as a partner of renewable energies. An already widely discussed solution for the storage problem is the „power-to-gas" technology. The surplus electricity from solar and wind energy splits water into oxygen and hydrogen. Electricity (electrons) is then converted into hydrogen (storable molecules). Thus hydrogen becomes an energy carrier.

"The energy carrier gas can be transported in large quantities safely and invisibly in existing underground infrastructure and environmentally friendly stored in natural gas reservoirs. Due to its good geological preconditions for storage, Austria can make a significant contribution to Europe's security of supply."

In our unique „Underground Sun Storage" flagship project, we have been working with partners to test the storage of hydrogen in depleted natural gas reservoirs as part of an in-situ field trial. In the framework of this project, we were able to gain many positive insights that motivated us to continue. A key finding led to the current project „Underground Sun Conversion", which will be presented in more detail in this brochure. Hydrogen and carbon dioxide can be converted into methane = renewable natural gas in suitable natural gas reservoirs through a microbiological process. This energy conversion as well as the increase in energy density and energy storage take place invisibly in the porous rock at depths of more than 1,000 metres.

Under the leadership of RAG Austria AG, the Underground Sun Conversion project is being carried out by an Austrian consortium and supported as part of the energy research program of the Austrian Climate and Energy Fund as a flagship project. The research project should be completed by 2021.

Project description

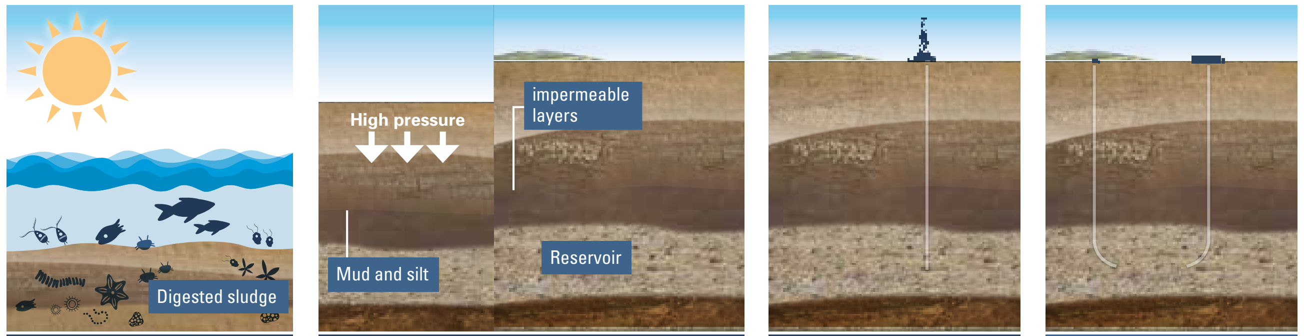
First, hydrogen is produced from solar or wind power and water, in an above-ground facility, and then injected with carbon dioxide into an existing (porous) natural gas reservoir. At a depth of over 1,000 metres, in a relatively short time naturally occurring microorganisms convert these substances into renewable gas which can be stored in the same reservoir, withdrawn as needed at any time, and transported to consumers via the existing pipeline network.
The aim of the research project is to use existing gas (pore) reservoirs as natural bio-reactors. The methanation process and storage take place naturally in underground pore reservoirs. This represents a huge source by potentially providing the urgently needed flexibility which renewable energy sources currently lack.

Initial laboratory tests conducted as part of the forerunner project, Underground Sun Storage – which is also supported by the Austrian Climate and Energy Fund – show that hydrogen and carbon dioxide injected into the reservoir are converted into methane by microbiological processes. This enables the creation of a sustainable carbon cycle. Laboratory tests, simulations and a scientific field test at an existing RAG reservoir will be carried out in collaboration with a group of project partners. A further objective is to test whether the outcomes can also be achieved at many other reservoirs all over the world. The striven results are therefore of outstanding importance for a successful energy transition.

Natural origin and current use of natural gas

The formation of natural gas storage reservoir takes millions of years. In the 20th century, due to its flexibility and versatility, natural gas is establishing itself as one of the most important (fossil) sources of energy.

Underground Sun Conversion Technology makes it possible to have available large volumes of seasonally storable natural gas in a renewable energy system available.



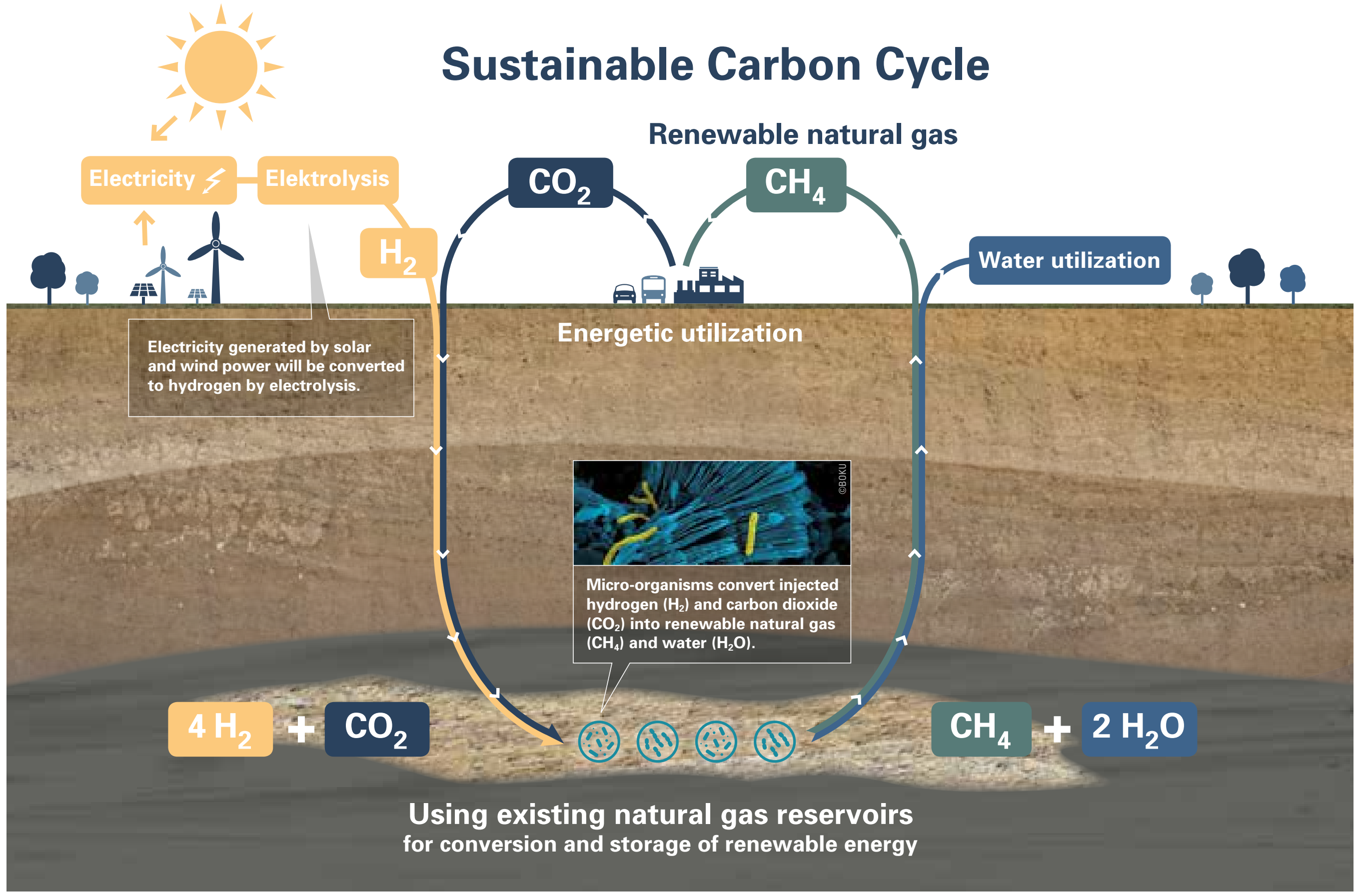
Formation of digested sludge
The sun provides energy for organic growth. Microorganisms sink to the seabed and are covered with sand and silt. This produces digested sludge.

The formation of natural gas
Over the millennia, many layers of mud deposited over it. Under high pressure and oxygen occlusion, microorganisms converted the digested sludge. Natural gas was created and accumulated in deposits between impermeable layers.

Exploration and production
In the 20th century, the production of natural gas from these reservoirs begins.

Underground Sun Conversion
In the future, this process in the natural reservoir will be copied and shortens it by millions of years. Within a few weeks, the Underground Sun Conversion technology will create „renewable natural gas".

250 million years | 50 million years | 1900 | 2017



Geological history in fast motion: Producing natural and renewable gas

This unique method recreates the process by which natural gas originates, but shortens it by millions of years – like geological history in fast motion. The time advantage is primarily due to two factors. On the one hand, organic substance must first be built up in natural formation (in principle, solar energy should also be stored). These organic substances die off, are decomposed and converted to (methane) natural gas. This process is shortened in Underground Sun Conversion technology by going straight into the process with the starting materials of the last conversion step. Secondly, the use of fossil natural gas requires a sedimentation process that produces porous storage structures with a corresponding clayey covering layer. This process takes a long time and only then can gas be stored in the geological structures. At that time, much methane was immediately returned to the carbon cycle, as is still the case in wetlands today. By using already existing suitable reservoirs, no sedimentation process has to be awaited, and the risk of developing suitable stratigraphy is eliminated.
In total, geological time periods can be skipped by using existing geological structures - hence „Geological history in fast motion".

This environmentally friendly process has three major advantages:

- **Carbon neutral**
  Renewable natural gas is carbon neutral if CO_2 that is already present – for example, from burning biomass – is utilised and absorbed by the production process. This creates a sustainable carbon cycle.
- **Renewable energy becomes storable**
  Solar and wind power output fluctuates due to changing weather conditions, meaning that production cannot be adjusted to demand. The problem of storing renewable energy is solved by converting it into renewable natural gas.
- **Use of existing infrastructure**
  Infrastructure already in place can be used for the natural production process, as well as for underground storage in natural gas reservoirs, and environmentally friendly transportation to consumers.

Thematic areas

In order to map and answer the scientific questions in the best possible way, a work plan with nine work packages was created.

Work package 1:

Project management

Among other things, the tasks of this work package are to maintain the interfaces between the individual work packages, to organize public relations and the dissemination of the results, to communicate with the funders and to report.

Work package 2:

Microbial methanation in underground natural gas reservoirs (sandstone formation)

Our primary goal in Underground Sun Conversion is to control microbial transformation processes in gas storages towards microbial conversion of hydrogen and carbon dioxide to methane (hydrogen trophic methanogenesis). Environmental conditions have to be identified that favour microbiological methanation and suppress potential adverse effects such as homoacetogenesis and pore clogging. Conversion processes will be established in laboratory experiments using specimen originating from the underground gas storage and verified at field conditions as present at the test site. Finally, an evaluation of the methane formation capacity with respect to industrial exploitation will be accomplished.

Work package 3:

Simulation of the microbiological process

The aim of this work package is to use computer simulations to elucidate the global feedback mechanisms between microbial growth and the properties of gas flow in storage and to identify optimal operating strategies for efficient methane production. Computer reconstructions of the gas storage facility are combined with mechanistic models of methane-producing microbes to understand the interactions between the microorganisms, the gas flow and the environment. The data obtained from the laboratory and the field trial are used to validate these models.

Work package 4:

Materials and corrosion

This work package involves conducting laboratory and field tests to determine whether the gases hydrogen and carbon dioxide required for the unique microbiological methanation process will cause corrosion of the steel grades used in the facility, and whether there is a possibility of changes occurring in the cementation of the wells.

Work package 5:

Product gas conditioning

This work package focuses on the conditioning of the product gas from the underground methanation. The main objective is the development of a membrane system for the separation of hydrogen and carbon dioxide from the withdrawn gas. Consequently, the produced gas is made compatible with natural gas infrastructure and can be injected in the gas grid.

Work package 6:

Planning, construction and operation – In-situ reservoir batch experiments

In the course of this work package, a scientific field test facility for the underground sun conversion process will be planned and built. Using an existing well, the hydrogen – carbon dioxide – natural gas mixture is injected into the test reservoir at a depth of about 1,000 metres. After a conversion phase under shut-in conditions, the gas mixture is removed via the same well. During the test procedure, analysis samples can be taken repeatedly and trends of pressure, temperature and gas composition can be observed.

Work package 7:

Planning, construction and operation – In-situ reservoir circulation experiments

As a major extension to work package 6 a second well will be drilled in order to further develop the reservoir. This allows cycling experiments in which conclusions can be drawn on the kinetics of the conversion reaction by continuous observation of the gas composition and other parametres. With the help of this second well, the gas mixture can be moved and monitored in circulation operation through the reservoir. Subsequently, the resulting methane production can be skimmed off using membrane technology and new hydrogen and carbon dioxide can be added to the process.

Work package 8:

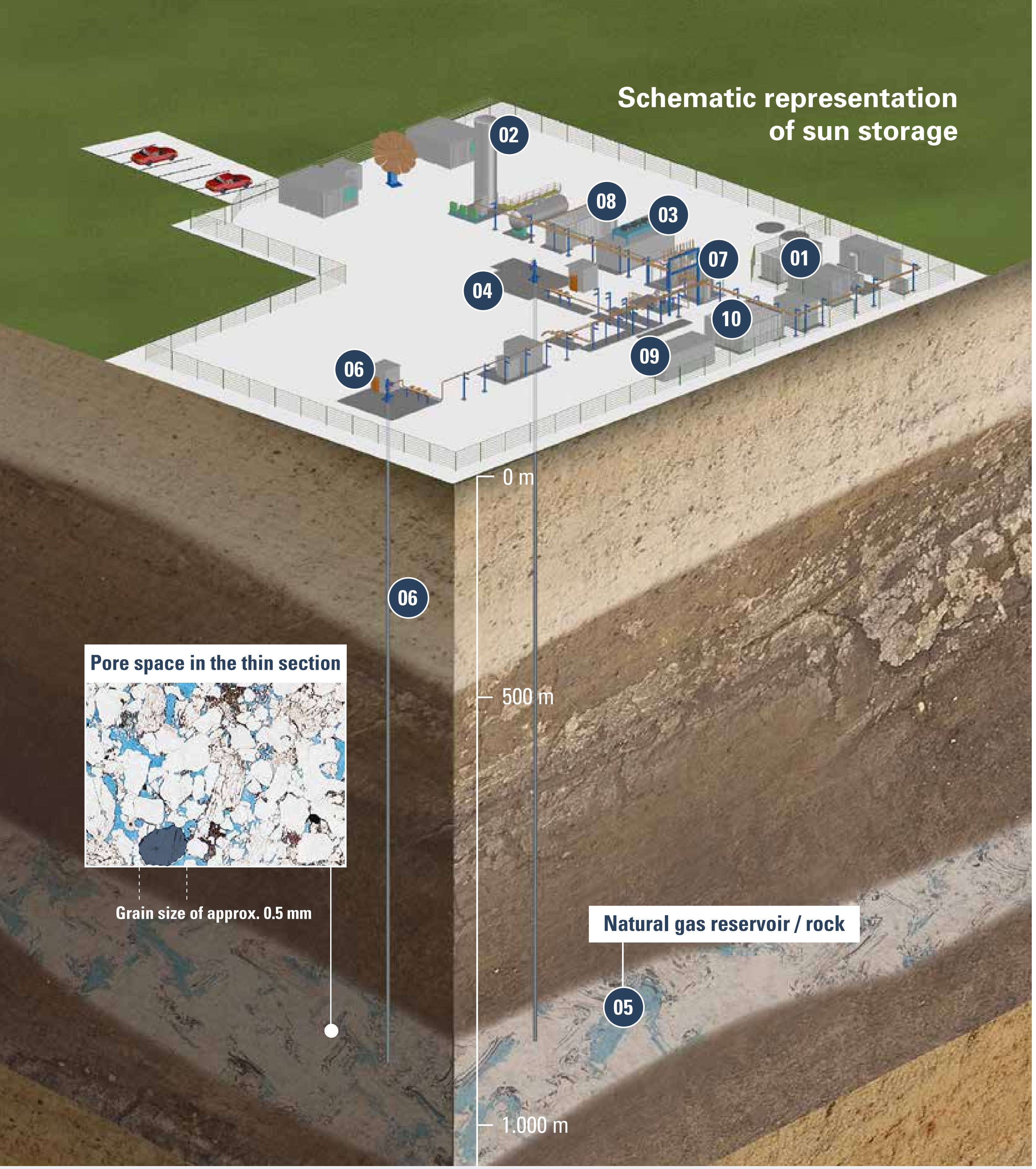
Technical ability for upscaling

This work package aims to develop process concepts for an industrial plant size, particularly for the required surface infrastructures. A reasonable plant capacity is derived related to suitable sites in a global view whereat the influences of specific locations framework conditions on the process concept are identified. Furthermore, the potential of combining geomethanation with surface catalytic post-methanation is assessed. The technical aspects of upscaling are provided for the potential analysis in WP9, including costs for main plant items.

Work package 9:

Potential assessment

This work package is lead by the Energieinstitut an der JKU. The work is compiled in cooperation with RAG and the Montanuniversität Leoben. It focusses on the techno-economic and ecological evaluation of the Underground Sun Conversion technology considering it as a systemic building block of a „Power-to-Gas“ system. The work package starts with a potential and site location analysis in order to estimate the global potential for establishing Underground Sun Conversion. Additionally a legal analysis is carried out aiming at determining the challenges and hurdles in the current legal system for establishing Underground Sun Conversion.



01 Elektrolysis

02 CO_2 - tank

03 Compressor station

04 Injection well

05 Gas reservoir

06 Withdrawal well

07 Drying unit

08 Gas conditioning

09 Electricity grid connection

10 Control unit / EMSR

01. Electrolysis

This is where hydrogen is generated from electric current. After cleaning the well water through a reverse osmosis system, the water is decomposed into hydrogen and oxygen by direct current. The hydrogen is dried and mixed with CO_2 and natural gas forwarded to the compressor. The oxygen is released as a by-product to the atmosphere.

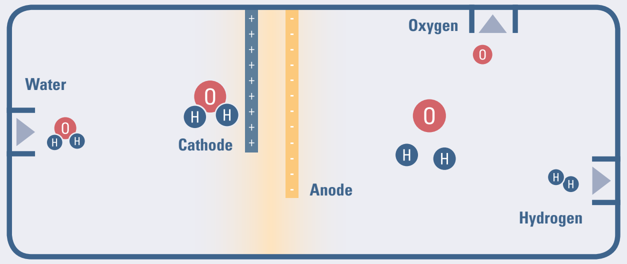
The electrolysis of water consists of two partial reactions, which take place at the two electrodes (cathode and anode chambers).

Cathode space: $2 H_2O + 2 e^- \rightarrow H_2 + 2 OH$

Anode space: $6 H_2O \rightarrow O_2 + 4 H_3O^+ + 4 e^-$

The overall reaction scheme of this redox reaction is:

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



In this process an alkaline electrolysis is used. KOH is added to raise the conductivity of hydrogen, which improves the efficiency factor.

02. CO_2 - Tank

For microbiological methanation in the reservoir, CO_2 is added to the process. CO_2 is supplied in liquid form and stored in a buffer tank on site and can be added as needed. The CO_2 comes from a biogenic source.

03. Compressor station

To bring the gas mixture methane / hydrogen / CO_2 to the required pressure in order to to be able to bring it into the reservoir, a compressor is needed. Here is a so-called piston compressor machine used. A maximum accumulator pressure of 60 bar is planned.

04. Injection well

The injection and withdrawal in batch operation take place via a well, which is equipped with appropriate safety features. In later cycle operation, this well is only used for storage.

05. Gas reservoir

Millions of years ago, natural gas reservoirs were created in the pores of the sandstone, which are sealed by more than 100 m thick clay layers. Here, large quantities of energy can be stored sustainably, safely and invisibly.

In the Underground Sun Conversion project, the microbiological generation of renewable natural gas will be restarted, a process that took place exactly here millions of years ago.

06. Withdrawal well

The removal of renewable natural gas takes place from the cycle operation via its own well, which is also equipped with appropriate safety features.

07. Drying unit

In a subsurface reservoir gas is absorbing moisture. Therefore, before the gas is discharged into the downstream systems and the pipeline network, a drying is required.

08. Gas conditioning

The gas taken from the reservoir may still contain residual unreacted hydrogen and carbon dioxide. In the course of the project, a membrane separation process is therefore being tested in order to reduce these gas components to a specification-compliant level.

09. Electricity grid connection

The Underground Sun Conversion Project is about storing renewable electricity by converting it into a storable energy source. The renewable electricity is supplied via the power grid and transformed via a transformer to the required voltage levels.

10. Control unit / EMSR

At this point all information comes together, measurement data is processed and forwarded for evaluation. The system operates autonomously during normal operation and is monitored by the headquarters in Gampern. In the event of any fault messages, the on-call service reacts.

Reservoir	
Max. pressure	107 bar
Temperature	40 °C
Depth	1,027 m
Working gas volume	1.7 mn cu m
Reservoir volume	6.2 mn cu m

Elektrolysis	
Installed power	500 kW 100 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 and Underground Sun Conversion research projects.

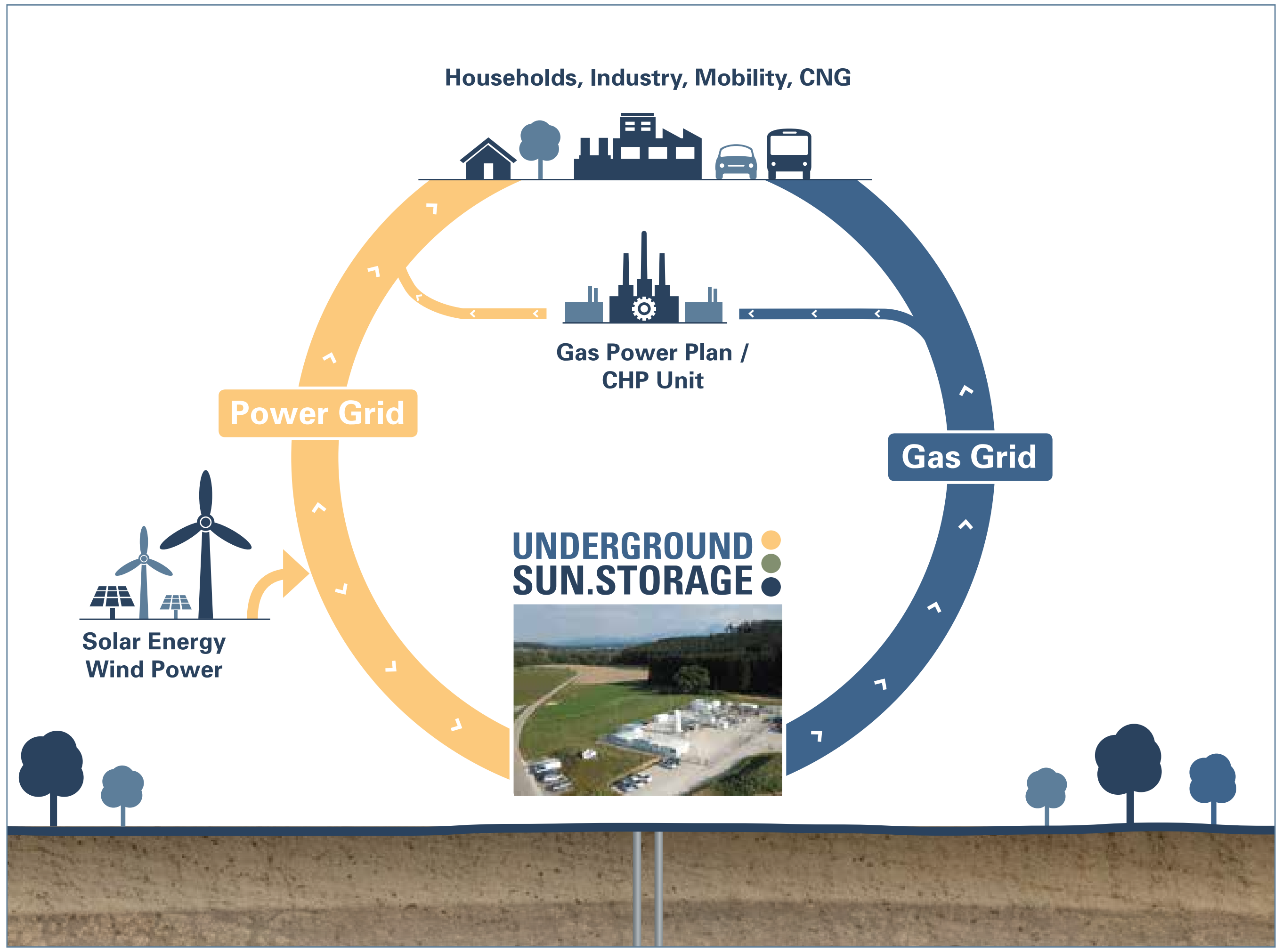
Future technology with enormous potential

This will make it possible to economically transport and store the renewable solar and wind energy in large quantities and thus to have it available at all times.

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.

Environmentally friendly power to gas technology

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). Preferably, the CO_2 comes from CO_2-rich gas streams (e.g. biogas or industrial plants). The product of the process is renewable synthetic natural gas.



Today the efficiency of the conversion process is already about approx. 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 natural 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.

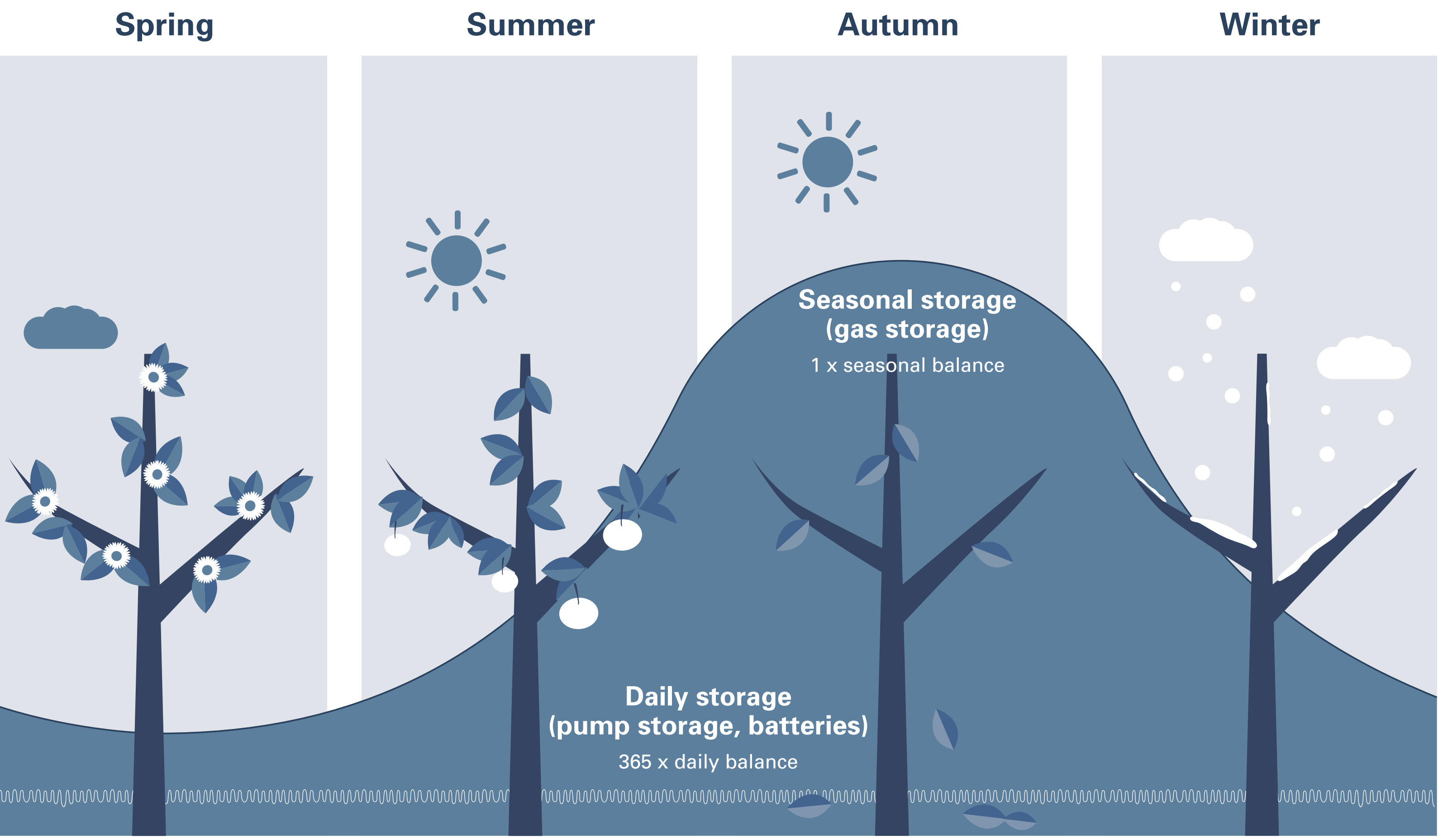
Energy storage

Energy consumption in Austria / Central Europe is significantly higher in winter than in summer. Natural gas storage systems that are located near consumption provide the essential service of seasonal compensation in the energy system.

In simple terms, gas is stored in summer and removed in winter. The storage has an annual cycle, as can be seen from the graph below. This involves very large amounts of energy – in the case of RAG Austria AG by up to 66 TWh. This service ensures that the energy supply is provided at all times of the year and even during supply interruptions (security of supply). The importance of the seasonal balance between supply and demand will increase significantly in the future if we gradually switch to solar and wind energy.

Another service in the energy system is provided by pumped hydro storages and in future by the much smaller battery storage. These storage systems ensure a day-night balance and stability of the power grid in the electricity system. Therefore these storages are filled and emptied up to 365 times a year. In addition they are much smaller. The overall storage volume of the Austrian pumped hydro storages is only 0.14 TWh (Source: Vienna University of Technology, ESEA / EA (ed.): „Super 4 Micro Grid“, final report on the research project, Vienna 2011), sufficient for this service but unsuitable for the needs of seasonal storage.

Energy storage during the year



Review: Underground Sun Storage

Harvesting, storing and supplying solar energy: RAG tested this groundbreaking approach to energy production and storage in a unique research project, Underground Sun Storage.

The storability of hydrogen produced using solar energy was demonstrated at a small depleted gas reservoir in Upper Austria/ Pilsbach.

The main purpose of this pioneering project was to investigate the hydrogen tolerance of underground gas storage reservoirs. The project demonstrated that gas storage facilities can tolerate hydrogen content of up to 10 %. This means that naturally formed gas storage reservoirs are not a limiting factor within the gas system as a whole, and with their vast storage capacity (more than 8 billion cubic metres in Austria, equivalent to 92 terawatt hours), their role in the energy system of the future could change significantly, since they can be used to store and balance supplies of renewable energy.
Based on these results further research at many other storage formations can now be undertaken.

Storage of regenerative hydrogen in porous gas storage tanks

- Electricity can not be stored, but hydrogen can
- Large amounts of solar and wind energy require seasonal and large-scale storage
- Sustainable use of the gas infrastructure is possible
- Renewable energy becomes baseloadable

Results

- Underground storage of renewable energy via hydrogen is possible
- Existing gas storage infrastructure has been successfully tested for the applicability of hydrogen
- There is no negative impact on the existing storage
- The integrity of porous gas storage is not compromised
  - No migration from the reservoir
  - No change in the storage rock
  - Microbial processes can be controlled
- Sustainable use of the existing infrastructure for the renewable energy future
- Synergies of storage and production of renewable gas
- Positive response from national and international storage operators and stakeholders

Future development opportunities

- Sun Conversion Project - Production and storage of renewable gas in an existing underground infrastructure
- Test the storage capacity of up to 100 % hydrogen in the underground storage

Project partner

RAG Austria AG
RAG is an innovative and traditional energy company focused on its core business of gas storage, developing innovative and sustainable energy solutions using its extensive underground expertise. In particular, the development of new energy technologies, through research and production of renewable gas. With the operation of a storage capacity of now approx. 6 billion cubic metres, RAG makes a significant contribution to the security of supply in Austria and Central Europe, making it one of the largest gas storage operators in Europe.
The focus of the company is clearly on the promising and versatile energy carrier „gas“. The classic, natural gas, which will make an indispensable contribution to the energy supply in the future, is only one aspect. The other is called „green gas“ - such as synthetic gas using power-to-gas technology. RAG is consortium leader and biggest investor within the flagship project „Underground Sun Conversion“. In addition to its many years of experience in the development, construction and commissioning of storage facilities, RAG brings with it the acquired expertise and insights from the project „Underground Sun Storage“.

The project will receive funding from the Austrian Climate and Energy Fund established by the Ministry for Transport, Innovation and Technology, as part of its energy research programme.

Montanuniversität Leoben
The Montanuniversitaet Leoben (MU Leoben), established in 1840, is unique in its high degree of specialization: the major research areas and degree programs are embedded in in the value chain from raw materials to recycling: the portfolio ranges from extraction and mining to the processing of resources and basic materials, metallurgy, high-performance materials, process and product engineering, environmental technology and recycling, complemented by power engineering and production logistics. MU Leoben contributes as scientific partner to this project with its expertise in material science, particularly corrosion, as well as with process technological aspects of the plant scale-up.

University of Natural Resources and Life Sciences Vienna / Department of Agrobiotechnology, IFA Tulln / Institute of Environmental Biotechnology
The institute's Geobiotechnology and Chemodynamics group (Andreas P. Loibner) adds biotechnological expertise to the project, offering comprehensive experience in the scientific description of microbial consortia and their metabolic capabilities. Research comprises microbial subsurface processes, which are then evaluated regarding their potential commercial use. As part of the Underground Sun Conversion project, the group investigates techniques that allow for a control of microbial processes in natural gas storage facilities with the focus being put on the microbial formation of methane from hydrogen and carbon dioxide. Insights gained from laboratory experiments (WP2) will feed into implementation of the *in-situ* reservoir experiments (WP6 and WP7).

Energieinstitut an der Johannes Kepler Universität Linz
The Energy Institute at the JKU Linz is responsible for the techno-economic, ecological and legal analyzes as well as for the survey of the technology potential in the project Underground Sun.Conversion: Through the techno-economic evaluation of the system, the process costs can be analyzed and predicted and compared with relevant benchmarks ; this is a comprehensive analysis involving learning curves and economies of scale of the system. In addition, national and international locations for the potential implementation of the technology are identified. Furthermore, Life Cycle Assessments (LCAs) are used to investigate the environmental impact. Moreover, as explained above, screening and analysis of the legal dimensions of the system are performed.

Axiom GmbH
was founded in 1992 as a company specializing in industrial applications of membrane technology. Besides employing reverse osmosis technology in water purification projects, Axiom carries out intensive research in gas permeation technology and has secured numerous patents. In a joint research cooperation with Vienna University of Technology's Institute of Chemical Engineering, Axiom developed new applications for membrane gas separation. These include the recovery of helium and hydrogen, the separation of carbon dioxide from natural gas and the biogas purification. 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 separation processes as one of tomorrow's key technologies.

acib (Austrian Centre of Industrial Biotechnology)
The Austrian Centre of Industrial Biotechnology (acib) is an international non-profit competence and research centre with more than 140 partners around the world. acib's research focus is in the field of industrial biotechnology. acib adopts tools and methods of nature for new production processes and products with improved ecological efficiency and higher economic efficiency. acib's major fields of research are bioinformatics/ modeling, biocatalysis, systems and synthetic biology, process engineering, and cell biology.

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