NUCLEAR ENERGY
IN FINLAND

SUOMEN ATOMITEKNILLINEN SEURA -
ATOMTEKNISKA SÄLLSKAPET I FINLAND r.y.
FINNISH NUCLEAR SOCIETY

CONTENT

NUCLEAR POWER IN THE WORLD

In spring 2022, a total of 440 nuclear power plant units were in use in the world and their total electrical power capacity was over 390 000 megawatts (MW). In 2020, nuclear power plants produced more than 2,550 terawatt hours of electricity (TWh), and nuclear power has accounted for just over 10% of the world's electricity consumption in recent years. In the European Union, nuclear electricity accounts for about a quarter of consumption. Finland has been close to the EU average, but the start of electricity production of Olkiluoto 3 unit will increase the share of nuclear electricity in Finland to around 40%. The construction of new facilities is progressing above all in populous and rapidly developing countries in Asia. The nuclear power plant units that have started their operation recently are still larger than earlier units in terms of unit-specific power. In planned and proposed projects small modular units are already more popular.

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SUOMEN ATOMITEKNILLINEN SEURA - ATOMTEKNISKA SÄLLSKAPET I FINLAND r.y. FINNISH NUCLEAR SOCIETY

FOR THE READER

The main task of the Finnish Nuclear Society (FNS) is to act as an information exchange channel for professionals employed by different organizations and to share information on Finnish and international nuclear technology and about the development of it to the public. In 2004, FNS first published a brochure entitled "Ydinenergia ja Suomi" describing Finland's energy solutions and the operation of nuclear power plants, and a similar brochure in English entitled "Nuclear Energy in Finland" was published a few years later. Since then, the brochures have been revised from time to time in line with events and timely topics in the nuclear sector.

In 2020, the lessons of the Fukushima Daiichi nuclear power plant accident were added to the nuclear facility requirements published by the International Atomic Energy Agency (IAEA). That accident was caused by the Japanese 2011 Tōhoku earthquake and related tsunami, which was larger than postulated in the design of the Fukushima Daiichi plant. On the other hand, the Nuclear Energy Agency (NEA) as a part of the Organisation for Economic Co-operation and Development (OECD) published the guidelines outlined at an international seminar in 2020 for the global harmonization of the licensing process of nuclear installations. These works will provide the basis for the EU's efforts to develop a coherent and administratively light and Europe-wide standardized small modular reactor (SMR) licensing process. This huge international challenge is explained in this brochure.

At the end of 2021, an Operating License Application for the encapsulation and disposal facility for the spent nuclear fuel used in Finland was submitted by Posiva Oy. Olkiluoto 3 unit received its first fuel core in 2021 and in 2022 the unit started regular power production. Two older units in Olkiluoto have valid operating licenses until about 2040. In 2022 Fortum submitted operating license extension applications for two Loviisa units until 2050.

In the transformation of European energy and security policy triggered by the war in Ukraine, nuclear power is playing an increasingly important role in reliable energy production. Nuclear power is one of the production methods of base load electricity in Finland's National Energy and Climate Strategy, which runs until 2030 and was renewed in 2022. The strategy aims to achieve carbon neutrality in Finland's energy production by 2035. The European Union's (EU) Green Deal development program aims for carbon neutrality in 2050. The program is accompanied by a sustainable finance classification system that entered into force at the beginning of 2022, i.e., a taxonomy, by which companies are required to classify environmentally sustainable activities. Nuclear power could be one of the ways to reduce the carbon footprint of energy production.

In 2021, the much-needed comprehensive reform of the legislation and regulations on Finnish nuclear facilities (SYTYKE) was launched. The program aims at reforming the nuclear regulations in a way that would allow rapid construction and commissioning of small modular reactors (SMR) approved in advance by the nuclear authorities. The aim is to avoid the costly and extensive redesign of nuclear facility to fulfill the national requirements, which has been a problem and caused delays in nuclear facility projects in Finland.

Due to recent changes in the operating environment in the nuclear power sector, FNS decided to renew its brochure to describe the current role of nuclear energy in Finland's electricity production and energy policy.

The brochure is aimed at anyone who deals with issues related to nuclear energy in their work, teaching or decision-making, or who are otherwise interested in Finnish nuclear power solutions. This brochure is based on the "Nuclear Energy in Finland"-brochures previously published by FNS.

Helsinki, 14 October 2022

FINNISH NUCLEAR SOCIETY

ENERGY CONSUMPTION AND PRODUCTION IN FINLAND

Energy production and consumption are basic functions of society. For industry, energy is an important factor of production, especially in many export fields. Our country relying on industry and located in the cold north consumes a lot of energy per capita and has only a few domestic energy sources. For this reason, Finland has always paid more attention to the availability, price and efficient use of energy than many other countries.

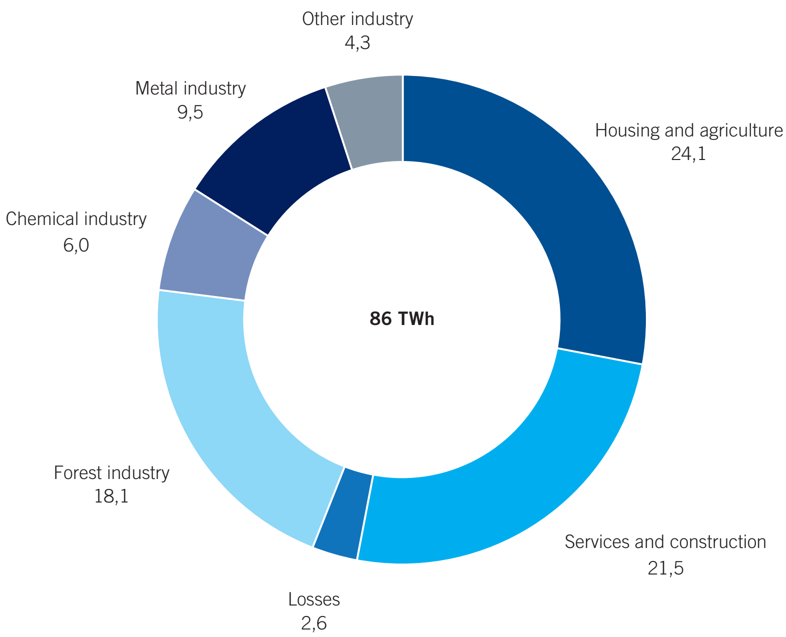
Finland's high energy consumption is among other things based on energy-intensive industries, high living standards, cold climates and long distances. In 2020, the total primary energy consumption in Finland was 1.28 million terajoules (TJ) and the total electricity consumption in 2021 was 87 TWh.

Energy consumption

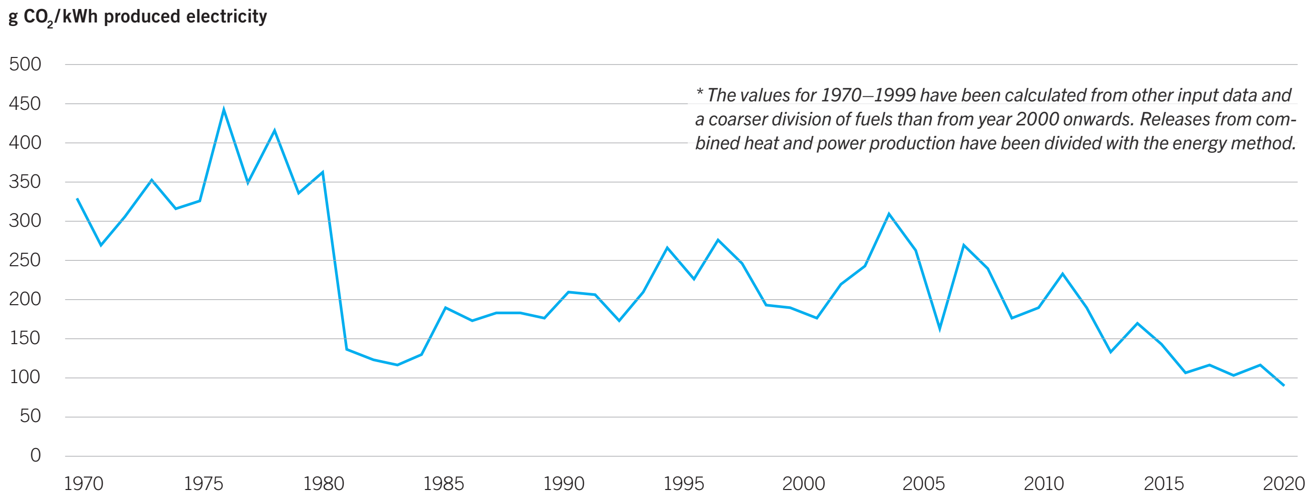
In 2021, industry accounted for 44% of final energy consumption and 28% for heating of buildings and agricultural activities. Of the other final energy consumption, 17% was spent on transport, 3% on losses and the remaining 8% on various public and private services. The high energy use of industry is due to its production structure and processes. The forest industry alone accounts for approximately 60% of the total energy consumption of industry. The combined share of the metal and chemical industries is approximately one-third.

Electricity accounts for a high share of all energy used in Finland. Approximately 40% of primary energy consumption is used for electricity production. By international comparison, the efficiency of electricity production in Finland is high. Mainly, efficiency is based on the fact that a significant share (22% in 2021) of the electricity consumed is produced by combined heat and power production, either in district heat production for houses or in industrial processes. In this case, electricity is produced in addition to the industrial process that requires compressed steam, and therefore the overall efficiency of this backpressure turbine process is relatively high.

Consumption of electricity in 2021 (Finnish Energy ET).



Carbon dioxide emissions from electricity production in Finland (Statistics Finland).



Imports answered for about 23% of the electricity consumed In Finland in 2021. In 2018–2021, imports of electricity have risen to about 5% of total energy consumption. The situation is changing rapidly as imports from Russia were stopped in 2022.

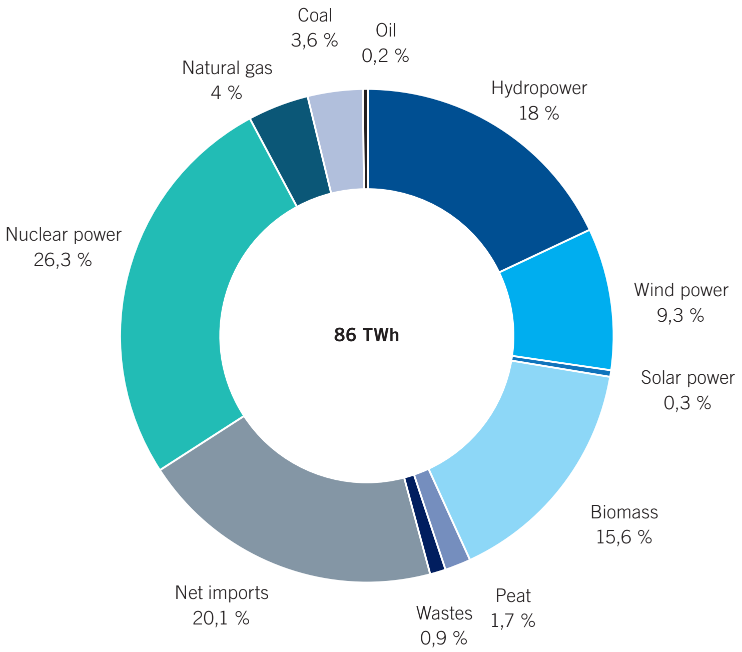
Energy supply

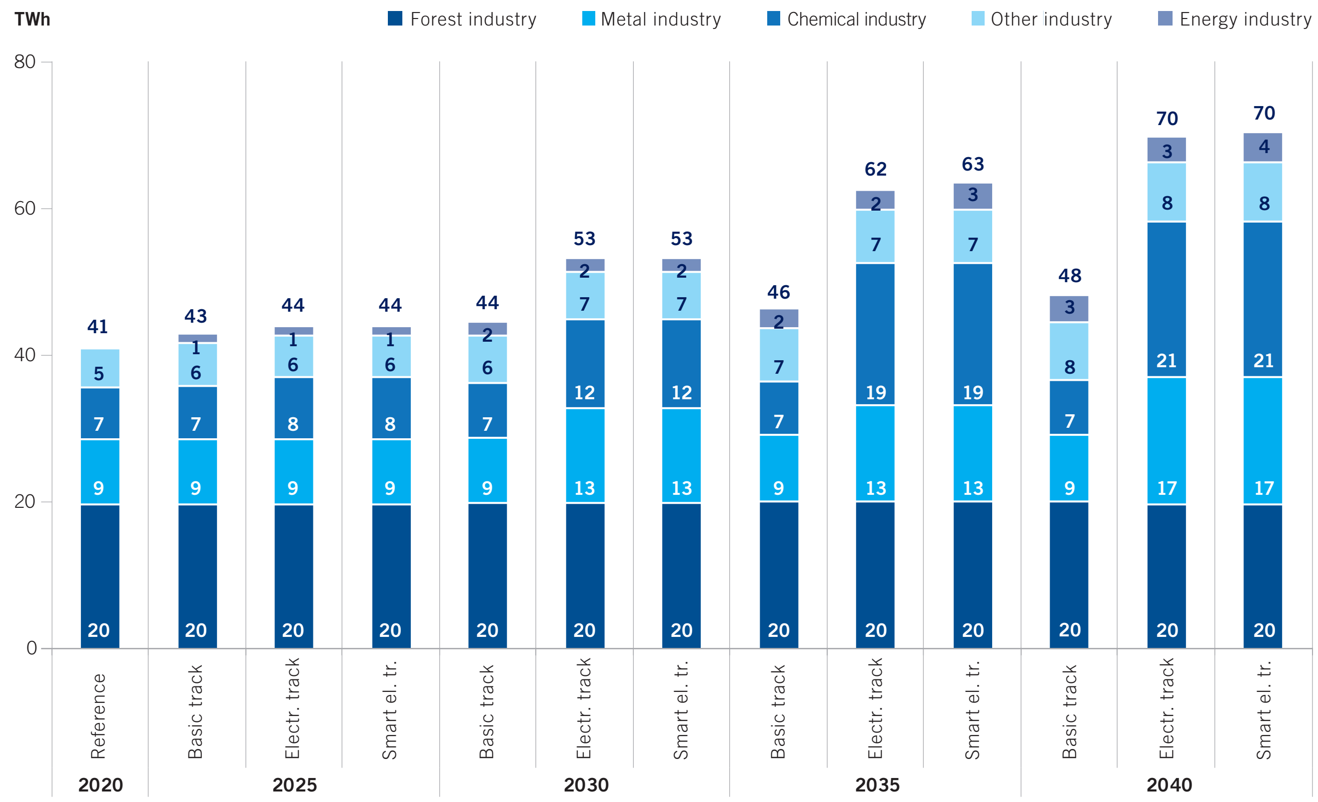
Finland is very dependent on foreign energy resources for its overall energy procurement. Imported energy covers about 70 percent of Finland's energy consumption.

The need to reduce carbon dioxide (CO_2) emissions has drastically reduced the use of fossil fuels. In 1973, oil covered as much as 58% of all energy consumption, while in 2021 its share had already fallen to 22%. In the last 10 years, carbon dioxide emissions from Finland's electricity production have decreased by a total of 69% from 2012 to the end of 2021, mainly due to decommissioning of coal-fired power plants.

In 2020, mainly Russian natural gas was in charge of approximately 8% of Finland's energy consumption and correspondingly in 2021 its share was around 6%. In 2022, invasion of Russia to Ukraine caused Finland to completely stop importing Russian natural gas. Domestic energy sources have answered for about thirty percent of energy consumption in recent years and the 2022 War in Ukraine significantly intensified efforts to self-reliance on energy. The main domestic energy sources are hydropower, wood-based fuels, waste liquids from the forest industry and peat, and growing wind power. Wood-based fuels answered for 28% of total energy consumption in 2021 and they will retain

Electricity generation by energy source and net imports in 2021 (Finnish Energy ET).





Electricity consumption forecast for Finnish industry. The growth scenarios are based on the strong electrification of transport and industrial processes. The intelligent control-based electrification scenario uses significantly more weather-varying production capacity (Finnish Government publications 2021:4).

their position as the most significant source of energy in the next few years as well.

In the Loviisa 3 nuclear power plant project, the plans were to use the planned reactor to produce both electricity and district heat for heating the apartments in the Helsinki capital region. The project ended in 2010 with a negative decision in principle by the Government. Nowadays, district heat is produced in a similar way, from the steam turbine of a nuclear power plant unit via an intermediate circuit, at least in Switzerland, Russia, Bulgaria, China and Slovakia. In the past, nuclear power plants have also produced district heating for nearby population centers in Lithuania and Sweden. However, the amount of energy produced for local district heating is usually small.

In recent years, the possibility of producing district heat with a nuclear reactor has become an integral part of various projects aimed at the construction of small modular reactors (SMR). The temperature and pressure of the cooling circuit of a small reactor designed for district heating is relatively low. This enables the application of simple production technology and safety solutions based on natural physical laws such as gravity. In densely populated countries, the possibility of locating a reactor close to consumption can be an important competitive advantage.

OPEN ENERGY MARKET

Almost all activities in society are based on secure access to electricity. A well-functioning electricity system has allowed Finland to become one of the most prosperous countries in the world. Electricity is relatively inexpensive in Finland, and in 2021, the price of household electricity in Finland was among the five cheapest countries in the EU in relation to the purchasing power of consumers.

The Electricity Market Act, which entered into force in 1995, and the Electricity Market Regulation adopted on the basis of it distinguished between electricity distribution and production. This measure improved the functioning of the electricity market and made it possible to put electricity prices out to tender to consumers. Since 1998, the Nordic electricity trade has been conducted through Nordpool, a common electricity exchange.

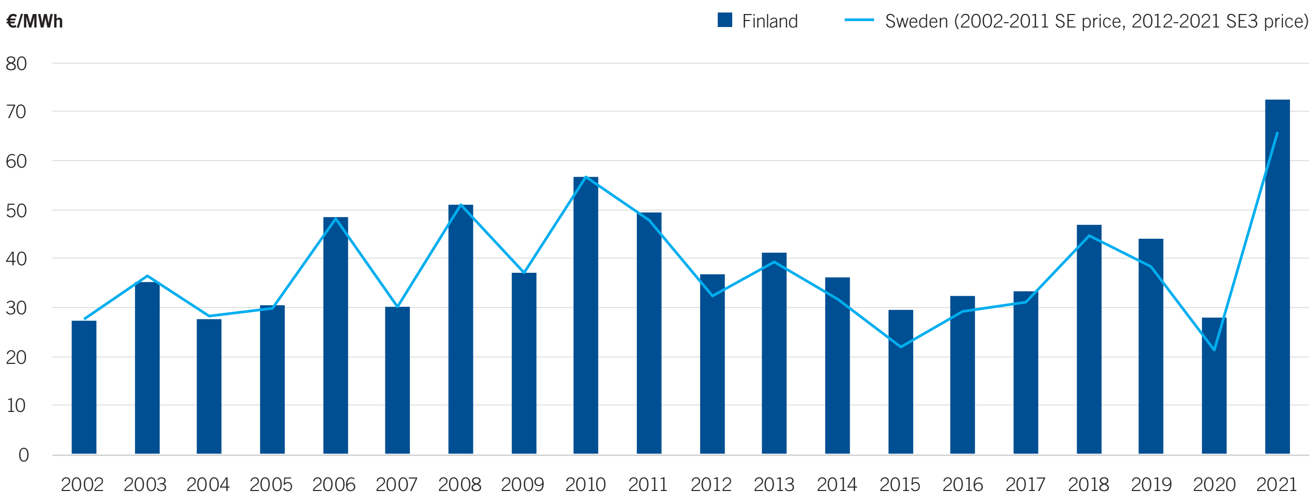
Electricity consumption

In the 1980s, Finnish economy experienced a strong growth and electricity consumption increased by more than 50% during that decade. During the recession in 1990s, growth slowed down and electricity consumption grew only by around 25% over this decade. The peak in Finnish electricity consumption was reached in 2007, when total electricity consumption was 90.4 TWh. Since then, electricity consumption has decreased slightly and in 2021 electricity consumption was 86.8 TWh.

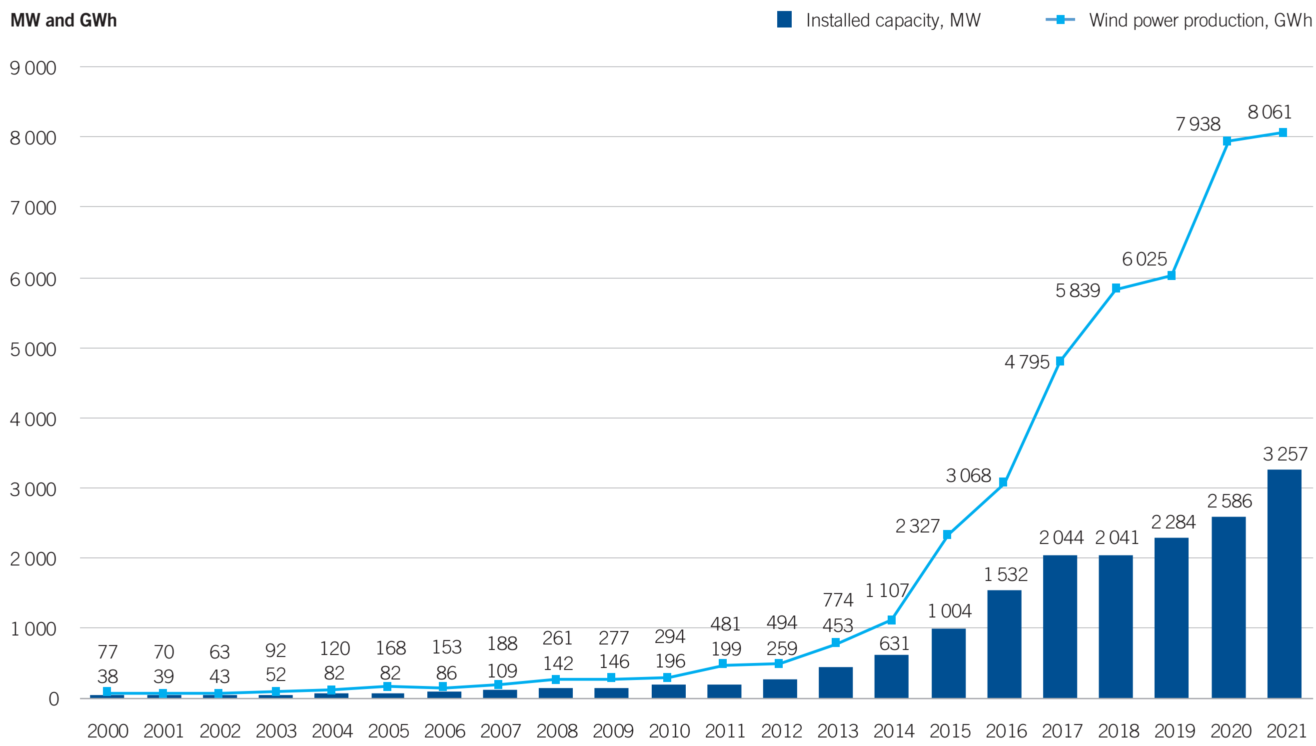
In 2021, industry processes consumed 44% of electricity, households and agriculture nearly one-third, and services, the public sector and transport a quarter. A few per cent of electricity was consumed in transmission and distribution losses.

Electricity generation

The highest electricity consumption peak in Finland so far was experienced in January 2016, when the electricity consumption was 15,105 MWh/h. In 2020, the backup power capacity for power grid confirmed by contracts to be started at the same time or capable of rapid production increase was approximately 600 MW. In addition, Finland has electricity transmission connections to our neigh-



Development of the average spot price of industrial electricity compared to Sweden. In 2021, the average price in Finland was 72.34 €/MWh (Finnish Energy ET).



Growth in wind power capacity (MW) and production (GWh) (Finnish Energy ET).

boring countries totaling approximately 5,100 MW. In 2022, there were roughly 450 power plants in the Energy Authority's power plant register, about 80 companies were distributing electricity and about 10 companies were engaged in the main grid operations for high-voltage distribution. Fingrid Oyj, which started operations in 1997, owns the Finnish national high-voltage grid used for electricity transmission and trading.

As recently as the early 1960s, Finland's electricity production was largely based on hydroelectric power. Today, most of the profitable hydropower potential has been harnessed for power production. Over the past decade, the share of hydropower in electricity production has settled at 12–16 TWh, depending on the amount of rainfall and on the use of the water reservoir in the water basins.

Finland is one of the world's leading countries in combined heat and power generation, which is widely applied in energy-intensive industries and district heating plants.

Need for new power plant capacity

Electricity consumption has not increased in Finland since 2007, but the fight against climate change has been estimated to increase the need for fossil-free electricity in the form of electrification. In direct electrification, fossil fuel is directly replaced by electricity. For example, internal combustion cars can be replaced by electric motor cars and combustion-based heating of buildings can be replaced by heat pumps. In indirect electrification, fuel is not replaced directly by electricity, but electricity is used, for example, to produce hydrogen by electrolysis or to produce synthetic fuels and other compounds.

Electrification is estimated to significantly increase Finland's electricity consumption, and an increasing proportion of consumption is produced with weather-varying production capacity, such as wind and solar power. This strongly increases the need for different storage solutions, but also maintains the need for stable basic production capacity.

The tightening of climate policy, state subsidies for renewable energies and the improved competitiveness of wind power technology will increase wind power capacity sharply. At the end of 2021, the capacity of wind power increased to over 3,200 MW and the energy produced was just over 8 TWh in the same year. On the other hand, growth in the production capacity of solar electricity produced by industry and households has been slow in recent years. Solar energy currently produces approximately 0.5% of total electricity production.

Nuclear fuel and its procurement

Fuel used in the nuclear power plants is uranium, of which the fission reaction generates a lot of energy. The production of typical nuclear fuel begins with uranium, which is a heavy metal found in the earth's crust as various compounds. In the earth's crust there are on average about four grams of uranium per ton and in seawater about three milligrams per ton. Most of the uranium produced in the world comes from special uranium mines, but about 5 percent of the world's uranium is also obtained as a by-product of other mining operations. The largest uranium producing countries Kazakhstan, Australia, Namibia, Canada and Uzbekistan produce more than 80 percent of all the world's uranium. In mines, uranium is mostly dissolved directly from the deposit, but almost a third of the world's uranium is also produced in traditional underground mines or open pits.

The first step in the manufacture of nuclear fuel is to separate uranium from side stone and other minerals. This stage is called milling and is carried out in a mill in connection with a mine or near it using the same methods as the milling of many other metals. The typical end product of milling is, for the most part, powder-like uranium oxide U_3O_8, which includes natural proportion of the different isotopes of uranium: the concentration of the easily fissionable uranium-235 isotope (U-235) is approximately 0.7%. The uranium compound resulting from milling is subject to safeguards, which means that its exact, accounting amount and location are reported to the authorities.

The uranium oxide (U_3O_8) from the quarry is chemically converted to gaseous uranium hexafluoride (UF_6) for the enrichment process by the use of hydrogen fluoride gas (HF). In isotope enrichment, the relative share of isotope U-235 in gas is increased. Techniques used for enrichment include: gas diffusion based on the mobility and mass difference of uranium isotopes, centrifuge technology based on centrifugal force and mass difference of uranium isotopes, or laser enrichment of uranium through highly selective laser excitation of the fluorinated form of uranium isotopes.

The self-sustaining chain reaction of a nuclear reactor requires the moderation of neutrons generated during the fissions of U-235 nuclei in order to enable them to cause the required number of new fissions. Some of the reactors are designed to use natural uranium, but in water-moderated reactors the relative proportion of U-235 nuclei in uranium fuel must be increased by enrichment. Some of the reactors in use in the world are designed to use natural uranium. However, in most of the world's reactors for electricity generation and in all reactors in Finland, the share of the isotope U-235 has been enriched to 3–5% of all uranium isotopes in the fuel.

At the fuel plant, uranium hexafluoride (UF_6) containing enriched uranium is converted into uranium dioxide powder (UO_2), which is compressed into cylindrical pellets and the pellets are compacted by sintering. After sintering, the pellets are about 1 cm in diameter and in length. The pellets are loaded into about 4 m long pipes made of zirconium alloys, i.e., fuel rods. Both ends of fuel rods are gas-tightly sealed. The rods are further assembled into fuel bundles or assemblies, whose geometric structure is selected according to the type of fuel and reactor. Depending on the structure of the reactor core, one reactor typically has 240–500 bundles of fuel.

Normally, fresh unused fuel does not include highly radioactive isotopes, e.g., plutonium, and fresh fuel emits minor amount of radiation. Low radioactivity allows fresh fuel to be stored in a space similar to a normal room, while the spent fuel used in the reactor is highly radioactive. If plutonium from recycling process of spent fuel is mixed with uranium (as in MOX fuel), the fresh fuel is also radioactive and effective radiation protection measures are necessary in fuel management. The MOX-fuel containing plutonium is not in use in the Finnish reactors.

NUCLEAR ENERGY IN ELECTRICITY PRODUCTION

The construction of four nuclear power plant units was decided at the turn of the 1960s and 1970s as the Finnish economy grew strongly. Two nuclear power plant units in Loviisa and two in Olkiluoto were commissioned between 1977 and 1980. In 2021, the load factor for four nuclear power plant units in Finland was 92.9%. Finland's fifth nuclear power plant unit was commissioned in Olkiluoto in 2022.

In spring 2022, about 440 nuclear power plant units were in use in the world and their total electrical power capacity was 393,700 megawatts. In the European Union, nuclear electricity accounted for approximately 25% of total electricity consumption in 2020, which was produced by more than 100 plant units. In Finland, the share of four operating reactor units of electricity consumption in 2021 was around 26%. Olkiluoto 3 will increase that share to around 40%. France with more than 70% nuclear power share in its power production is the leading country among the 13 countries in the European Union that use nuclear energy.

According to the World Nuclear Association (WNA), a total of 55 nuclear power plant units were under construction worldwide in 2022, with a combined output of approximately 55,600 MW. More than half of the ongoing new plant projects are located in populous Asian countries such as China, India and South Korea. The construction projects of new reactors in Europe, in the UK, France, Slovakia and Hungary, as well as the now completed Olkiluoto 3 project in Finland, have all suffered from significant delays and increased costs.

Nuclear power reactors in Finland.

Unit	Model	Current power level (MWe)	Commissioning	Load factor (%)	
				2020	2021
Loviisa 1	VVER 440 (V-213)	507	1977–02–08	83,3	93,7
Loviisa 2	VVER 440 (V-213)	507	1980–11–04	91,1	92,2
Olkiluoto 1	ABB-III, BWR-2500	890	1978–09–02	93,5	95,1
Olkiluoto 2	ABB-III, BWR-2500	890	1980–02–18	93,1	90,4
Olkiluoto 3	EPR	approx. 1,600	2022–03–12	–	–

In 2021, the average annual load factor (capacity factor) for Finnish nuclear power plants was 92.9%, which is one of the best in the international comparison. The average annual load factor of units has almost invariably exceeded 90% since 1983. Good annual availability, cost-effective implementation of the modifications and 20–35% increase in the original rated power capacities of four units have made Finland's nuclear investments economically profitable.

The operational reliability of Finnish nuclear power plants has continuously improved with operational experience. The excellent usability of the Finnish nuclear power plants has been based on short annual outages and uninterrupted operation. The extensive preventive maintenance of the equipment during power operation and the multiple safety systems is the key for power operation without interferences. The existence of redundant equipment in safety systems allows safety systems to be maintained and inspected without relevant risks to the safety or personnel during power operation of the unit, which has been a prerequisite for keeping the refueling and maintenance outages very short.

Long term planning and scheduling the larger works on selected periodic maintenance outages keep a large part of the annual outages of the nuclear power units very short. The diversity of electricity generation methods and possibility to optimize the annual outage schedules of large power units has enabled the continuous use of nuclear power plant at their nominal power. To date, nuclear power units have not been significantly involved in the load-following production required by the daily variation in electricity consumption.

According to the continuous improvement principle, major modernization projects as well as yearly modifications have been

The Loviisa nuclear power plant (Fortum).

carried out in all units. Extensive condition monitoring and equipment exchange programs have been used to take into account the ageing of units and equipment. The safety of all Finnish units has been improved from the original by modifications in safety systems and improvements in operating methods and procedures based on operational experience. Technological development in many key areas, increased accuracy of safety analysis tools, diversification of safety verification methods and improved efficiency of the steam process and turbine generator efficiency have enabled the increase of rated electrical power in all four reactors in use in 2021.

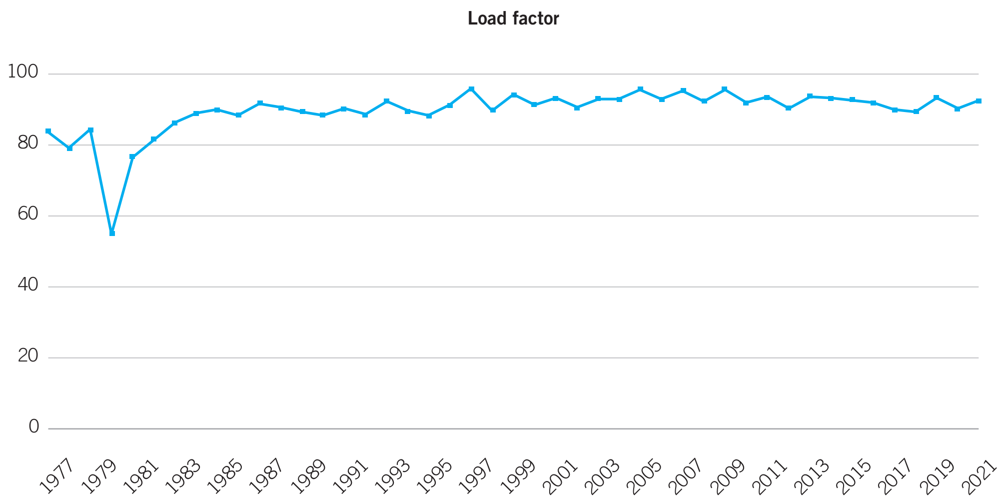
Loviisa nuclear power plant

Finland's first nuclear power plant is located on the island of Hästholmen, about 12 kilometres from the centre of Loviisa town. The facility is owned by Fortum Power and Heat Oy. The Loviisa nuclear power plant has two VVER-440 pressurized water reactors delivered by the Soviet Union at the time. Original net power of both units has been increased by more than 20% from 420 MWe (465 MWe gross) in 1977 and 1980 up to 507 MWe net power (531 MWe gross). Main primary components of units, such as the reactor pressure vessel, steam generators, main piping and turbines, are original Soviet delivery. The plant's safety and automation systems, steel containment building with ice condenser, and operational limits, conditions and procedures were already originally implemented in accordance with Finnish and international safety regulations and procedures based on defense-in-depth principle.

Loviisa (LO1 and LO2) units are surrounded by an accident-limiting containment building and the units are equipped with western protection and safety automation, which has been extended several times from the original. The most extensive renovation of the units' automation systems was carried out in the project from 2014–2018. In the reforms, the safety systems of the LO1 and LO2 have been supplemented to take into account and mitigate the environmental emissions of a highly unlikely severe accident leading to melting of the reactor core.

As lessons learned from operating experiences, research results and accidents at nuclear power plants around the world, the

The average annual load factor of Finnish nuclear power plants (OL1 and 2; LO1 and 2) in 1977–2021.



The Olkiluoto nuclear power plant (TVO).

safety of the plant has been improved by renewal of safety systems, automation systems and fire protection arrangements, and by developing more specific operational limits and conditions and plant procedures. The levels of defense-in-depth have been supplemented to take better into account the very unlikely weather phenomena, situations caused by earthquakes or external threats, and rare events caused by the common cause failures of similar components in safety systems.

For the very rare severe accident with core melting, dedicated safety systems mitigating the environmental releases and doses have been added to the LO1 and LO2, such as an external spray system for the steel containment designed to remove residual heat inside containment in the long term, and controlled passive recombination or active burning of explosive gases, e.g., hydrogen, produced by molten core. Safety modifications implemented in the Loviisa plant have been replicated and implemented at other VVER-type plants.

Fortum has announced significant investments in the life time extension of Loviisa units and has applied for permission to operate both units until at least 2050. Fortum has purchased nuclear fuel assemblies from Russia. The procurement procedures of nuclear fuel will be assessed again as a part of the Loviisa plant's operating permit application.

In 2021, the Loviisa power plant produced 8.2 TWh of electricity (net production). In year 2021 the load factor of LO1 was 93.7% and that of LO2 was 92.2%.

Olkiluoto nuclear power plant

The Olkiluoto nuclear power plant owned by Teollisuuden Voima Oyj is located in the municipality of Eurajoki, approximately 20 kilometres north of Rauma. The power plant has two boiling water reactors (BWRs) OL1 and OL2 delivered by the Swedish Asea-Atom in 1980s and a European Pressurized Reactor (EPR) type reactor OL3 delivered by French Areva and German Siemens and commissioned in 2022.

The initial 660 MW net electric power of the OL1 and OL2 BWRs has been increased to the current level of 890 MW in several stages: first in the form of increases in reactor power between 1982 and 1984, then in the modernization and reactor power increase project in 1995–98, and improvements in turbine-side steam processes and efficiency in 1995–98, 2005–2006 and 2010–2012. The power increases in 1995–97 and 2010–2012 also required the renewal of the generators. The current net electrical power of each plant unit, 890 MWe, is approximately 35% more than the original. In connection with power increases and the modernization of equipment, the safety systems of the units have been renewed and supplemented based on the operational experiences and the recent research results.

The functionality of the defense-in-depth levels of the electrical systems of the OL1 and OL2 BWRs has been supplemented in connection with the renewals. Independent power supplies for safety

systems and the ability to cool the reactor in the unlikely event of an accident have been increased. Also, the ability to supply electricity from one unit to another between all three units on site increases safety in very exceptional and rare situations. In addition, accident procedures and safety analyzes have been supplemented to take better into account the rare accidents that are more serious than those postulated in the design and very rare severe accidents with core melting. Similarly, preparedness for extremely rare weather events and external threats has been complemented by equipment and instructional improvements. The safety systems of the OL1 and OL2 units have been systematically improved and modernized in the maintenance outages every second year. More extensive modernization projects have been carried out in longer maintenance outages of units approximately every 5 years.

The construction of OL3 EPR unit began in 2005 and power production started in 2022. OL3 is a Pressurized Water Reactor (PWR) type unit with a net electricity output of approximately 1,600 MWe. OL3 is designed and implemented as a Franco-German collaboration. However, already during the construction license phase of 2003–2004, the safety systems and operational design were supplemented to meet Finnish safety and operability requirements. The OL3 unit has modern technology based on the approved and tested technology of PWRs and advanced safety features related to design extension accidents and management of the very rare severe accident with melting of reactor core. The service life of all three Olkiluoto nuclear power plant units is planned to be at least 60 years from the date of commissioning of the unit.

Uranium for Olkiluoto units is procured under long-term contracts mainly from Canada and Australia. Uranium is enriched in Russia and the EU. The fuel bundles delivered to Olkiluoto are manufactured in Germany, Spain and Sweden.

In 2021, the two operating units OL1 and OL2 produced 14.4 TWh of electricity (net production). In year 2021 the load factor of OL1 was 95.1% and that of OL2 was 90.4%.

New projects

Hanhikivi 1 planned by Fennovoima Oy, Finland's sixth nuclear power plant unit, received a positive decision in principle in 2015, but the project was discontinued by decision of its owners in 2022. The decision ended the last of three nuclear power construction projects discussed by the Government in 2010. However, according to opinion polls in 2022, the majority of Finns support the use of nuclear power and the construction of new nuclear power plants in Finland.

ENVIRONMENTAL IMPACTS AND RADIATION EXPOSURE

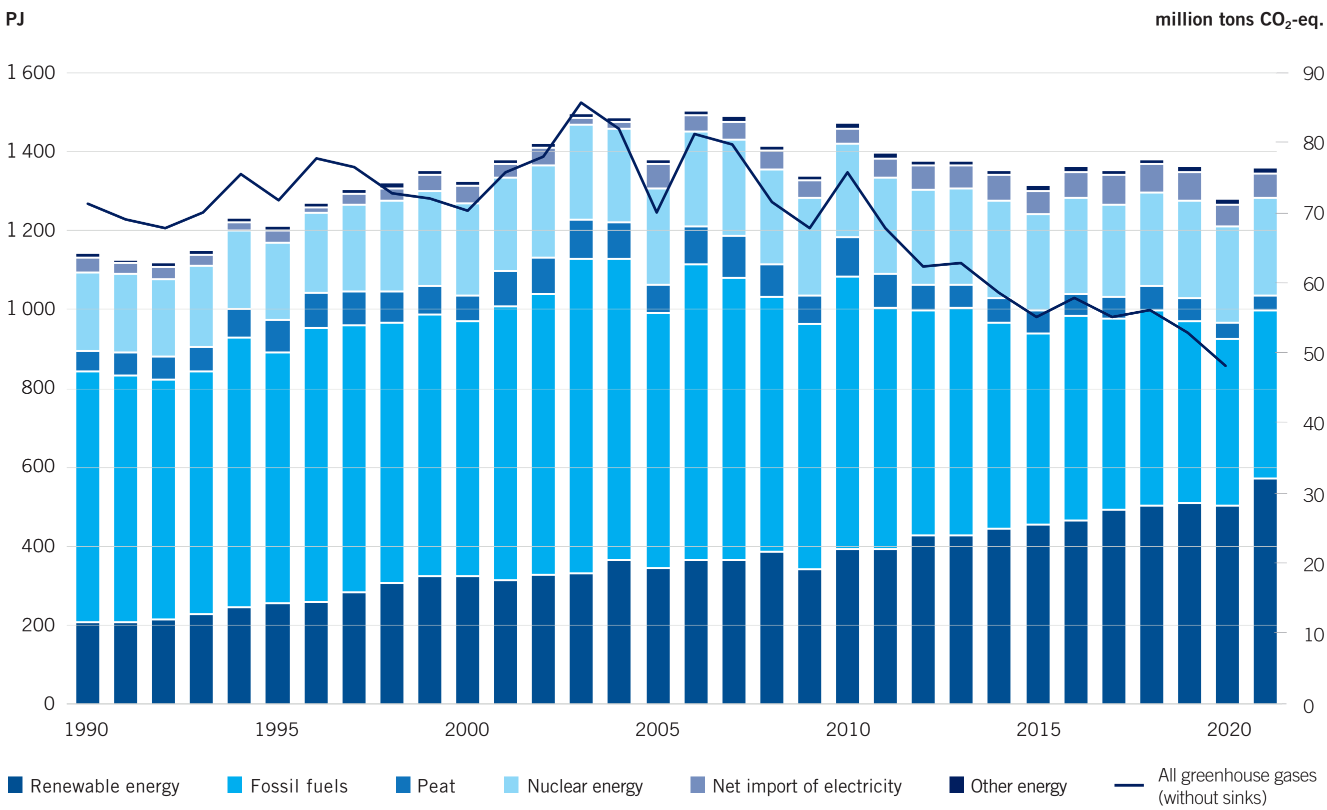
Nuclear power plays an important role in the fight against climate change, as the power production process does not emit relevant amounts of greenhouse gases. The radiation level at the surroundings of nuclear power plants and the minute releases of radioactive substances from nuclear power plants to nearby areas are regularly monitored by measuring samples taken from the environment. The radiation doses of nuclear power plant personnel and nearby residents have been well below the prescribed limits in Finland.

Nuclear power as part of environmental policy

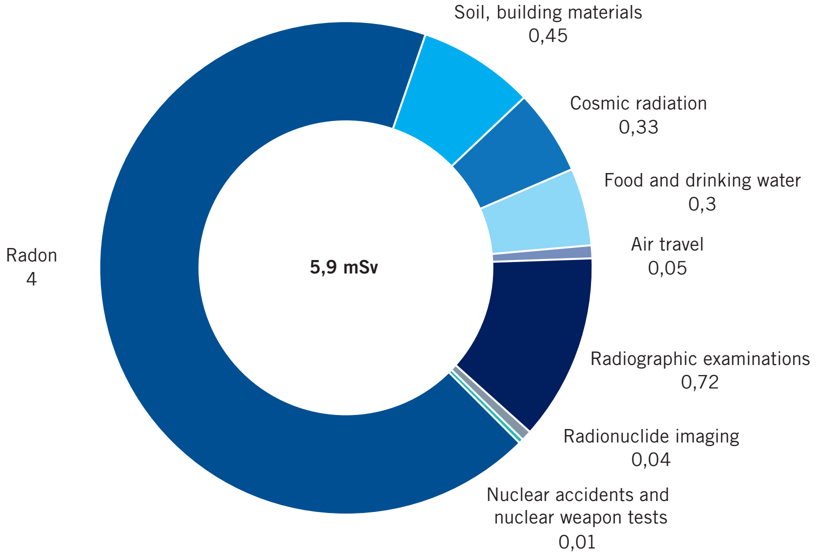
Increased awareness of Finns about climate change has increased support for nuclear power in Finland for several years. The popularity of nuclear power in Finland has been boosted by the price of fossil energy raised by the policy of limiting carbon dioxide emissions as well as the need to reduce dependence on energy imports from Russia, which was quickly decided in 2022.

A demanding carbon neutrality target by 2035 has been set for Finland's climate policy. Nuclear power plays an important role in achieving this objective as a low-emission form of electricity generation. The production process of a nuclear power plant does not

Energy consumption by energy source and greenhouse gas emissions (Statistics Finland).



Average radiation dose of a Finn in millisieverts (mSv) from different sources (STUK).



cause remarkable greenhouse gas emissions. The low greenhouse gas emissions relate only to the periodic testing of safety-related systems and the manufacture of plant structures and equipment. When assessing the life time emissions of nuclear power, carbon dioxide emissions during production of construction materials and fuel must be taken into account. According to the latest estimates, the life time emissions of nuclear energy are a few tens of grams of carbon dioxide per kilowatt-hour produced, which is comparable with wind power.

Finland has successfully reduced the amount of sulfur dioxide and nitrogen oxide emissions that acidify the environment. Reducing carbon dioxide emissions further is a very challenging task, of which the most important means are the efficiency of electricity and heat production, energy saving, increasing the use of renewable energy resources and nuclear energy, and replacing coal with natural gas.

According to the Statistics Finland, total greenhouse gas emissions in 2020 amounted to 48.3 million tons of carbon dioxide equivalent (million t CO2 eq.). Emissions decreased by 9% from the year before. Emissions have fallen by 32% since 1990 and by 44% since 2003.

Average radiation dose of Finns

The average annual radiation dose received by Finns from different sources is 5.9 millisieverts (mSv). Two-thirds of this dose is caused by radon in room air. These doses have been reduced by building new houses radon safely and repairing old houses to be radon-safe. However, a change in the calculation method led to a three-fold increase in the dose caused by indoor radon in 2020. This change does not affect estimates of actual health impacts of radon that have been gradually decreasing.

Operation and environmental impact of the nuclear power plant

Limits for radioactive releases into water and air from nuclear power plants for the main categories of radioactive substances are monitored in accordance with official regulations. The concentration in the environment are measured by samples taken from the environment. The radiation doses to personnel of nuclear power plants and residents of nearby have been well below the prescribed limits in Finland.

The limits for radioactive releases for Finnish nuclear power plants have been set in such a way that the radiation dose to the most exposed population group in the vicinity caused by releases from the normal operation of all nuclear power plant units in a site must be well below 0.1 mSv per year. The radiation dose of the most exposed individual in the environment, calculated on the basis of the actual releases measured annually, has been less than 1% of that limit at both sites.

Prior to the construction of a nuclear power plant, a radiological environment baseline study has been carried out in its surroundings. During the operation of the plant, hundreds of samples are taken each year from the terrestrial and marine environment of the plant: for example, ferns, mushrooms, berries, game and milk, as well as seawater, aquatic plants, benthic animals, fish and seabed sediments. In addition, air, rainwater and a sample group of people living in the surrounding area are monitored. The quantities of radioactivity from the nuclear power plant detected in the environment are so small compared to nature's own radioactivity that they are not relevant to the radiation exposure of the environment or population.

Exposure to radiation from emissions can be calculated by measuring releases to air and water and by using meteorological statistics and dispersion data, as well as data related to the ecological and biological behavior of various substances. The identification of releases from a nuclear power plant is facilitated by the fact that it is easier to detect radioactive substances released in the environment than many other substances involved in industrial emissions. Assessed in this way, the annual radiation doses from releases of nuclear facilities to the most exposed group of people in the vicinity of the facilities are in the order of 0.0001 mSv. Such small dose increments cannot be distinguished from natural background radiation by any direct measurement technique.

The most significant environmental impacts of Finnish nuclear power plants are related to the warming of seawater, because the plants use seawater for cooling like other Finnish condensing power plants. Seawater warms by 10–13 degrees as it passes through the plant, but cools quickly as it mixes with the large mass of water in the open sea. The warm water area at the mouth of the seawater drainage tunnel becomes eutrophic and remains open even in winter. The size of the completely ice-free and weakened ice area depends on the thermal power of the nuclear power plant unit and temperature variations of Finnish winter.

Professional radiation exposure

The radiation doses of people who have worked in Finnish nuclear power plants have decreased in the 21st century, e.g., as a result of the development of working methods and materials selection as well as operation procedures of units. For example, the Loviisa plant units achieved the lowest radiation dose of personnel in the history of the plant in 2021, and in the same year in all four operating units in Finland about 95 percent of the radiation doses of individual employees were less than 5 mSv. Most of the radiation doses are obtained during work performed during annual maintenance outages. The annual radiation dose of employee must not exceed 20 mSv. The Loviisa and Olkiluoto power plants have dose limitations lower than the dose limit in order to limit workers' personal radiation doses in accordance with the as low as reasonable achievable (ALARA) principle.

In 2020, the collective radiation dose of the Loviisa power plant personnel was 0.90 manSv for both plant units and 0.56 manSv for the Olkiluoto power plant units. The majority of the radiation dose is accumulated during the annual maintenance.

Impact of mining projects

The environmental impacts vary at different stages of mining projects: in mineral exploration, production and after the end of operations. The magnitude of the impacts depends essentially on, e.g., the mineral to be extracted, the extent of the activity, the environmental conditions, and the technologies used. Actual mining, i.e., the exploitation of mining ores, usually takes years, even decades. The environmental impacts are mainly in the vicinity of the mine and usually last for the duration of the operation.

There are currently no uranium mines in Europe, but the concentration of uranium in the Finnish bedrock is high and uranium recovery as a by-product of the rest of the mining process is possible. In 2022, the government granted a license for the recovery of uranium at the Terrafame (formerly Talvivaara) nickel mine in Sotkamo. Terrafame has estimated the mine to produce 150 tons of uranium per year.

Waste from uranium mining is waste rock and various process wastes. The concentrations of natural radioactive substances they contain are relatively low, but on the other hand the volumes of waste are of the same magnitude as the amount of ore extracted. At the end of the mining operation and when the waste stone dumping area has been filled, a cover layer insulating the soil is built on top of it. Uranium mining waste does not cause significant environmental damage, but the condition of the insulation layers in the waste facility requires periodic monitoring. At the turn of the 1950s and 1960s, roughly 30 tons of uranium were mined in Eno's Paukkajanvaara. As a result of the operation, waste rock and tailings that clearly exceed natural radiation levels remained in the area, but the mine has otherwise been restored to its natural state.

Locations of Paukkajanvaara and Talvivaara (background map: National Land Survey of Finland).

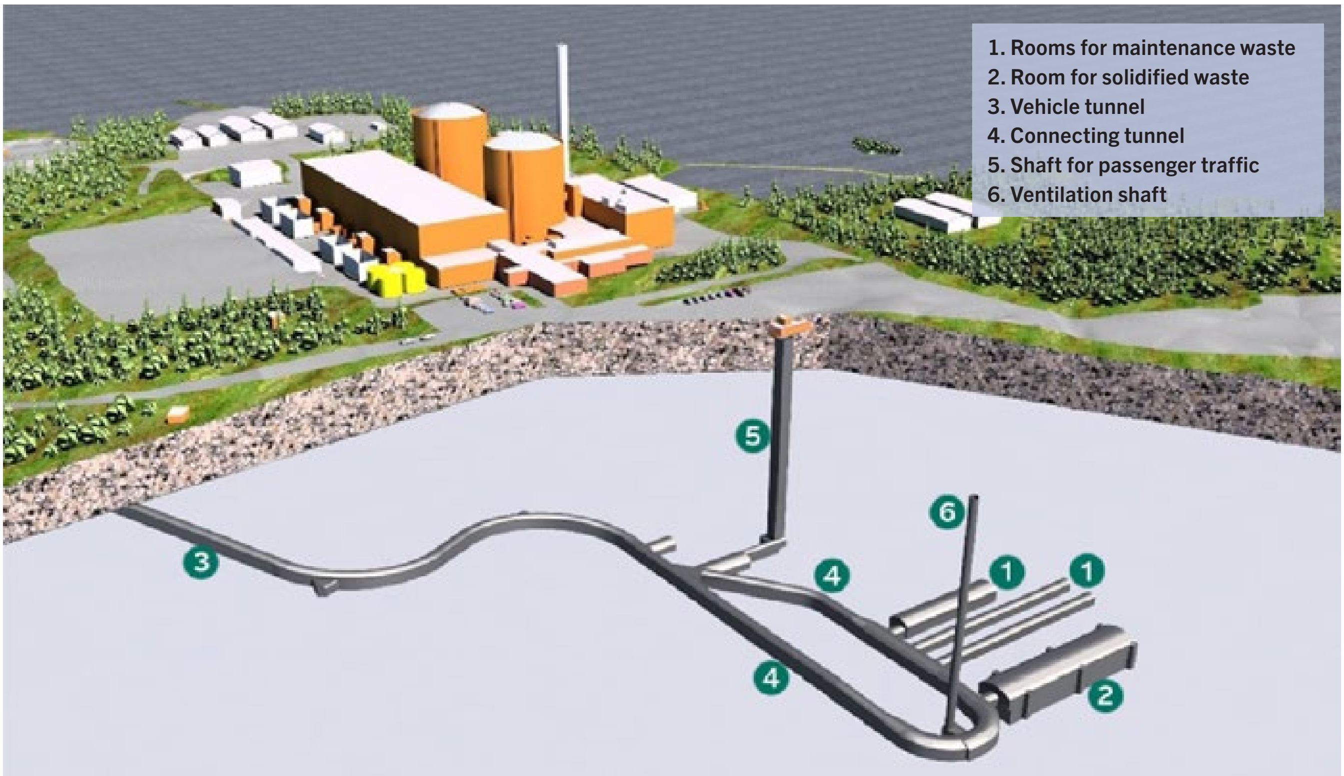
NUCLEAR WASTE MANAGEMENT

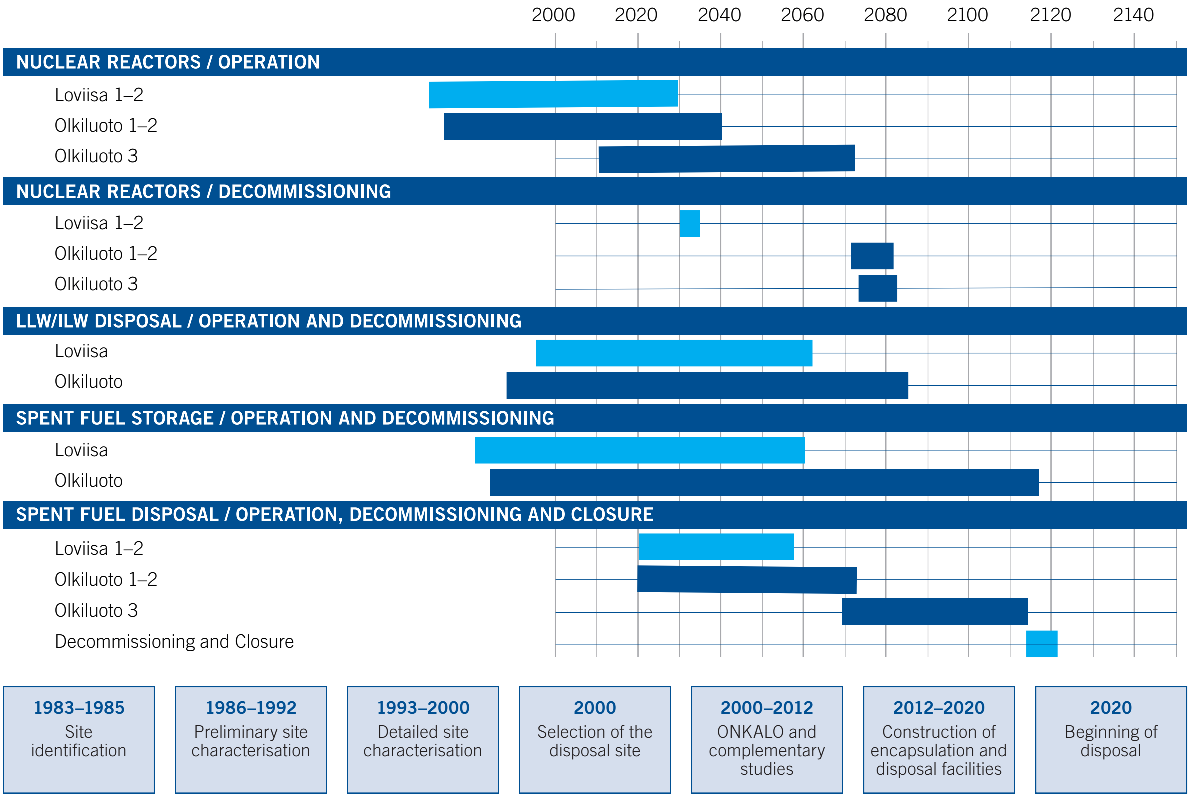
The use of nuclear power in electricity production generates two types of radioactive waste: low and intermediate level power plant waste and high level nuclear waste (spent nuclear fuel). A total of approximately 110 tonnes of spent nuclear fuel is produced per year in Finland's five nuclear power plant units. Power plant waste is generated by nuclear facilities in process water purification systems, as well as in maintenance and repair work. When the nuclear power plants are permanently closed and the plants are decommissioned, decommissioning waste such as power plant demolition waste is generated.

Operational waste

The final repository for low and intermediate level power plant waste (VLJ cave) is located on the outer end of Olkiluoto peninsula, called Ulkopää. Construction of the VLJ cave began in 1988 and was commissioned in 1992. The VLJ cave will be expanded for the disposal of radioactive waste from extended operation and decommissioning waste from the power plant in the 2050s, according to current estimates. The operational waste from the OL3 unit and the waste generated by the decommissioning of the plant can also be placed in the final disposal area of the power plant waste.

Low and intermediate level waste disposal facility at Loviisa nuclear power plant (Fortum).





The current schedule for nuclear waste management (MEAE). The originally planned schedule from 1980s is shown in the boxed bottomline and it has held astonishingly well. In 2022 Fortum submitted an operating license extension application for two Loviisa units until 2050. If it passes, the operating and decommissioning schedules for Loviisa will change accordingly.

According to the plans, the use of VLJ cave in Olkiluoto will continue as the units continue to be used at least until the 2080s, so a new license will be applied for when the current operating license expires at the end of 2051. The current licenses issued in 2012 also allow other radioactive waste, not generated by the operation of nuclear power plants, to be placed in the cave.

A cave for disposal of the low and intermediate power plant waste has been excavated to a depth of 110 metres in Loviisa NPP site on the island of Hästholmen. The premises will be expanded in time for the final disposal of the demolition waste from the Loviisa units. According to a recent application, the Loviisa units will continue to be used until 2050 and are planned to be dismantled in 2050–2060.

Spent fuel

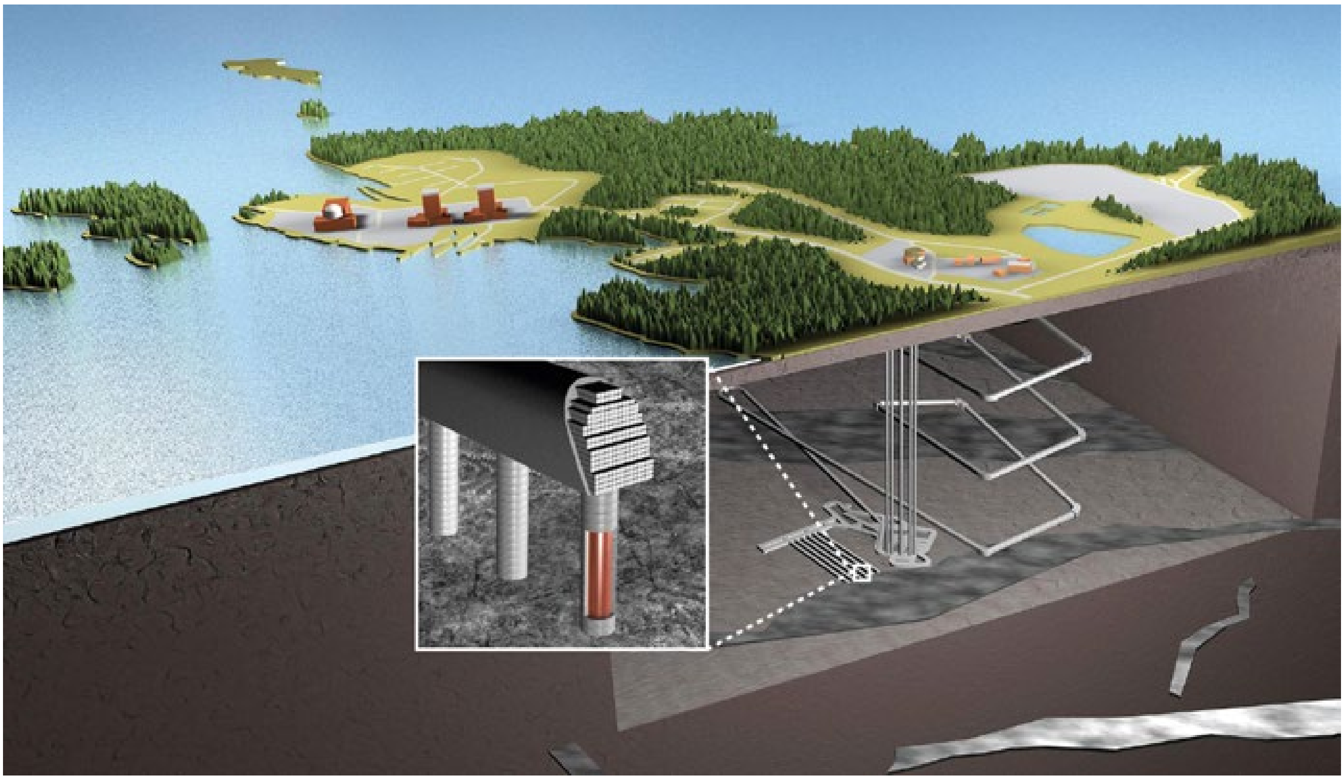
At the Loviisa plant, spent fuel from the reactors is stored at the plant site before final disposal. In addition to the storage pools located in the containments of the LO1 and LO2 units, the auxiliary building of the Loviisa plant has a separate storage room for longer-term interim storage of spent fuel. The storage capacity will be gradually expanded by installing more dense storage racks or even by building new pools when necessary. The operation of the Loviisa units will continue until 2050, and the activities related to the decommissioning of units are planned to take place between 2050 and 2060.

The storage pools of OL1 and OL2 units have the storage capacity of approximately 285 tU (tonnes of uranium) of spent fuel in each reactor building and the storage capacity of the fuel building connected to the OL3 unit's reactor building is 520 tU. The fuel used for longer-term storage is transferred to a separate interim storage facility in a special transport cask. The interim spent fuel storage facility is located in the Olkiluoto plant area and it has seven storage pools and a connecting transfer pool. Five storage pools with a total capacity of 2,300 tU are currently reserved for fuel in OL1 and OL2 and two pools with a total capacity of 870 tU are reserved for OL3. The interim spent fuel storage facility was commissioned in 1987 and the expansion completed in 2014.

Disposal deep to the bedrock – Onkalo

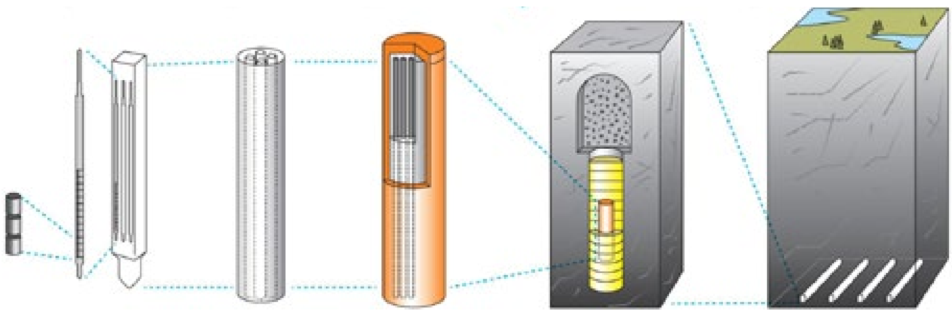
The final disposal of spent fuel for all Finnish nuclear power plant units deep into the Finnish bedrock is carried out by the Onkalo disposal plant owned by Posiva Oy, located near the Olkiluoto nuclear power plant. Long-term safety is based on the multi-barrier principle, in which radioactive substances are contained in a number of mutually supportive but as independent barriers as possible. In this case, the radioactive substances cannot spread even if one of the barriers to release fails.

The disposal solution is designed to withstand rare large earthquakes at the site, as well as the predicted ice ages of the future up to one million years, as well as the stresses caused by the continental ice weight and movement during the ice ages. The solution is based on the placement of spent fuel in durable copper-cast iron capsules surrounded with bentonite and buried at a depth of about 430 meters inside the bedrock. The safety justification has shown that the final disposal of spent nuclear fuel does not harm people or the environment.



Posiva's final disposal concept for spent nuclear fuel (Posiva).

Details of the final disposal concept (Posiva).



A full-scale model of the copper-cast iron capsule (Posiva).

State Nuclear Waste Management Fund

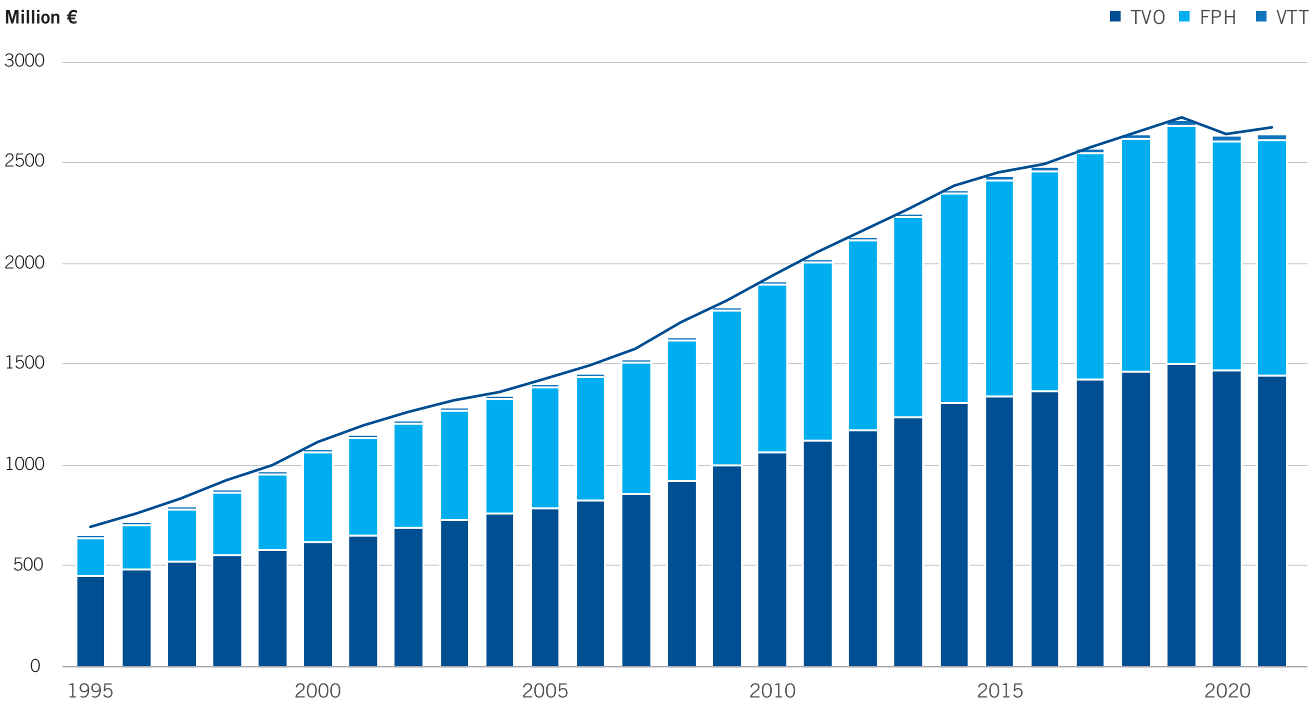
In accordance with the Nuclear Energy Act, the State Nuclear Waste Management Fund was established in 1988 as a fund outside the state budget. It operates under the authority of the Ministry of Economic Affairs and Employment (MEAE). The State Nuclear Waste Fund (VYR) collects and invests the funds needed in the future for the costs of nuclear waste accumulated in Finland and the final disposal of spent fuel. The funds cover decommissioning of current units and they are collected in the price of nuclear electricity. The funds needed for the disposal of waste produced so far by the Loviisa units and the two older units of Olkiluoto and for the construction of an encapsulation plant and disposal facility for spent nuclear fuel (Onkalo) for all units have already been collected. Part of the funds have been used by the end of 2021 for the construction of an encapsulation plant and disposal facility for spent nuclear fuel and an operating license application for this facility is in the regulatory process. The funds needed for the disposal of waste produced by four older units and the Olkiluoto 3 unit in the future will continue to be collected in the price of nuclear electricity using the same principle.

In addition to final disposal, the funds also cover the costs of research and development and regulatory oversight related to nuclear safety and nuclear waste management.

Other radioactive waste in Finland

Radioactive waste from the use of radiation (e.g., in industry, healthcare and research), which cannot be returned to the manufacturer or exempted from control, is stored in a state-administered small waste repository in Olkiluoto. Their placement in the Olkiluoto low and intermediate level waste disposal facility (VLJ-cave) began in 2016. The possible final disposal of radiation sources containing high-activity sealed sources together with spent nuclear fuel is currently being investigated.

The FiR 1 research reactor, which started operating in Otaniemi in 1962, commissioned by Finland from the United States, was acquired for research and training purposes in due course and was later also used for isotope production and radiotherapy. The maximum fission power of the water-cooled, pool-type TRIGA reactor was 250 kW. In January 2021, under the original NPT contract, the reactor's spent fuel was delivered to the U.S. Geological Survey (USGS) reactor in Denver. From there, the fuel will be transferred to the Idaho National Nuclear Research Center in the United States. After the defueling, the FiR 1 research reactor received a decommissioning license in June 2021. The demolition waste from the research reactor will be disposed of in the disposal facility of the low and intermediate level waste located in the Loviisa power plant area.



The curve shows the balance of the State Nuclear Waste Management Fund VYR, being 2.68 billion EUR at the end of 2021. The Finnish authorities decide the fund goal and legal responsibility for each company annually. In 2021 the share of Fortum was 1,167 million EUR, that of TVO 1,451 million EUR and that of VTT 19 million EUR. The remaining 40 million EUR was annual profit from investments.

RESEARCH AND EDUCATION

Research and development related to nuclear energy is carried out in several research units in Finland, which operate in research institutes, universities, power companies and expert organizations. Publicly funded nuclear research ensures that the control of the use of nuclear energy is based on objective expertise. In addition, it maintains the competence of the personnel of research institutes, the functionality of Finnish research facilities and it enables participation in international research cooperation and in large international research projects.

The annual funding of national research programmes on operational safety and nuclear waste management of existing fission plants is collected from power companies, as part of the activities of the State Nuclear Waste Management Fund (VYR), to two separate funds. The aim of the funds is to ensure high-quality research and nuclear expertise in the long term. Nuclear power companies invest funds in reactor safety research in relation to the thermal output of the operating plant units or the thermal output indicated in the permit documents of a new unit. The funds for nuclear waste research are collected in the same proportion as the funds used for the nuclear waste management.

At the beginning of 2023, a significant amendment will be made to the Nuclear Energy Act: the national research programmes for nuclear safety and nuclear waste management and their funds will be combined. The previous SAFIR and KYT research programmes will be combined into a SAFER research programme, and the programme period will also change from four years to six. At the same time, the annual amount collected from nuclear power companies in the fund will be increased.

National nuclear safety and nuclear waste management research programmes have formed the backbone of research in this field, and the new combined programme is expected to continue the tradition. The total scope of the research programs in 2021 was about 8 M€ and this funded the research for about 60 person-years.

Research institutes and units

In Finland, research in the field of nuclear energy is divided into research on nuclear safety and nuclear waste management and is divided into several different organizations. The majority of publicly funded research and development activities are carried out at VTT Technical Research Centre of Finland Ltd. Other important research institutes include Aalto University and Lappeenranta-Lahti University of Technology (LUT), Geological Survey of Finland (GTK), Finnish Meteorological Institute, and the universities of Helsinki, Eastern Finland, Jyväskylä, Tampere and Turku. In addition to these, STUK and nuclear energy companies fund their own research and order research in the aforementioned research organizations and other expert organizations.

Research related to nuclear energy covers a wide range of fields of technology, natural sciences and human sciences. Many thematic areas utilize the know-how developed in other applications in research related to nuclear energy and, on the other hand, many of the methods developed in nuclear energy research are transferred to wider use.

Research programmes

The main objective of public research programs on reactor safety and nuclear waste management is to produce a high level of expertise and research results on the safety of nuclear power plants and nuclear waste management and disposal, and thus to support the activities of the authorities. Projects in research programs train new experts in the field and promote the exchange of technology and information, as well as participate in the international research projects.

In addition to national research programmes, there are research subjects that primarily serve the needs of the nuclear industry. Related research is paid directly by industry to a research or expert organization in nuclear field.

Since the beginning of the 21st century, national safety research programs for nuclear power plants have been implemented as 4-year SAFIR research programs; the most recent of these is SAFIR2022 (2019–2022). The research challenges of the SAFIR programs have been the ageing of existing nuclear power plants and the renewal of knowledge in various areas of nuclear technology, as well as the capacity to analyze new nuclear power plant designs. The programme includes projects that familiarize new experts with demanding special tasks, thereby contributing to the progress of generational change in the nuclear sector.

National nuclear waste management research programmes were also launched in the 1990s and have been known from the beginning of the 2000s as KYT research programmes. The last KYT programme is KYT2022 (2019–2022). The KYT programmes have funded technical science projects to strengthen the national com-

Finnish universities, companies and VTT are developing a wide range of technologies needed by fusion power plants, such as robotics and materials. The picture shows a MiR robot in research use at VTT's FutureHub office (VTT).

petence base in the field of nuclear waste management. The aim has been to develop and maintain the basic capabilities needed in Finland to implement solutions in accordance with the nuclear waste management plan. The studies are divided into strategic studies and projects to ensure the long-term safety of the geological disposal of spent fuel.

VTT has been responsible for coordinating the SAFIR programs and has implemented a large part of the programme's research projects. Most KYT programs have also been coordinated by VTT, and in addition to VTT, GTK and several universities have participated in the research. Various actors in the nuclear power industry have been represented in the management teams of the research programs.

Development of fusion energy

ITER fusion reactor is under construction in international cooperation in Cadarache in the South of France, near the city of Marseille. The Tokamak-type cylindrical ITER reactor is scheduled to produce its first plasma in the late 2020s. The actual fusion tests with fuel consisting of heavy hydrogen isotopes deuterium and tritium are planned to begin in 2035. The EU, which hosts and finances almost half of the project, is responsible for a significant part of the equipment deliveries in which Finnish companies have also participated.

Since 2014, the EUROfusion consortium, a consortium of companies and publicly funded organizations, has been responsible for the EU fusion studies. Finland's contribution to the research programme is implemented by the national FinnFusion consortium of universities and companies, led by VTT Technical Research Centre of Finland. In addition to research, EUROfusion and FinnFusion also support and fund the work of postgraduate students in their member organizations.

The goals of the Finnish fusion energy program are in technology, science and business related to major science projects. The priorities of the Finnish program are: the development of technology related to the construction and systems of the ITER reactor together with industry; participation in fusion technology development activities as a member of the EUROfusion consortium; and the concept development of a next-generation European DEMO fusion power plant to illustrate the potential of electricity generation.

Commissioned research

Publicly funded research programs focus on topics that benefit a wide range of actors and whose results can be published transparently. In contrast, research that is clearly related to licensing processes, individual facilities, and facility upgrades is conducted within the organizations' own R&D activities or as commissioned research, where the research organization is a domestic or foreign player. In addition to participating in public programs, Fortum, TVO and Posiva each have their own research programs in the field of nuclear technology, the content of which is determined by the needs of the company and the nuclear facilities.

VTT and universities also conduct some research related to nuclear energy with their own funding and other external funding than in VYR-funded research programmes. However, these are small-scale projects that mainly complement research programmes and commissioned research and create new capabilities.

Education and training of nuclear energy

In the field of nuclear energy, competence is necessary in quite a number of special areas. An extensive competence survey was conducted under the leadership of the Ministry of Economic Affairs and Employment in 2010–2012 and it was updated in 2017–2018. These reports of the National Nuclear Energy Competence Working Group are publicly available on the website of MEAE. Based on the survey results and past developments, the necessary human resources will be maintained in Finland, but the training and education of young experts in certain areas of expertise will need special attention in the future.

Master's degrees (M.Sc.) related to nuclear energy are obtained by 10–20 students annually in Finland. Nuclear energy technology can be studied at Aalto University and LUT University and radiochemistry at the University of Helsinki. The scope of studies may be that of a Master's degree minor or major, and these programs may also lead to a doctoral degree. On the basis of competence surveys, masters and doctors from many other fields as well as graduates from polytechnics are also recruited to the nuclear energy field.

YJK – National Course on Nuclear Safety and Waste Management

One of the goals of research programmes in the field of nuclear energy is to train new experts in the field, needed not only to replace the retirees but also for the construction, maintenance and decommissioning of current and future nuclear facilities. However, new experts without nuclear-energy-related studies in their curricula are also being recruited in the nuclear energy field. In order to familiarize such workers in particular, a nuclear safety course (YK-course) providing basic information on the nuclear field, has been organized by all main stakeholders annually since 2003. In 2017, the content of the national nuclear waste management course was combined with the YK-course, which created the National Course on Nuclear Safety and Nuclear Waste Management or YJK.

Since 2003, 50–90 employees from various nuclear organizations have participated in YK and YJK courses each year. So far, more than a thousand people have attended the course, which lasts 21–30 days. The teachers of the course are the best experts in their fields from different organizations, and in return for the teaching input of the competent experts, the organizations get student places for their young employees. The voluntary collaboration concept in YK and YJK-courses is internationally unique. The course material has been prepared so that different organizations can also use it in their own internal training.

Autoclave by Platom Oy for processing uranium hexafluoride UF_6 (Platom).

LEGISLATION AND REGULATORY CONTROL

The regulation concerning nuclear power plants in Finland consists of the Nuclear Energy Act and Decree, the regulations and guidelines for nuclear power plants (YVL Guidelines) provided by the Radiation and Nuclear Safety Authority (STUK) as well as the international nuclear guidelines and standards applicable according to YVL Guidelines and STUK decisions.

The Finnish Nuclear Energy Act (990/1987) entered into force on 1 March 1988 and repealed the Atomic Energy Act of 1957 (356/57). The main principle of the law is the pursuit of the safety of the use of nuclear energy and compliance with the general interest of society, and the use of nuclear energy in Finland is not allowed to promote the proliferation of nuclear weapons. Democracy was realized through a decision in principle by Parliament on the construction of a nuclear power plant or other nuclear facility of general significance, as well as at public events related to a project in which citizens can present their opinions to the Government. In accordance with the Nuclear Energy Act (990/1987) and Decree (161/1988), Parliament has the final authority to authorize the construction of new nuclear facilities, including nuclear waste disposal facilities.

The Nuclear Energy Act stipulates that the use of nuclear energy and waste management are subject to licensing and conditions of use, as well as the obligations and powers of the authorities. The starting point for the Finnish regulations is an unambiguous and indivisible responsibility of the operator for the safety of the nuclear facility and the costs throughout its lifecycle. The entire lifecycle includes the scope and responsibilities for the scope of the required regulatory oversight and the lifecycle management of nuclear waste. The funds collected during the operation of the plant are returned to be used for the waste management.

Another characteristic of the Finnish regulation is the extensive power of the Radiation and Nuclear Safety Authority (STUK), which inspects periodic safety reviews and safety assessments of facilities, draws up the regulations and also monitors their implementation. STUK is totally independent from licensees and political decision-makers.

Licensing of a new nuclear facility

Before building a new nuclear facility, the Environmental Impact Assessment is provided according to the Environmental Impact Assessment Procedure Act (252/2017) by the responsible organization. According to the Nuclear Energy Act and Decree, the Finnish licensing process for a new nuclear facility has four main steps as follows:

- Decision in Principle
- Construction License
- Operating License
- Decommissioning License

The first step, the Decision in Principle, is authorized by Finnish Parliament based on proposal of the Government. Additionally, a positive statement from the municipality where the nuclear facility is to be located as well as arrangement of public hearings in the actual municipality and its neighboring municipalities are necessary for the positive Decision in Principle.

Construction License, Operating License and Decommissioning License stages are authorized by Government and managed by the Ministry of Economic Affairs and Employment (MEAE). In all these three steps, a comprehensive review of obligatory licensing documents and a safety assessment of STUK with positive conclusions are a prerequisite for a positive decision of the Government.

Regulatory oversight

According to Finnish practice, a license is usually granted for a fixed period of 10–20 years, combined with a periodic safety review (PSR) of each plant every 10 years. The licensing procedure aims at a strong continuous improvement of safety and technology at the operating nuclear power plant. Supervision work related to nuclear safety is at the responsibility of the Radiation and Nuclear Safety Authority (STUK).

In addition to the nuclear safety oversight, STUK's task is to take care of the oversight of security, emergency preparedness arrangements, and the supervision of nuclear materials intended to prevent the proliferation of nuclear weapons. Non-proliferation safeguards under the International Non-Proliferation Treaty ensure that nuclear facilities and technology are used only for peaceful purposes. The drafting of regulations governing nuclear safety has also been entrusted to STUK in legislation.

In addition to the Nuclear Energy Act and Decree, the regulation on the use of nuclear energy consists of STUK's binding regulations and STUK's more detailed YVL guidelines. The STUK's YVL guidelines provide detailed safety requirements and indicative operating models for various technical areas in design, construction and operation of nuclear facilities.

Legislative reform

In 2022, the Ministry of Economic Affairs and Employment launched legislative preparations aimed at a comprehensive re-

The decision-making process on building a nuclear facility (MEAE).

THE DECISION-MAKING PROCESS ON BUILDING A NUCLEAR FACILITY *A nuclear facility can be a nuclear power plant or a final disposal facility of nuclear waste.*
1. The project executor will carry out an environmental impact assessment (EIA) on the construction, operation and decommissioning of the nuclear facility.
2. The project executor applies to the Government for a decision in principle that the construction of the facility is in the overall interest of society.
3. The Ministry of Economic Affairs and Employment (MEAE), which is responsible for preparing the decision, requests a preliminary safety assessment from the Radiation and Nuclear Safety Authority (STUK) and statements deemed necessary from other authorities, at least from the Ministry of the Environment, as well as statements from the municipal council of the planned location and neighboring municipalities. The planned location municipality has the right of veto against the facility. MEAE organizes hearings for residents of the planned location municipality and neighboring municipalities.
4. The Government makes a decision in principle that the construction of the facility is in the overall interest of society.
5. The Parliament confirms or overturns with a simple majority vote the Government's decision in principle regarding the compatibility of the project with the overall interest of society.
6. The project implementer applies to the Government for a construction permit in accordance with the Nuclear Energy Act (the construction permit also includes a building permit application of the facility to the location municipality). The MEAE, which is responsible for preparing the decision, requests a preliminary safety assessment from STUK and other necessary official statements. The Government decides on the granting of the permit.
7. After the construction has progressed to its final stage under the supervision of STUK and according to the documents approved by it, the project implementer will apply to the Government for an operating permit in accordance with the Nuclear Energy Act. The MEAE, which is responsible for preparing the decision, asks STUK for a safety assessment of the application for a use permit and other necessary official statements. After receiving the statements, the Government decides on granting the use permit.

form of the Nuclear Energy Act. The aim of the work is that the utilization of nuclear energy will continue to be in the overall interest of society, safe and economically profitable.

The need for reform is based on the prospects for the development of the nuclear sector and on changes in the sector's operating models and technology, and on the need to reform the regulation to take into account the small modular reactors (SMRs). The draft of the new Nuclear Energy Act is due to be approved in 2024 and the law itself is due to enter into force in 2028.

The need to comprehensively reform the Finnish nuclear regulation has also been affected by the fact that the periodic changes in the requirements of the regulation and the application of new requirements to ongoing nuclear power plant projects have made it more difficult to implement these projects on schedule. The contract models used to direct responsibility for meeting regulatory requirements and managing the permitting processes for plant parts to foreign plant and equipment suppliers have made it difficult to apply the changes.

A key principle of the overall reform of nuclear energy legislation is the predictability of the acceptability of design solutions in the facilities. The necessary scope of national regulatory oversight, the emphasis on oversights activities on the safety significance service,

An artist's vision of VTT's Small Modular Reactor: district heating reactor LDR-50 from outside and a cross-section of the reactor building (VTT).

system or equipment, and the possibility to use project-specific requirements, will be assessed as part of the actual reform.

The substantive and structural reform of the safety regulations emphasizes the operators' own planning and supervision responsibilities and the focus of STUK's oversight actions according to the risk importance (graded approach). The reform also assesses the periodicity of operation licenses for nuclear facilities and the need for a periodic safety review (PSR) of facility every ten years.

Other legislation

In addition to the Nuclear Energy Act, the use of nuclear power is also regulated by the requirements contained in the Radiation Act, which prevent and limit radiation effects harmful to human health, both to the general population and persons performing radiation work. In 2018, the Radiation Act (2018/859) was amended and based on the new Act, the regulations of the Radiation and Nuclear Safety Authority were updated in 2018–2021. The revised Radiation Act, the regulations under it and STUK's regulations issued pursuant to the Act (S series regulations) also implemented the revised European Union Radiation Safety Directive (Basic Safety Standards, BSS).

The Finnish Nuclear Liability Act (now 484/1972) implements the Paris Agreement on Compensation to Third Parties for the Use of Nuclear Energy as well as the Brussels Supplementary Convention and the 1994 Joint Protocol merging the two agreements. The Nuclear Liability Act will not enter into force until an international agreement has been ratified by all OECD member countries. The entry into force of the amending protocols linking the Paris and Brussels agreements has been delayed internationally, but is expected to be ratified in the coming years.

According to the Nuclear Liability Act, last amended by the Amending Protocols in 2021, the amount of liability of a Finnish plant operator is unlimited insofar as the damages exceed the amount of EUR 1,500 million to be covered in accordance with the Brussels Supplementary Convention. The operator of a nuclear facility located in Finland is liable for damages caused by a nuclear incident up to EUR 700 million.

After the 2021 revision, the maximum nuclear liability for the Posiva-owned nuclear waste disposal facility will be EUR 250 million. The maximum liability for the transport of nuclear fuel or other nuclear material is EUR 80 million, respectively.

The Environmental Impact Assessment Procedure Act (252/2017, hereinafter the EIA Act) lays down obligations for the environmental impact assessment procedure (EIA procedure) if a project is considered to be likely to have significant effects on the environment. According to the law, the environmental impact assessment (EIA) is mandatory for nuclear facility projects.

The Waste Act (646/2011) relates to the use of nuclear energy, especially in the event that nuclear waste is exempted from control and thus falls within the scope of the Waste Act. The Waste Act does not apply to nuclear waste.

Several other general laws also deal with the production of nuclear power, for example:

- The Electricity Market Act (2013/588) increases competition and separates electricity generation and distribution; it also enables foreign electricity suppliers to enter the Finnish market.
- The Competition Act (948/2011) is compatible with EU competition directives.
- The Land Use and Construction Act (132/2021) requires land use planning and zoning for the nuclear power plant and other facilities to be built in the plant area.

The Administrative Procedure Act (434/2003), the Act on Public Access to Public Administration Activities (621/1999) and the Public Administration Information Management Act (906/2019) exercise the right to receive information on public administration activities and public documents provided for in Finland as a fundamental right. They also apply to the official processing of documents by nuclear facilities.

The Environmental Protection Act (527/2014) and the Water Act (587/2011) contain provisions that apply widely and regardless of sector to all industrial and other activities that must be carried out in an environmentally sustainable manner and that may cause environmental pollution. In addition, the requirements of the Rescue Act (379/2011) aim to improve human safety and reduce accidents. Among other things, the law contains requirements for emergency plans, which supplement the specific requirements for emergency plans for nuclear facilities.

INTERNATIONAL COOPERATION

Finland has been involved in the activities of international organizations since the 1950s, and in addition to constantly renewing its own regulations, Finland has joined to key international agreements. These agreements include Convention on Nuclear Safety (INFCIRC / 449, iaea.org), Convention on the Safety of Fuel and Radioactive Waste Management (INFCIRC / 546), Convention on the Safety of Nuclear Material and Nuclear Facilities (INFCIRC / 274) and the Treaty on the Non-Proliferation of Nuclear Weapons (INFCIRC / 140).

Finland has also approved several agreements on international non-proliferation control. The International Atomic Energy Agency (IAEA) monitors compliance with the NPT through safeguards. The control of nuclear materials aims to prevent the use of nuclear materials for military purposes.

More international agreements related to the use of nuclear power can be found on the Internet at:

- https://tem.fi/en/international-and-eu-cooperation-in-the-energy-sector
- www.stuk.fi/tietoa-stukista/yhteistyo/kansainvaliset-sopimukset

IAEA and OECD NEA

The International Atomic Energy Agency (IAEA) is an independent organization of the United Nations, founded in 1957, to which Finland joined in 1958. The IAEA promotes the peaceful and safe use of nuclear energy and carries out nuclear safeguards and provides technical assistance for the safe use of nuclear power. Finland co-operates closely with the IAEA and offers its national expertise to other IAEA member states through the organization. The IAEA is based in Vienna, Austria, and develops standards and guidelines for nuclear safety with the assistance of its member countries. The key tasks of the IAEA include: monitoring compliance with the 1968 Non-Proliferation Treaty (NPT), promoting radiation and nuclear safety, and promoting the peaceful uses of nuclear energy through technical assistance. Finland was one of the first signatories to the Non-Proliferation Treaty, and today more than 190 countries have signed the treaty. Under the auspices of the IAEA, a number of international agreements have been concluded, such as the Conventions on Nuclear Safety and Waste and the Convention on the Safety of Nuclear Material.

The Nuclear Energy Agency (NEA) was set up in 1958 under the auspices of the United States-funded Organization for Economic Co-operation and Development (OECD) to implement the Marshall Plan (the European Recovery Program, ERP), and to assist its member countries in developing the technical and safe solutions needed for the peaceful uses of nuclear energy. 34 member countries of NEA participate in the work of the organization. The European Commission and the IAEA are also represented in the NEA working groups. The Ministry of Economic Affairs and Employment (MEAE) and the Radiation and Nuclear Safety Authority (STUK) participate in the co-operation of the authorities under the auspices of the NEA. NEA coordinates joint security research projects in its member countries and compiles and combines member countries' research data and projects into larger entities.

The European Atomic Energy Community (Euratom) was set up in 1957 to promote the peaceful uses of nuclear energy in Europe. Euratom has the same legislative powers as the European Community in its field, on the basis of which EU countries have adopted several regulations on radiation and nuclear safety and safeguards.

Ministry of Economic Affairs and Employment

The top management and control of the use of nuclear energy in Finland belong to the Ministry of Economic Affairs and Employment (MEAE). The Ministry prepares the relevant legislation and international agreements for Finland and takes care of their implementation. The MEAE supervises planning and implementation of nuclear waste management and manages the State Nuclear Waste Management Fund.

The MEAE supervises research and development work related to nuclear safety. The main goal is to guarantee a high level of safety and operational reliability of nuclear power plants and to support the safe and timely implementation of nuclear waste management. The Ministry of Economic Affairs and Employment represents Finland in the European Atomic Energy Community, the IAEA and the OECD NEA.

ORGANIZATIONS IN THE NUCLEAR ENERGY FIELD

Nuclear regulators

Ministry of Economic Affairs and Employment	tem.fi/etusivu
Radiation and Nuclear Safety Authority (STUK)	www.stuk.fi

Other authorities

Ministry for Foreign Affairs	um.fi/etusivu
Ministry of Social Affairs and Health	stm.fi/etusivu
Ministry of the Environment	ym.fi/etusivu

Nuclear energy industry

Fennovoima Oy	www.fennovoima.fi
Fortum Oyj	www.fortum.fi
Fortum Nuclear Services Oy	www.fortum.com/products-and-services/power-plant-services/nuclear-services
Posiva Oy	www.posiva.fi
Posiva Solutions Oy	www.posivasolutions.com
Teollisuuden Voima Oyj	www.tvo.fi
TVO Nuclear Services Oy	www.tvo.fi/tvons.html
AFRY Oy	afry.com
Mitta Oy	mitta.fi
Platom Oy	platom.fi
STUK International Oy	www.stukinternational.fi

Research institutes and universities

Geological Survey of Finland (GTK)	www.gtk.fi
Finnish Meteorological Institute	www.ilmatieteenlaitos.fi
Technical Research Center of Finland VTT Oy	www.vttresearch.com
Aalto University	www.aalto.fi/fi
University of Helsinki	www.helsinki.fi/fi
University of Eastern Finland	www.uef.fi/fi
University of Jyväskylä	www.jyu.fi/fi
LUT University	www.lut.fi/fi
Tampere University	www.tuni.fi/fi
University of Turku	www.utu.fi/fi

Other Finnish organizations

Business Finland	www.businessfinland.fi
Finnish Energy (ET)	energia.fi
FinNuclear	finnuclear.fi
Finnish Nuclear Society (ATS/FNS)	ats-fns.fi/fi

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