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ENERGIE-SPIEGEL

FACTS FOR THE ENERGY DECISIONS OF TOMORROW

CO_2-free Electricity for Switzerland

New Nuclear Technologies

In spite of all appeals for savings, electricity use in Switzerland has grown steadily since 1990. By 2020 there will be a gap between supply and demand that must be filled. In focusing the debate on how this need can be met in the most cost-effective and CO_2-free ways, new nuclear technologies stand alongside new renewable energy sources.

PSI has investigated the potential and costs of future nuclear technologies as part of its work for the Bundesamt für Energie (BFE) in its report Energieperspektiven 2035/50[1].

Beznau und Mühleberg will cease generation in 15 to 20 years at the latest, and important electricity import contracts will expire in 2020. Whether nuclear or non-nuclear, possible solutions for their replacement must now be prepared. They should avoid additional CO_2 emissions as well as electricity costs that would endanger Switzerland's economic competitiveness.

Nuclear power plants deliver today about 40% of Swiss electricity. Together with renewable hydropower they provide an electricity supply that is affordable, generally reliable and almost completely free of air pollution. Nuclear technology that is developed towards the goal of sustainability can continue to make such contributions in the future.

The technical and economic potential of nuclear energy at existing plant locations would allow various supply levels – from current production to increases based on more efficient and larger capacity installations. Costs are expected to be about at today's levels. Future reactor systems could find greater public acceptance, but they must demonstrate especially high safety levels and long-term conservation of resources, as well as strongly reducing nuclear waste and necessary confinement times. If so, the advantages which nuclear energy has today may even further outweigh its drawbacks.

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[1] Neue Erneuerbare Energien und Neue Nuklearanlagen: Potenziale und Kosten Beitrag zu den Energieperspektiven 2035/2050 des Bundesamtes für Energie www.energie-schweiz.ch/; http://gabe.web.psi.ch/projects/bfe/index.html

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Nuclear Technology in Flux

Like every technology, nuclear technology has continued to develop from its beginnings. Lessons have been learned, profiting from new advances – above all in materials and information technology. Reactors of the latest generation are safer than their predecessors, and nuclear systems of the future will present innovative solutions to the problems of resource conservation and waste minimization.

Passive Safety Systems are designs that react on their own (i.e. without human intervention and without external energy sources) when there is any departure from normal operating conditions. They are initiated and driven only by physical properties like temperature, hydrostatic pressure, etc. The performance of such systems for use in Generation III reactors is already being tested in the PANDA facility at PSI.

Inherent Safety means: Certain dangerous situations, e.g. overheating of the reactor, are excluded under all circumstances, because any disturbance of the reactor will be returned to a safe condition on the basis of physical laws.

The first generation of prototype reactors for civil power production was built in the 1950's and 1960's. From these reactors came various second-generation lines of commercial technologies, only a few of which were successful. The light water reactor (LWR) technology came to dominate the current reactor fleet, with over 80% of current plants. The resulting operating experience of over 10,000 reactor years has allowed Generation II reactors to reach a high level of operating safety. Older reactors and systems with safety deficiencies have been either comprehensively upgraded or retired.

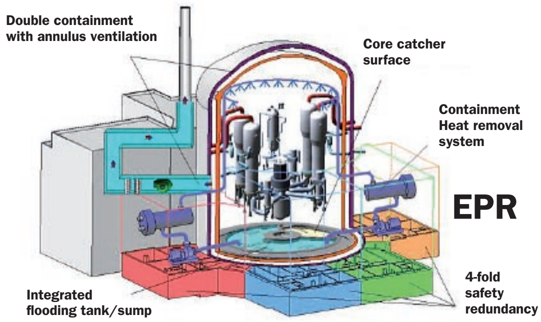


Figure 1: The most marked new elements of the EPR (1600 MWe) include a double containment, a special containment heat removal system, and a core catcher surface, which in the case of a core melt will spread out the molten core material and prevent damage to the foundation. All safety systems are built with four-fold redundancy.

In the course of the 1990's, safety systems were further developed in a targeted way on the basis of experience and integrated in new reactor concepts to achieve a new level of safety. Such concepts practically exclude that even so unlikely an event as a core meltdown will have any effects beyond the plant boundaries: Emergency measures in the surrounding area would no longer be necessary. These concepts are incorporated in the third generation of reactors; some of these are already in operation (in East Asia) and others are under construction (also in Europe).

Development Goal: Protect Resources and Minimize Waste

The best-known representative of this generation of reactors is the European Pressurized Reactor (EPR) that is currently being built in Finland (Figure 1). The EPR is a further development of the proven, standardized French and German reactors. Other Generation III designs rely upon passive safety systems or use inherent physical properties of the system to make overheating and melting of the core impossible.

And the development continues. Already designs for Generation IV reactors have been proposed for evaluation within a framework of international cooperation, which could enter service in 20 to 40 years. In comparison to Generation III reactors, these designs would raise safety levels still further. Depending upon the design concept, some of these reactors would also allow as much as possible of the uranium's energy content to be utilized (current LWR's use only about 1 to 1.5%), minimize the volume of nuclear waste, and reduce to several hundred years the storage time required for waste radiation to fall to natural ore levels. These benefits would require 'fast' neutrons from a reactor or accelerator. Such reactor concepts had already been sketched in the 1950's, but were at the limits of what was then technically and economically possible (e.g. the French fast breeder reactor Superphénix). The current status of materials and process technologies, as well as information technology, now makes their successful realization appear possible.

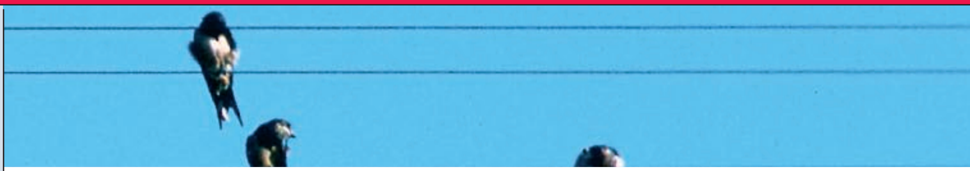
Table 1 shows the chief characteristics of the different Generation IV concepts that have recently been investigated. But before they can be built there are still some technical challenges that must be met with targeted research and development.

Table 1: Comparing Generation IV Systems.

System	Temperature [°C]	Fuel Cycle	Size [MWe]	Product(s)	Technological Challenges
Gas-cooled Fast Reactor (GFR)	850	closed, in-situ	288	Electricity, Hydrogen	Fuels for the fast neutron spectrum Core design, safety, fuel cycle technology Development of high performance helium turbine
Liquid-metal-cooled Fast Reactor (LFR)	550–800	closed, regional	50–150, 300–400, 1200	Electricity, Hydrogen	Fuels and materials System, non-nuclear share of plant Remote controlled fabrication of metallic fuels
Molten Salt Reactor (MSR)	700–800	closed, in-situ	1000	Electricity, Hydrogen	Long-term behavior and reprocessing of the fuel Materials compatibility Preparation, separation and reprocessing of salt
Sodium-cooled Fast Reactor (SFR)	550	closed	300–1500	Electricity	Proof of mastery of boundary events Reduction of capital costs Remote controlled fabrication of oxide fuels
Supercritical Water-cooled Reactor (SCWR)	510–550	open/ closed	1500	Electricity	Materials and structures: corrosion, radiolysis, durability, safety, including performance and flux stability
Very High Temperature Gas Reactor (VHTR)	≥ 1000	open	250	Hydrogen, Process heat Electricity	New fuels and materials for high temperatures Hydrogen production with the sulfur-iodine process Development of high performance helium turbine

Flexible Solutions as Needed

Nuclear energy in Switzerland could go in different directions – retiring current plants, maintaining the status quo, or further building up nuclear capacity. The referenda of May 2003 defeated a mandate to exit nuclear power; building plants in new locations appears today to be hardly possible politically. Therefore this study focused on an intermediate way – replacement of plants at existing locations. This path also essentially depends upon the acceptance of nuclear technology.



With a technical and economic life of 50 (Beznau and Mühleberg) to 60 years (Gösgen and Leibstadt), the Swiss nuclear power plants will retire between around 2020 and 2040 to 2045. The Generation IV concepts will probably not be yet ready for market or sufficiently tested elsewhere. For this reason, all cases in this study are based on the replacement of retiring reactors by Generation III reactors. The possibility of replacing Leibstadt (which retires last) with a Generation IV reactor has also been tested.

Core questions: acceptance and long planning times

Generation III systems have capacities from 1000 MWe to 1600 MWe. One can flexibly decide whether to hold constant the current capacity of the Swiss nuclear plants, or to fully exploit each site's potential (based on available cooling capacity – usually a river). Three specific replacement scenarios were investigated (Figures 2, 3, and 4).

According to the scenario chosen, nuclear electricity produced in 2050 varies between 26 and 44 TWh. If nuclear energy production was held constant at 26 TWh, then moderate demand growth (1.5% per year through 2010, then 0.75% per year) would produce a supply deficit by the year 2020. To fill it would require an additional 5 TWh/year every ten years, equivalent to building a series of new plants of 600 to 700 MWe capacity.

Depending upon how electricity demand grows (from 0 to 2% per year), nuclear energy could cover between 3200 to 5200 MWe of total installed Swiss capacity, or 30 to 68% of domestic demand, by the year 2050.

Figure 2:

Scenario 0: ■ The existing nuclear power plants are removed from service after a life of 50 or 60 years and not replaced.

Scenario 1: ■+■ The nuclear plants Mühleberg and Beznau are replaced with a single unit of about 1000 MWe. Gösgen and Leibstadt are each replaced with a unit of 1000 MWe to 1200 MWe in 2040 and 2045, respectively.

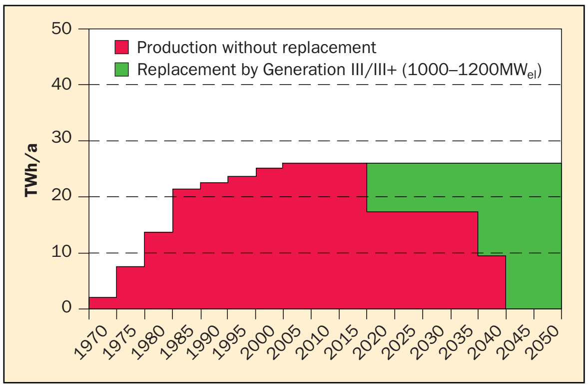


Figure 3:

Scenario 2A: ■+■ The nuclear power plants Mühleberg and Beznau are replaced with a single EPR 1600. Gösgen and Leibstadt are each replaced with an EPR 1600 in 2040 and 2045, respectively.

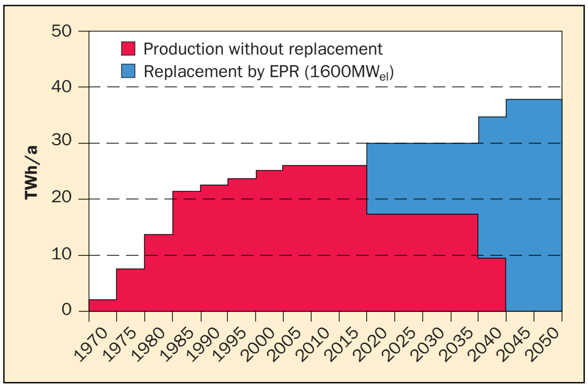
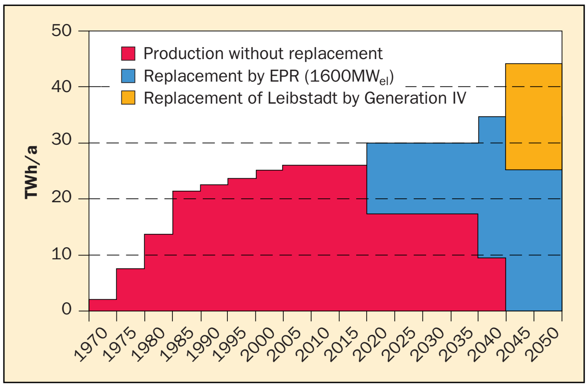


Figure 4:

Scenario 2B: ■+■+■ The nuclear power plants Mühleberg and Beznau are replaced with a single EPR 1600. Gösgen is replaced in 2040 by an EPR 1600, and Leibstadt is replaced in 2045 by a modular Generation IV reactor with a total capacity of 2000 MWe.



Financial Aspects

A legally required, long permitting process implies that each new nuclear plant will need a long planning lead-time. This can mean that earnings may be delayed from 10 to 15 years after the decision to build. This demands courage on the side of the investor. But the generation costs can then be very reasonable. Average costs today are between 4 to 5.5 Rp./kWh (including waste disposal and site restoration costs), and should stay at about the same level for the EPR. The ambitious cost target given today for Generation IV reactors is between 2.5 to 3.5 Rp./kWh.

Acceptance

The potential for nuclear energy is most influenced by the public acceptance of this demanding – and for many people, still scary – technology. If nuclear power is to grow worldwide, then the accident-free performance of the last twenty years must continue, and convincing answers to the questions of waste and proliferation must be delivered – a challenging socio-technological process.

"We Also Need Nuclear Energy"

What is your vision of the future Swiss electricity mix in the intermediate and long term?
Energy demand will continue to climb in the future. The Swiss electricity mix must continue to be generated with close to zero CO_2. That means a demand for hydropower, nuclear energy and the development of new renewable energy resources at market prices. Generation from gas power plants is not a good long-term solution for Switzerland.

What would be the specific role of nuclear energy in this electricity mix?
Nuclear power will remain important from our current viewpoint, because it guarantees CO -free generation of electricity. Because nuclear fuel has a very high energy density and can be readily stored, it also contributes to the security of supply. New energy resources, e.g. biomass, should first be used for the substitution of imported oil or gas.

Only our own contributions offer access to knowledge generated worldwide

What does that mean for Swiss research? For the electricity industry?
The good training of nuclear engineers is an important requirement for the safe operation of nuclear power plants. Exciting research attracts the necessary number of students. As a small country, we must work with a network of foreign partners, for example France and Japan.

A very large job for the electricity industry is to raise the general social acceptability of nuclear energy, particularly through public relations on the issue of waste disposal. Otherwise, the financial risk of a public referendum that would force a nuclear collapse is too large.

How do you ensure that the development of research and teaching is compatible with these goals?
The ETH domain, including ETHZ, EPFL and PSI will soon offer a Masters degree in Nuclear Engineering that is in line with European requirements. Diploma and doctoral work can be carried out at PSI's research facilities. The outstanding cooperation and dialogue with the nuclear power plant operators also makes sure that the research at PSI remains market relevant.

PSI concentrates on the safety of current nuclear plants and waste disposal – is that enough?
Nuclear power plants may only be operated so long as their safety can be guaranteed. It is important to know enough, for example, about materials fatigue. But we must also be able to judge the technology of future plants. Therefore PSI is engaged in an international team

Europe-compatible training and research: the ETH Masters in Nuclear Engineering

on certain aspects of Generation IV reactors. Only those who have something to contribute will have access to the knowledge generated worldwide.

What is the role of the new competence centers for energy and mobility (CCEM-CH) in the view of the energy outlook for Switzerland?
Only a comprehensive knowledge of all technologies and their economic requirements allows the creation of dependable perspectives. This overall competence will be available in the CCEM-CH through their own research at a high level in various energy conversion technologies. The GaBE project at PSI and CEPE at ETH use the technical results produced to formulate possible

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scenarios that include economic and social aspects.

Electricity demand is only about a quarter of our total energy use. Therefore the areas of mobility, space heating for buildings and efficiency gains are just as important research areas when it comes to reducing our use of fossil energy carriers.

Nuclear power will remain important from today's perspective

Impressum

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Energy Systems Analysis at PSI: The goal of energy systems analysis at the Paul Scherrer Institute in Villigen is to analyze present and future energy systems in a comprehensive and detailed way, considering in particular health, environmental and economic criteria. On the basis of Life Cycle Assessment (LCA), energy-economic models, risk analysis, pollution transport models and finally multi-criteria decision analysis, it is possible to compare different energy scenarios to create a basis for political decision-making.

GaBE works together with:
ETH Zürich; EPF Lausanne; EMPA; Massachusetts Institute of Technology (MIT); University of Tokyo; European Union (EU); International Energy Agency (IEA); Organisation für Economic Cooperaton and Development (OECD); United Nations Organization (UNO)