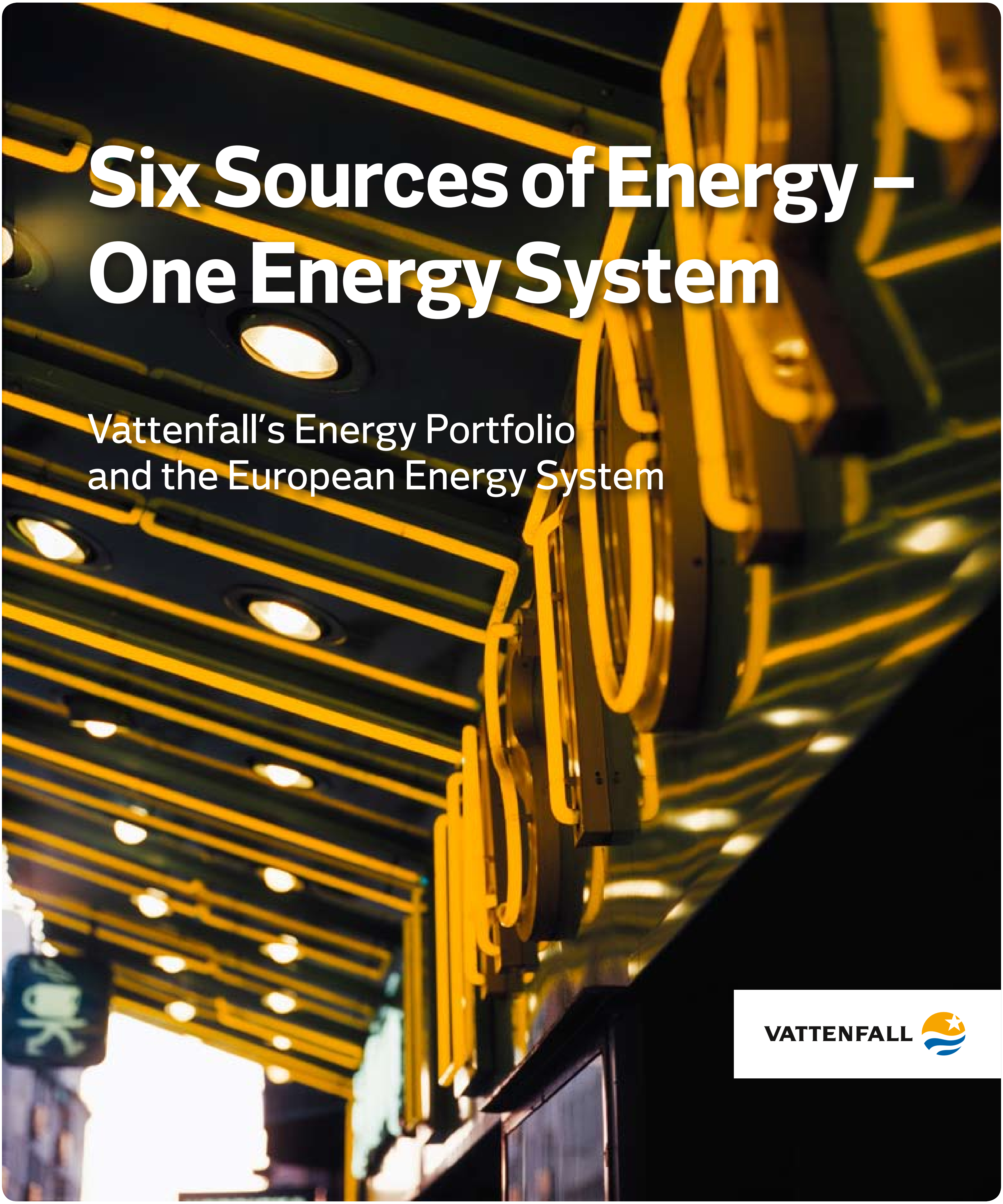
Six Sources of Energy – One Energy System

Vattenfall's Energy Portfolio and the European Energy System



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NUCLEAR POWER

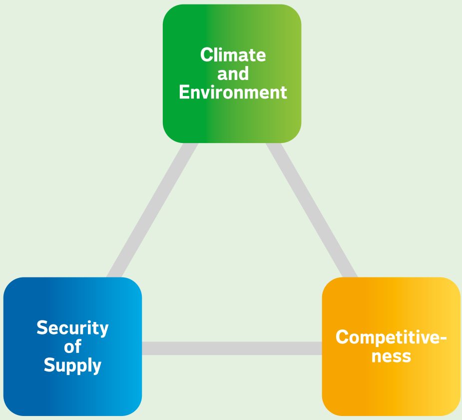
Nuclear power plays a vital role in many European countries due to its economic attractiveness, security of supply and low CO_2 emissions. In the reactor of a nuclear power plant, energy is derived from splitting atomic nuclei, a process called fission. There are 143 nuclear reactors operating in the EU, with another four under construction. In total, these power plants account for approximately 28 per cent of the EU's electricity generation.

The Energy Triangle – Nuclear Power

Climate and environment

All energy sources have environmental impact during their life cycles. Combustion of energy sources, particularly fossil fuels, generates CO_2 emissions and contributes to global warming. In the long run, emissions from power production will need to be close to zero if greenhouse gas levels in the atmosphere are to be stabilised.

> Nuclear power emits low levels of CO_2 across the life cycle. The management of spent, highly radioactive nuclear fuel requires storage in secure facilities for up to 100,000 years. Uranium mining interferes with nature, though damage to the landscape is repaired after mining is completed.



Security of supply

Fuel shortages and unreliable electricity systems cause societal and economic problems. Securing supply means guaranteeing that primary energy is available, and that delivered energy is reliable, essentially 100 per cent of the time. This is a major political and technical challenge.

> Nuclear power provides stable and large-scale electricity generation, and fuel availability is stable. Uranium, used as fuel in the reactor, is commonly found in nature and is geographically distributed. Reactors must be taken offline periodically for refuelling and the performance of maintenance required by high safety standards. These outages may be prolonged if significant modernisation work is required, but this can be planned well in advance.

Competitiveness

Energy is a fundamental input to economic activity, and thus to human welfare and progress. The costs of producing energy vary between different energy sources and technologies. A competitive energy mix will keep overall costs as low as possible given the available resources.

> Nuclear power is a cost-competitive energy source, with relatively low costs for fuel, operation and maintenance. The construction of a new nuclear power plant requires major investments, but these investments are recovered through the plant's large production volumes and long useful life.

The History of Nuclear Power

The world's first nuclear power plant for commercial electricity generation, Calder Hall in Sellafield, Great Britain, was completed in 1956 and produced electricity as well as plutonium for defence purposes. The inauguration of the power plant marked the beginning of the utilisation of nuclear technology for large-scale electricity generation. The technological evolution, however, had begun much earlier.

One of the most significant discoveries that would underpin our knowledge of nuclear energy occurred in 1905, when Albert Einstein's theory of relativity described the way mass is converted into energy. The French physicist Henri Becquerel had made another important discovery, radioactivity, a decade earlier.

Progress took off during the 1920s and '30s thanks to a number of discoveries and experiments. Atomic structure was identified and the first nuclear fission was confirmed by scientists Niels Bohr and Enrico Fermi. A few years later, in 1942, the first research reactor was put into operation in Chicago in a project led by Fermi.

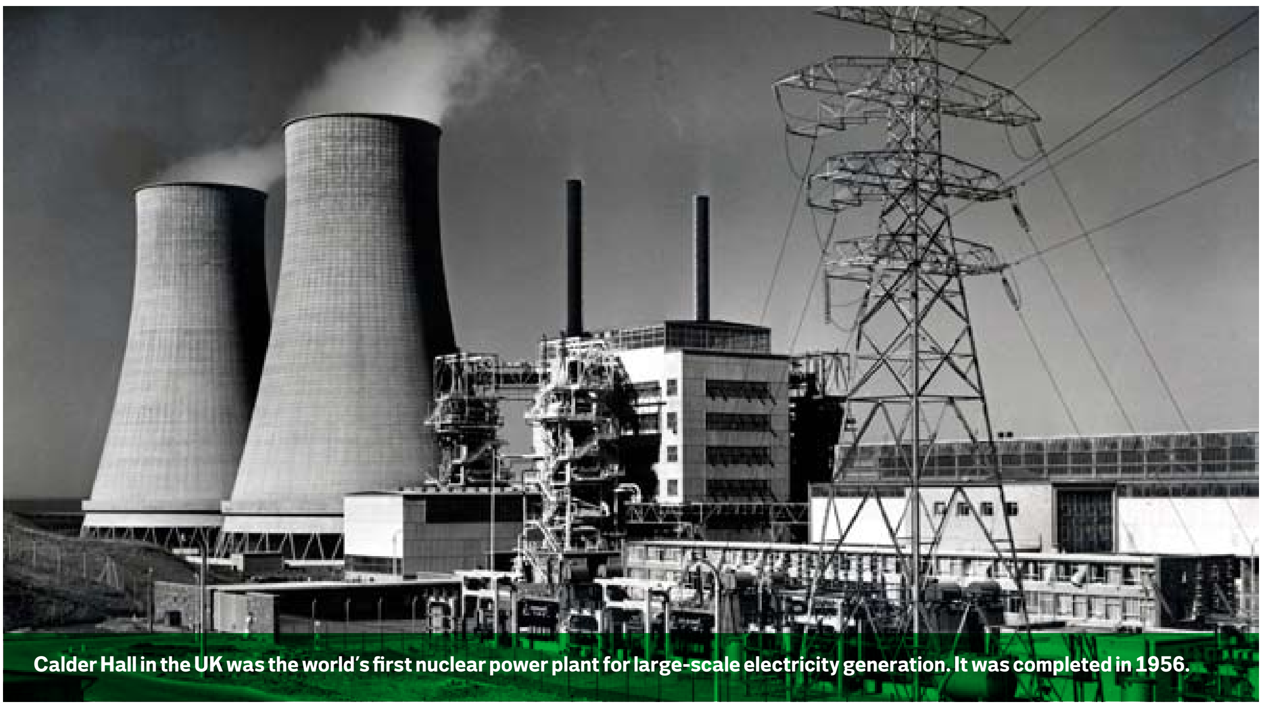
Massive nuclear expansion in the 1960s and 1970s

The development of nuclear power proceeded for a long time in parallel with the development of nuclear weapons. Many of the major nuclear power countries of the day, such as the UK, the USA and the Soviet Union, intensified their nuclear research during World War II, for nuclear armament purposes. Interest in nuclear weapon development waned after WW2 and the Nuclear Non-Proliferation Treaty came into effect on March 1970. The treaty prohibits the spread and development of nuclear weapon technology. The focus at the time had largely shifted towards the development of nuclear power for peaceful purposes.

From 1960 through the late 1970s, the world's nuclear capacity grew from barely 1 GW to over 100 GW. Today, global installed nuclear capacity is approximately 391 GW.[1] Reasons behind this massive nuclear expansion were the growth of electricity consumption due to industrial development and a political desire to move away from oil dependency following the oil crisis of the 1970s. During the second half of the 20th century, nuclear power produced a stable supply of economically competitive electricity with low levels of CO_2 emissions and formed the basis of the electricity supply for many countries.

Nuclear accidents impacted public opinion

Public opinion in the western world grew more critical of nuclear power in the mid 1970s. There was a fear of accidents and an



Calder Hall in the UK was the world's first nuclear power plant for large-scale electricity generation. It was completed in 1956.

uncertainty as to the handling of radioactive waste. The spirit of the times also made nuclear power a symbol of growth and consumption which was rejected by people of many different political affiliations. Nuclear power's link to nuclear weapons was also detrimental to its image.

Criticism was heightened on 28 March 1979, when the Three Mile Island nuclear power plant near Harrisburg, Pennsylvania in the USA suffered a series of technical errors which resulted in a partial meltdown. One reactor was destroyed, but no radioactive material leaked out and no people were injured. Even so, the accident had a major impact on the public debate and policy development, and was the direct cause of the 23 March 1980 referendum in Sweden on the future of nuclear power.

A serious nuclear accident occurred at Chernobyl in northern Ukraine in 1986. The accident was the result of a poorly planned and executed experiment in combination with several technical errors and disconnected emergency systems. The reactor in which the accident occurred was of a special design that was only used in the former Soviet Union. The uranium fuel became overheated and melted, the surrounding graphite ignited and large portions of the power plant exploded due to the heat and the reaction between graphite and steam. The ensuing fire lasted for one week, and radioactive material spread over large parts of Europe. One reason for such a wide spread of radioactivity was that the Chernobyl reactor did not have a leak-proof containment structure surrounding the reactor, something that all existing power plants have today.

Thirty people were immediately killed in the accident and 134 people received acute radiation injuries. Increased incidents of thyroid cancer have been discovered in nearby areas in the former Soviet Union and have been linked to the Chernobyl accident. Pressure around the world to phase out nuclear power increased after the accident, and Italy had closed down all of its four reactors by 1990.[2]

Conclusions based on both the Three Mile Island and Chernobyl accidents have resulted in additional safety improvements in operating nuclear power plants.

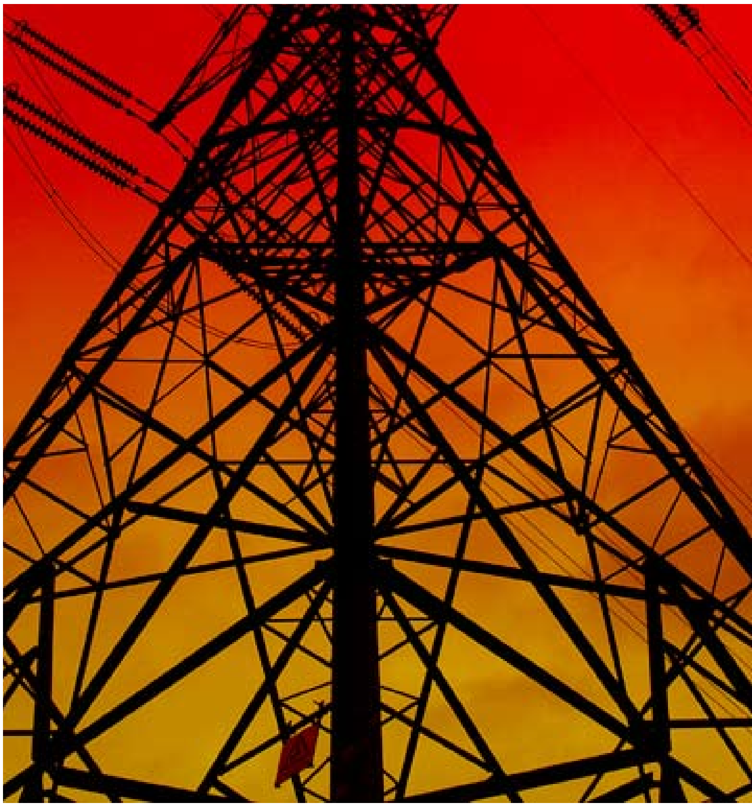
Public attitudes to nuclear power have become more positive in recent years and several countries have decided to replace old reactors or expand nuclear power capacity. The positive public opinion trend is similar across Europe, though there are distinct differences in the level of public support for nuclear power between countries. In general, opinion is more positive in countries that have their own nuclear power plants, such as Sweden, Finland and France. In September 2010, the German government agreed to repeal the parliamentary resolution that called for the phase-out of nuclear power in Germany by 2025.

Comprehensive safety developments

Nuclear power plant safety has been an important element of nuclear power development; today's safety systems are the result of long, intensive research. These results include safety routines for nuclear power plants employees, the development of new, more durable, materials that encapsulate the fuel pellets in the reactor and improvements to the systems that prevent or mitigate accidents.

Safety development applies both to operating plants, which have been improved through investment programmes, and plants under construction which include safety features in the original design. Significant improvements have also been introduced to plant security; i.e., protection against malevolent acts.

Major improvements have also taken place in education, training, preparation and international co-operation. The UN's International Atomic Energy Agency (IAEA) was founded in 1957 for the purpose of strengthening and developing nuclear power safety through the transfer of information and experience between nuclear power countries. Different types of national safety authorities have been created, and safety provisions for nuclear power plants are very advanced today.



How a Nuclear Power Plant Works

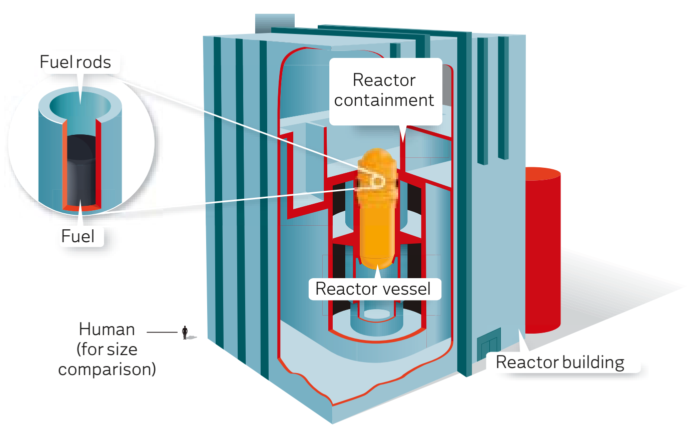
In the reactor of a nuclear power plant, energy is derived from splitting atomic nuclei. Splitting an atomic nucleus, a process called fission, generates heat. This heat is used to heat water into steam that powers a turbine, which in turn powers a generator that produces electricity. A nuclear power plant often consists of several reactors located in separate buildings. Each has its own turbine and generator. There are several different types of nuclear reactors, the most common of which are the pressurised water reactor and the boiling water reactor.

Splitting an atomic nucleus

The actual nuclear fission process occurs in the reactor core. The nuclear fission process is based on splitting the atomic nuclei of uranium by bombarding them with neutrons. When an atomic nucleus is split, it sends out new neutrons that can split new atomic nuclei, creating a chain reaction. A nuclear power plant typically uses uranium-235, a special isotope of the element uranium, as fuel. In order to control the process, various types of control rods are used to absorb the discharged neutrons, reducing the fission rate or stopping it entirely.

Radioactive materials transmit different types of radiation that can be dangerous to humans and to nature. The fission process creates extremely high doses of dangerous radiation.

Four safety barriers



The safety barriers prevent leakage of radioactive material from the plant in the event of an accident or malevolent act. The fuel, in the form of small pellets, is packed inside sealed zirconium alloy tubes to form fuel rods. The fuel rods are placed in a reactor vessel of 15 to 20 centimetre-thick steel and the reactor vessel is placed in a special building, the containment, built of metre-thick concrete and gas-tight metal. Outside the containment, there is a reactor building that serves as an additional barrier against the release of radioactivity.

To prevent this radiation from escaping, the reactor core is surrounded by several independent barriers. The fuel, in the form of small pellets, is packed inside sealed zirconium alloy tubes to form fuel rods. The fuel rods are placed in a reactor vessel of 15 to 20 centimetre-thick steel and the reactor vessel is placed in a special building, the containment, built of metre-thick concrete and gas-tight metal. The containment is constructed to be leakproof even if severe accidents occur. Outside the containment, a reactor building houses equipment that is needed to operate the plant. In many cases, the reactor building itself serves as an additional barrier against the release of radioactivity. Safety systems are available to protect the barriers from failing. There are multiple redundant systems to assure safety in the event one or more of the safety systems fail to work when called upon.

From uranium mine to nuclear fuel

The uranium used as fuel in a nuclear reactor is extracted from uranium ore. Uranium is a silvery metal, the heaviest of all the elements that exist naturally on Earth. Uranium is found in large quantities in the Earth's crust, though only in very low concentrations. Concentrations are also relatively low in places where uranium ore is mined. Consequently, mining is often done in large quarries. Uranium ore is mined principally in Australia and Canada, but also in places such as Kazakhstan and Namibia. Uranium mining is the part of the nuclear life cycle that has the most environmental impact.

After uranium ore is mined, the uranium is extracted through various chemical processes. The uranium is then enriched (from the 0.7 per cent of natural uranium to up to five per cent) into uranium-235, the isotope that can be split by neutrons. During the continued process a colourless crystal (uranium hexafluoride) is produced, which is then converted into a powder (uranium oxide) and pressed into pellets. This enriched uranium is then packed into long metal tubes of zirconium or stainless steel and assembled to form the fuel element used in nuclear power plants. Before the fuel elements are used, they emit very low levels of radiation and can be handled without special safety equipment.

Waste management – from reactor to terminal storage

Radioactive waste arises throughout the nuclear process, from the mining of uranium to the demolition of reactors. The waste is normally divided into three categories: operational waste, demolition waste and spent nuclear fuel. Waste is also classified according to its level of radioactivity and whether it is short- or long-lived. This determines the way in which the waste is managed.

Operating waste accounts for roughly 85 per cent of all nuclear waste. Most consists of low- or medium-active waste such as used protective clothing, mechanical equipment that may have been contaminated, and filters. Some of this waste is so safe that it can be treated as ordinary waste after being sorted and washed. Medium-active waste must be isolated for about five hundred years before it is no longer considered hazardous. During this time it must be radiation-shielded, which is done by sealing it in steel or concrete containers which are stored in rock shelters or under the sea bed.

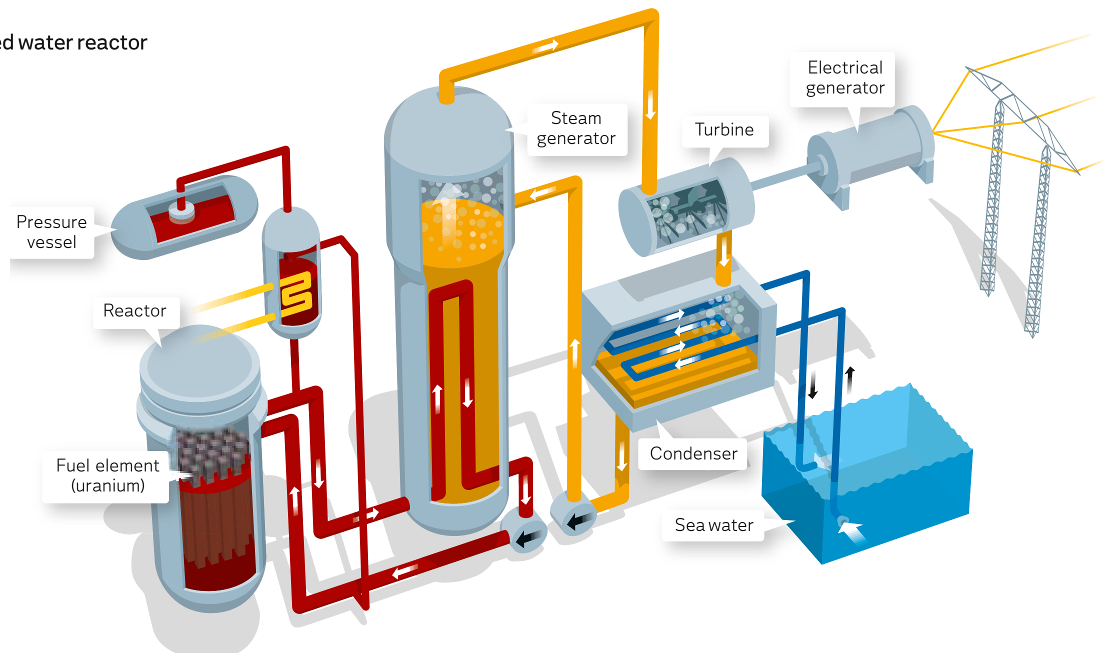
Demolition waste consists of metal and concrete residue from the demolition of a nuclear power plant. Most is low- and medium-active waste but some, such as structures that have been close to the core and other components of the core, is long-lived and must be isolated for thousands of years.

The spent nuclear fuel, which is highly radioactive, accounts for 99 per cent of the radiation but only around five per cent of the total volume of nuclear waste. Several metres of water or several decimetres of steel are needed to contain the nuclear fuel radiation. Since the half-life (the time it takes for radioactive material to lose half of its radioactivity) of high-active waste is often very long, the waste must be isolated for at least 100,000 years.

Before the high-active spent nuclear fuel is isolated it is treated to make it less radioactive. To reduce radioactivity and make the fuel easier to manage, it is brought to interim storage facilities. There it is stored in deep water reservoirs for thirty to fifty years, until approximately 90 per cent of the radiation has dissipated. After that, it is ready for terminal storage.

In many countries, the main solution for isolating spent nuclear fuel is geologic terminal storage. With this method, the fuel is encased in various types of protective material such as copper-clad cast iron. These capsules are then stored, surrounded by clay, in vaults or tunnels drilled 400 to 1,000 metres underground. This type of terminal storage is being built in several areas but is not yet operational for use.

Pressurised water reactor



The reactor contains uranium and water. When the uranium atoms are split, the energy released heats the water to 325°C. The high pressure within the reactor, regulated by the pressurisation vessel, prevents the water from boiling.

The hot water from the reactor transfers heat to the water circuit of the steam generator. Steam is formed here, since the pressure is lower. Pressure from the steam causes the turbine blades to rotate. The turbine powers the electric generator which generates electricity. The steam is then conducted to a condenser composed of many small tubes. Sea water is pumped through the tubes, and when the steam meets the cold tubes it is chilled and condensed (i.e., it is reconverted to water). The sea water is then pumped back into the sea and is 10°C warmer than when it entered the condenser.

The water is pumped back from the steam generators into the reactor to be reheated and begin a new cycle. The water in the reactor thus circulates in a closed cycle, so neither the steam generator's water circuit nor the cooling sea water come in contact with water from the reactor.

Nuclear Power in Europe

After decades of negative public opinion and political opposition, investments in nuclear power have regained momentum in several European countries. The possibility of producing a secure supply of electricity on a large scale, without emitting large amounts of CO_2, has led more and more people to reconsider nuclear energy's prospects.

Nuclear power a crucial part of EU's electricity generation

In 2010, there were 143 nuclear reactors operating in the EU, with another four under construction.[3] In total, these power plants represent an installed capacity of 135 GW and account for over 28 per cent of the EU's electricity generation.[4] According to the International Energy Association (IEA), the rate of expansion for nuclear reactors is expected to increase as more countries review their previous decisions to phase out nuclear power.

In global terms the US has the largest nuclear power industry, with 104 reactors in operation and one under construction.[5] The US alone accounts for 31 per cent of the annual amount of nuclear-produced electricity in the world.[6] Japan, too, has a significant nuclear power industry, with 55 reactors in operation and another two under construction.[7]

Major differences between European countries

The EU accounts for roughly one-third of the world's annual nuclear-based electricity generation,[8] but the significance of nuclear power's role varies widely among European countries. Several countries have no nuclear power at all, while France, for example, has 58 reactors in operation[9] and produces three-quarters of its total electricity generation in nuclear power plants.[10] France's extensive nuclear power expansion has positioned it as a leader in the development of nuclear technology.[11]

Nuclear power on the rise

During the 1980s, several countries decided to introduce a ban on the construction of new nuclear power plants and to phase out existing reactors. But views on nuclear power have changed, and discussions on new nuclear projects have commenced in several European countries.

In 2002, Finland's Parliament gave the green light to the construction of a new nuclear reactor at the existing Olkiluoto power plant. This decision marked a turning point in the trend that has characterised energy development in Europe in recent decades. After Finland's decision, several other European countries, including Great Britain, Poland and Italy, started planning the construction of new reactors.

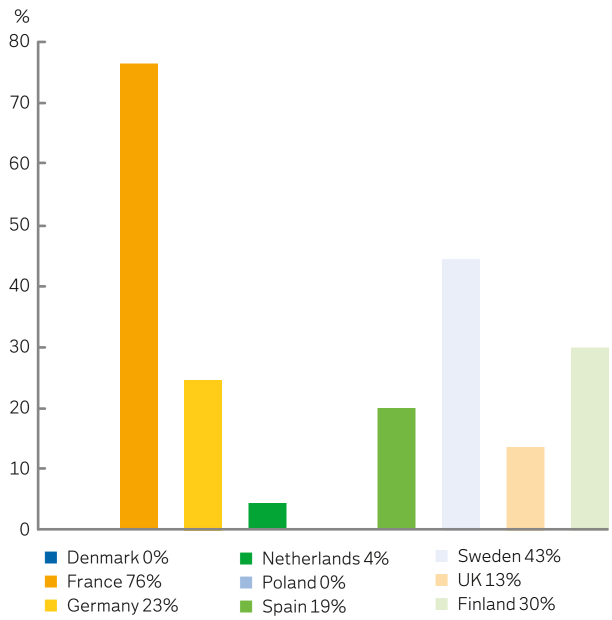
Great Britain was the first country to use nuclear power for large-scale electricity generation and it currently has a relatively large share of old reactors that will be closed by 2023 according to present plans. It plans to put a number of new reactors into operation by 2020.[12]

Italy currently has no reactors in operation following the shut-down of its four reactors pursuant to the post-Chernobyl referendum. But in 2009 Italy initiated collaboration with France to expand Italian nuclear power once again. Options for constructing four new reactors are being explored, and plans are in place to begin construction of the first new reactor in 2013. The long-term plan is to build between eight and ten new reactors, the first of which is expected to be operational in 2020.[13]

In Germany, prevailing law prohibits new investments in nuclear plants and requires the phasing-out of existing capacity by the year 2025. All reactors built in East Germany prior to reunification have also been closed down for security reasons. But in September 2010 the government's centre-right coalition agreed to repeal this law.

The prospects for nuclear power have changed in Sweden as well. The Swedish Parliament passed a bill in the summer of 2010 that lifted the ban on constructing new reactors.

Share of nuclear power in electricity generation (2008)



Source: IEA Statistics, Electricity Generation, 2010

Constructing a Nuclear Power Plant

The design of a new nuclear power plant takes the entire value chain into account, from uranium mining to terminal storage of radioactive waste. Several factors guide the planning of a nuclear power project; for example, geographic location, acceptance of local residents, extensive authorisation processes, long construction period, availability of skilled engineers and management and storage of radioactive waste. A long-term process is highly dependent on a stable planning and decision process, as well as on a regulatory framework. There are also significant financial challenges.

The financial conditions of nuclear power

It is relatively inexpensive to produce electricity with a well-designed nuclear power plant. Fuel, operational and maintenance costs are significantly lower for nuclear power than for, e.g., coal power. The predominant portion of a nuclear power plant's costs is comprised of capital costs.

Constructing a new reactor requires a substantial investment, but the useful life of a reactor is long. The life cycle of a nuclear power plant, from construction through close-down, is between 80 and 90 years. This period includes a 10 to 15 year start-up period preceding the plant being put into operation. The effective operational time (i.e., the time the nuclear power plant produces electricity) is roughly half as long as the full life cycle, between 40 and 60 years. A significant investment is required from the investors involved in financing the project.

The large initial investment costs are recovered after 20 to 25 years. Additional investments for safety and modernisation may be required; in general, though, low operating costs and a long operating life make nuclear power plants a profitable investment.

The long-term nature of the project increases the risk that uncertainties may accumulate and present obstacles to completing the project. Significant effort is therefore required early in the project to identify and manage uncertainties and risks. These include supply chain capability to deliver to and construct the plant, applicable regulatory requirements, project financing terms and conditions, and future electricity price trends.

Planning – site selection

Numerous factors are considered when selecting a site for a nuclear power plant. Requirements include large physical areas for reactors, interim storage and assembly facilities for the construction phase, cooling equipment, transportation and communication facilities, etc. Many reactors rely on proximity to the coast to draw sea water used to cool the condenser. And the plant shouldn't be located too far from end-users, since much electricity is lost in long-distance transports.

Availability of nuclear power plant designs

There are many modern nuclear power plant designs available today, most of which have been applied in new build projects and some of which are in operation. Several of these designs have been subject to review by one or more licensing bodies. Nevertheless, experience in building new nuclear plants in Europe in recent years is not extensive, and this poses additional risks in terms of failing to meet time schedules and thus potentially increasing the cost of new builds. This uncertainty, though, is being gradually reduced as new plants are built. Design standardisation is one method of reducing the time it takes to learn how to construct new plants, and has been adopted by all plant suppliers.

Constructing a new reactor requires a substantial investment, but the useful life of a reactor is long. The life cycle of a nuclear power plant, from construction through close-down, is between 80 and 90 years.

Due to the renewed interest in nuclear power plant construction, deliver times are long for some of the large components that are difficult and time-consuming to manufacture; for example, reactor pressure vessels. This problem can be solved by ordering such components early.

Also essential to nuclear power projects is the availability of skilled personnel and the expertise to install and operate the reactor. Experienced project managers and skilled welders are needed during the construction phase and specialised engineers and technicians are needed for operation and maintenance.

Storage of spent nuclear fuel

The long-term management of radioactive waste is a key issue in the planning of new nuclear plants. Spent nuclear fuel and radioactive waste are handled at the nuclear power plants and by specialist organisations tasked with providing longer-term interim storage and deploying and operating final repositories. The internationally preferred option is a geological repository located several hundred metres underground. Sweden, Finland and France are leading the way in the development of and licensing processes for this type of final repository, which will allow the industry to meet long-term safety requirements that may exceed 100,000 years. Costs incurred by waste management as well as for future decommissioning of nuclear power plants are included in financial and operational calculations.

The Future of Nuclear Power

Energy systems of the future will require energy sources that can produce large amounts of electricity without emitting greenhouse gases. Nuclear power is an energy source that has the potential to meet these requirements. European research plays a key role in the field of nuclear technology and focuses on, among other things, waste management optimisation and fuel conservation. The framework for future nuclear power has also been established through several international organisations and networks related to research and development.

Existing reactors are unable to use more than a small portion of the available nuclear fuel. The resulting energy surplus can only be captured if spent fuel is reprocessed and recycled into the fuel cycle. Improving reactor design or providing better options for reprocessing and reusing nuclear fuel would reduce hazardous waste levels and result in better use of available uranium resources.

A new generation of nuclear power

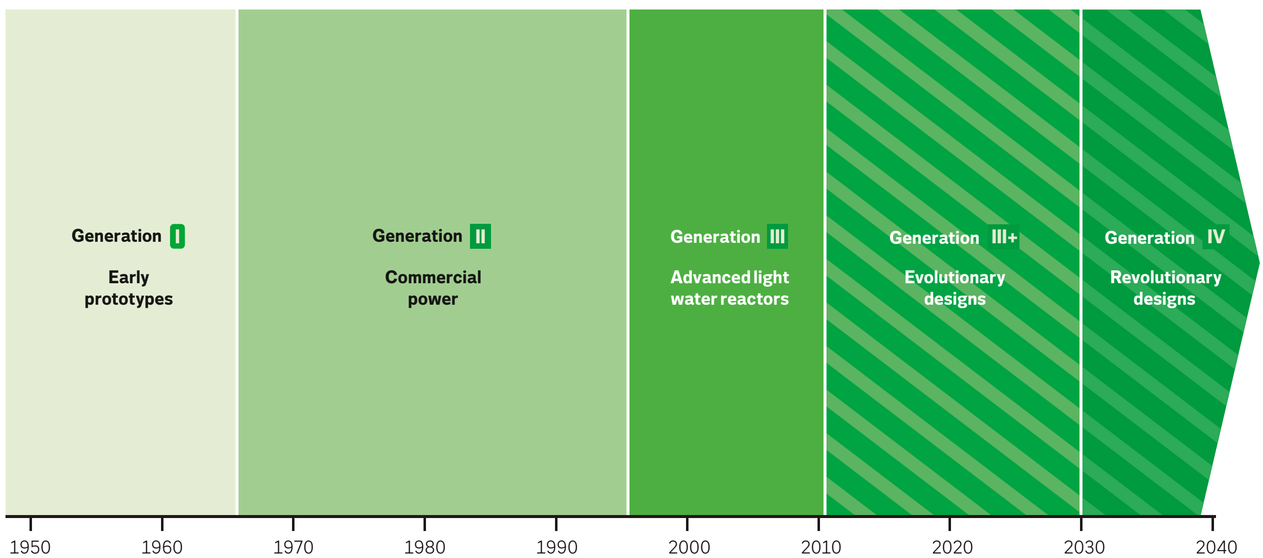
Nuclear reactor development is divided into generations. The first reactor prototypes and nuclear facilities, Generation I, were put into operation during the 1950s and were the first to be developed solely for energy (as opposed to nuclear weapon) purposes. With the launch of Generation II, nuclear reactors were developed to be used for commercial purposes on a wide front. Generation III includes the modern reactors in operation today. Generation III+ reactors, connecting modern technology with the technology of tomorrow, are already under construction. Future technological developments include Generation IV reactors, expected to be put into operation in 20 to 30 years.

Development of Generation IV reactors

The Generation IV International Forum (GIF) was established in the early 2000s to develop the requisite new technology. The organisation represents governments from 13 countries. The GIF has defined four objectives and criteria that must be met by Generation IV reactors: sustainability, economics, physical safety and non-proliferation, and reactor and operational safety.[14]

The first criterion, sustainability, is aimed at creating a long-term power generation that meets global environmental goals. Nuclear waste will be minimised and managed to burden future generations as little as possible. Under the second requirement, economics, the reactor's live cycle must have a clear cost

Nuclear power development phases



Source: Argonne National Laboratory, U.S. Department of Energy, Nuclear Engineering Division advantage over other power generation methods while financial risks must not exceed those of other energy projects.

In terms of physical safety and non-proliferation, the systems must demonstrate that they impede the theft or concealment of weapons-grade materials and ensure protection against terrorist attacks. The final criterion, reactor and operational safety, emphasises extremely high levels of operational safety and reliability and the minimal probability of core damage.

The primary objectives of the new generation are to increase fuel efficiency, reduce long-lived nuclear waste and facilitate the reprocessing of high-level waste from existing reactors. Part of the reactor concept designed by GIF will include not only electricity generation but also the ability to use the heat produced to assist with other production; e.g., of hydrogen.

Fusion energy – an energy source of the future?

Fusion energy is based on combining two light nuclei to form a new, heavier nucleus. The fusion creates large amounts of energy in the form of heat that can be used to produce electricity. Fusion is, so to speak, the opposite of conventional nuclear power, fission, which is based on splitting a heavy nucleus into two light nuclei. The sun is a natural fusion reactor: all thermal and luminous energy radiating from the sun is produced by the fusion of light nuclei.

The advantages of fusion power are its potential to generate exceptionally large amounts of energy, powered by inexpensive, ordinary materials, and the fact that it leaves no hazardous waste behind.

The advantages of fusion power are its potential to generate exceptionally large amounts of energy, powered by inexpensive, ordinary materials, and the fact that it leaves no hazardous waste behind. The disadvantage is that it requires extremely high temperatures, which are difficult to control. Fusion power research has been conducted since the 1950s and is steadily advancing, but when and if fusion power will become commercially viable remains unclear. Today, the ITER (International Thermonuclear Experimental Reactor) research project, a collaboration between the EU, the US, Russia, India, Korea and China, supervises the development of fusion reactors. [15]

Vattenfall and Nuclear Power

Nuclear power plays a vital role in many European countries due to its economic attractiveness, security of supply and low CO_2 emissions. Vattenfall has played a major role in constructing Sweden's nuclear power plants, and is an owner of nuclear power in Germany. Vattenfall aims to maintain its current nuclear power operations in Sweden and Germany and to keep its growth options open. Vattenfall is intensifying its efforts to achieve impeccable safety and availability levels.

Vattenfall's nuclear power operations

Vattenfall owns ten nuclear reactors (one with a minority stake). Seven of these are located in Sweden (four at Ringhals, three at Forsmark), and three in Germany (Brunsbüttel, Krümmel and Brokdorf). Reactors 1 and 2 at Ringhals nuclear power plant, south of Gothenburg in Sweden, were Vattenfall's first two reactors and have been in operation since 1976 and 1975, respectively. Since 2003, Vattenfall and other joint owners of the Swedish nuclear power plants have made safety improvements and life extension investments in the Swedish reactors. These investment programmes are now approaching their concluding phases.

The Krümmel nuclear power plant in Geesthacht, east of Hamburg, is the largest of Vattenfall's reactors with an installed capacity of nearly 1,350 MW. The reactor has been in operation since 1984. The reactor at the Brunsbüttel plant west of Hamburg is the smallest of Vattenfall's reactors in terms of installed capacity.

Vattenfall is engaged in continuous safety efforts at all of its power plants, and has invested several billion SEK to enhance safety. Additional investments will be made to complete these enhancements by 2015. Vattenfall owns the uranium used as fuel, from point of extraction through the entire fuel cycle, and can therefore impose comprehensive monitoring and control

Ringhals nuclear power plant in southwest Sweden.

procedures. Vattenfall imposes strict CSR requirements on its uranium suppliers.[16]

For a full list of Vattenfall's nuclear power plants, please see the production site at www.vattenfall.com/powerplants.

Vattenfall's nuclear power operations going forward

Nuclear power is gaining support in Europe and, as one of Europe's prominent nuclear operators, Vattenfall is in an advantageous position. Nuclear power produces a secure supply of electricity, is economically competitive and has low CO_2 emissions. Vattenfall therefore considers nuclear power to be a crucial part of the energy system of the future.

Nuclear power is an important component in Vattenfall's efforts towards a carbon neutral operation, as well as the EU's 2020 goals to reduce climate impact. Several countries, including France and Finland, are building new nuclear reactors and in many other countries, including Sweden, the issue is being discussed. Vattenfall welcomes an expansion of European nuclear power and the development of tomorrow's nuclear technology, and will keep its options for growth in the field of nuclear power open.

Footnotes – Nuclear power

1 International Energy Agency (IEA), World Energy Outlook 2010
2 You can read more about nuclear safety and nuclear power in different countries on World Nuclear Association's webpage, www.world-nuclear.org
3 World Nuclear Association, World Nuclear Power Reactors (2010), www.world nuclear.org, (November, 2010)
4 IEA, op. cit.
5 World Nuclear Association, op. cit.
6 IEA, op. cit.
7 World Nuclear Association, op. cit.
8 IEA, op. cit.
9 World Nuclear Association, op. cit.
10 IEA Statistics, Electricity Generation 2008, www.iea.org
11 You can read more about nuclear safety and nuclear power in different countries on World Nuclear Association's webpage, www.world-nuclear.org
12 Ibid.
13 Ibid.
14 You can read more about The Generation IV International Forum on their webpage, www.gen-4.org
15 You can read more about nuclear safety and nuclear power in different countries on World Nuclear Association's webpage, www.world-nuclear.org
16 You can read more Vattenfall's nuclear fuel procurement on Vattenfall's webpage, www.vattenfall.com

SUMMARY

- **Nuclear power is a competitive energy source with relatively low costs for fuel, operation and maintenance. Constructing a nuclear power plant is expensive and time-consuming, but the useful life of a power plant is very long, up to 60 years**
- **Nuclear power provides stable and large-scale electricity generation**
- **Nuclear power emits low levels of CO_2 across the life cycle. Uranium mining interferes with nature, though damage to the landscape is repaired after mining is completed**
- **Nuclear power accounts for roughly 28 per cent of the EU's electricity generation, but the significance of nuclear power's role varies widely among European countries**
- **The long-term management of radioactive waste is a key issue in the planning of new nuclear plants. Much of the hazardous waste is handled in direct connection to the plant, while the most hazardous portions are isolated for several thousand years in geological final disposal repositories. Waste management and power plant demolition are included in financial and operational calculations starting in the waste planning phase**
- **Nuclear power is gaining support in Europe and Vattenfall is one of the prominent European nuclear operators. Vattenfall welcomes an expansion of European nuclear power and the development of tomorrow's nuclear technology. Standardisation of designs and harmonisation of requirements imposed on the plants are key factors to success**
- **Vattenfall aims to maintain its current nuclear power generation in Sweden and Germany and to keep its replacement and growth options open**