Doel nuclear power plant
Uranium as a source of energy
**Electrabel Key Figures**

- **Employees**: 4,945
- **Electricity and natural gas sales**: 98.6 TWh
- **Generating capacity**: 9,020 MW
- **Energy capacity**: 461 MW
- **Million customers**: 2.86
- **Investments and maintenance**: EUR 419 million
- **Electricity generation**: 42.7 TWh

**Values**

- Drive
- Commitment
- Daring
- Cohesion

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1. Year 2013/generating capacity and employees at mid-2014
2. Electrabel share
Electrabel is Belgium’s biggest energy company. It is part of the GDF SUEZ Group, a global leader in energy.

Electrabel generates electricity using efficient, safe and reliable generating facilities, and also sells and supplies electricity, natural gas and energy services. These activities are optimised by Energy Management & Trading operations on the energy markets.

Electrabel offers its customers efficient and innovative energy solutions and services, which are customised and tailored to their needs.

As major employer and investor, the company delivers a significant contribution to Belgium’s economy and society.

It invests in research and innovation in order to meet the new energy needs and challenges of the future: more sustainable power generation, more rational consumption, a smart grid.

Rooted in the Belgian landscape for over a century, Electrabel fully lives up to its social responsibility, with particular focus on the disadvantaged in society.
Strategic diversification

Electrabel has its own diversified set of generating facilities in Belgium, with a total capacity of 9,020 MW. These consist mainly of high-efficiency natural gas power plants (combined-cycle gas turbines (CCGTs), cogeneration or combined heat and power (CHP) units), high-performance nuclear power plants and facilities powered by renewable energy.

This diverse range of technologies and fuels ensures a stable power supply for customers while respecting the environment.

Small carbon footprint

The carbon footprint of this energy mix, 64% of which emits no CO₂, is very small and among the lowest in Europe.

With its 50 wind farms, hydroelectric power plants, photovoltaic facilities and biomass power plants, boasting a total capacity of 461 MW, Electrabel is the country’s biggest producer of green power. Multiple offshore and onshore projects, currently under development, will further enhance the importance of renewable energy.

Electrabel’s generating facilities emit below-average amounts of CO₂ compared with other European energy producers.
Electrabel has 2.86 million electricity and/or gas customers in Belgium, its historical home market. Its portfolio encompasses all market segments, including residential, professional, SMEs, industry and public bodies.

Innovative solutions and services

As well as offering competitive prices, the company aims to stand out through the quality of its services and its constant customer focus.

Electrabel constantly seeks to develop innovative solutions and services to reduce energy consumption and the ecological footprint. Its offer ranges from eco-energy products and applications through to green energy and sustainable mobility.

The company is committed to staying close to its customers. To meet their expectations, it offers easy access via multiple channels: single points of contact for businesses, a dedicated contact centre in Belgium, a website with personalised access, a network of authorised partners, and so on.

Consumers are always looking for innovative ways to save energy. Electrabel’s Smart range taps into this need: [www.electrabel.be/smart](http://www.electrabel.be/smart)

Watt Watchers

With over 26,000 fans, Electrabel’s Watt Watchers Facebook platform has become the community for people looking to optimise their energy consumption and share tips and advices.
There are currently 436 nuclear reactors operating in 30 countries worldwide. They account for 1/8th of the electricity generated in the world. (IAEA, July 2014)
In the 1960s, Belgium opted to generate part of its electricity from nuclear power: consumption was increasing steadily and significantly and fossil fuels could no longer provide the only viable option for meeting energy demand.

This policy resulted in the construction of four nuclear reactors at Doel and three at Tihange.

The order to build Doel 1 and 2 came in 1968. An ideal site was chosen, close to the village of Doel on the left bank of the Schelde river, which offered a plentiful supply of cooling water.

Work began with the filling-in of 80 hectares of polders. The dikes were raised to a height of 11 metres above sea level.

The proper construction work began in 1969, and the first staff were hired in 1970. The Doel 1 reactor was commissioned in early 1975. Meanwhile, the construction of Doel 2 was making good progress and the plant was officially ready for service by the end of that year. In late 1974, work began on Doel 3, which came online in autumn 1982. Doel 4 was completely ready by summer 1985.

Did you know?

Following a decision by Belgium’s federal parliament, the Doel 1 and 2 reactors are due to be decommissioned in 2015, after 40 years of service. The closures of Doel 3 and Doel 4 are scheduled for 2022 and 2025 respectively.
WHAT ARE THE ADVANTAGES OF NUCLEAR ENERGY?

The use of nuclear energy to generate electricity is a key factor for energy supply.

Nuclear power offers a number of benefits, both economic and energy-related, as well as in terms of CO₂ reduction:

- it enables electricity to be generated 24 hours a day, virtually 365 days a year;
- it reduces reliance on major suppliers of fossil fuels (oil, coal, natural gas);
- it slows the depletion of fossil fuels;
- it is currently one of the cheapest sources of power generation in Belgium;
- it enables large volumes of electricity to be generated without emitting CO₂;
- it limits the need to import electricity;
- it creates a large number of jobs, both direct and indirect.

Did you know?
Since the mid-1990s, peregrine falcons have been nesting on one of Doel’s cooling towers. The birds of prey use those towers as an alternative nest site to cliffs, their natural habitat.
Did you know?

69% of the electricity generated by Electrabel is free of CO₂ emissions. This is due in no small part to nuclear power plants.
How is electricity generated?

In a power plant, electricity is generated by a series of energy transformations. The burning of fuel (chemical energy) or the nuclear fission (nuclear energy) releases heat (thermal energy) which transforms water into steam. This steam drives a turbine (mechanical energy), which turns a generator. The generator transforms the mechanical energy into electrical energy.

The operating principle of a nuclear power plant is essentially very similar to that of a conventional thermal power plant. Whereas in a thermal power station heat is produced by burning coal, gas, biomass, etc. in a boiler, in a nuclear power plant the heat is generated by a process of nuclear fission inside a reactor.

Nuclear fission: transformation of nuclear energy into thermal energy

All matter consists of atoms comprising a nucleus around which electrons gravitate. The nucleus itself is made up of protons and neutrons.

In a nuclear reactor, thermal energy is released by splitting apart heavy atoms, such as those of uranium, in a process known as fission.

This fission reaction is brought about by bombarding the uranium nuclei with neutrons moving at the right speed.

Every time a nucleus undergoes fission, it releases two or three neutrons. These in turn can cause additional fissions, thereby triggering a chain reaction.

Because the chain reaction needs to be controlled, each fission must only cause one additional fission brought about by a new neutron.

Consequently, the surplus neutrons released inside the reactor have to be eliminated. By adding boric acid to the water circulating inside the reactor (primary circuit water) and inserting control rods into the reactor, it is possible to absorb the surplus of neutrons and so control the reaction. Lowering all the control rods into the reactor simultaneously halts the reaction within 1.3 seconds.

1. Pressurized Water Reactor
It creates a fission reaction that releases energy in the form of heat and radiation. This results in fission products as well as new neutrons that will collide with other uranium nuclei to produce a chain reaction.

The water present in the reactor basin acts as a speed moderator, slowing the neutron down to enable it to reach the nucleus.

A neutron.

The neutron hits the nucleus of a uranium atom.

The total fission of 1 kg of uranium-235 provides 3,000,000 times more thermal energy than burning 1 kg of coal.

3 million
Operating principle of PWR reactors

A PWR nuclear power plant such as Doel has three water circuits, each entirely independent from the others. Almost two-thirds of the world’s reactors are of this type.

Did you know?

There are several types of nuclear reactors, including:
- PWR: pressurised water reactor (Doel)
- BWR: boiling water reactor (Fukushima)
- RBMK: pressurised light water-cooled reactor graphite-moderated (Chernobyl)

The water and steam in the secondary circuit never come into contact with the primary circuit water.
Fuel

Doel power plant uses uranium as its fissile material. Uranium occurs naturally in the form of three isotopes: 99% as uranium-238, 0.7% as uranium-235 and a tiny fraction as uranium-234.

The nucleus of uranium-235 is fissile, whereas that of uranium-238 is not. The uranium extracted from mines is therefore enriched to obtain a quantity of approximately 4% uranium-235: this is the ideal concentration for maintaining a chain reaction in a PWR.

Reactor: heat production

The reactor consists of a large vessel made of thick steel. This houses the fuel rod assemblies, which are filled with small pellets of uranium oxide. The rods are meshed together to form assemblies, which are placed vertically in the reactor.

The heat released by the fission of uranium nuclei is transmitted to the primary circuit water. The water is brought to a very high temperature – over 300°C – but does not boil and does not turn into steam because it is kept at a high pressure of around 155 bar by a pressuriser (hence the name pressurised water reactor).

Did you know?

After four years, the useful energy in the nuclear fuel is exhausted and the fuel is replaced.

1. Isotopes are elements with the same chemical characteristics but a different atomic mass: they have the same number of protons but a different number of neutrons.
Steam generators: heat exchangers

The hot water in the primary circuit is conveyed to a heat exchanger called a steam generator. This is a cylindrical tank containing thousands of inverted U-shaped tubes. The water transits inside these tubes and transmits its heat to the secondary circuit water circulating along the outside of the tubes. It heats up and turns into steam, which will power a turbine coupled to a generator.

Following the transfer of thermal energy in the steam generator, a primary pump transports the primary circuit water in a closed loop back to the reactor.

Steam turbine: from heat to mechanical energy

The steam leaving the steam generators powers one or more steam turbines, made up of a series of blades mounted on a shaft. The pressure of the steam hitting the blades causes the shaft to rotate at high speed.

Steam turbines consist of a high-pressure chamber followed by several low-pressure chambers. The steam therefore expands in successive phases.

In the high-pressure chamber, the steam pressure drops from around 60 bar to approximately 10 bar. It then expands in the low-pressure chamber to reach a pressure of around 0.05 bar at the outlet.
Generator: from mechanical energy to electricity generation

Finally, a generator coupled to and powered by the turbine generates electricity. The generator consists of a rotor rotating inside a fixed stator. The rotor is an electromagnet which is excited by a direct current. The stator consists of a static cylinder with copper windings, in which a three-phase alternating current is generated by the rotation of the rotor.

The rotors turn at a constant speed of 1,500 rotations per minute in order to produce a continuous exact net frequency of 50 Hz.

Transformers

To minimise losses during transmission of the power to users, transformers step up the generator output voltage to 380 kV. The power is conveyed to consumers on the grid at the required voltage thanks to transformer substations.
Condenser and cooling tower: cooling in a closed circuit

The condenser is a heat exchanger consisting of thousands of tubes through which flows the tertiary circuit cooling water taken from an external source – the river Schelde in Doel. The steam leaving the turbine passes between these tubes, transfers its heat to the cooling water, cools and turns into water. It can then return to the steam generator where it is reheated into steam.

The cooling water heated in the condenser is conveyed to a cooling tower where it is cooled through contact with an upward air flow (natural draught effect). The majority of the water is collected in basins situated at the base of the tower and returned to the condenser. Only 1.5% evaporates to form a steam plume that escapes from the top of the tower.

Control room

The control room is the nerve centre of the nuclear power plant. From here, operators monitor, control and manage all of the plant’s facilities, 24 hours a day. Start-ups, shutdowns and power modulations are centralised in the control room. It is also the place from which appropriate measures are coordinated in the event of an incident.
OPERATIONAL SAFETY, A CONSTANT PRIORITY

Nuclear safety encompasses all the steps taken to ensure that the power plant’s operations have no harmful impact on people and the environment. It also safeguards the long-term operation of the facilities.

From the design and construction phase, every effort is made to prevent significant quantities of radioactive material from coming into contact with the environment.

**Redundancy principle**

Moreover, the design of the plant takes account of possible equipment failure. Safety-critical equipment therefore exists in duplicate, at least. This is known as the redundancy principle: it prevents the failure of one component from compromising the safety of the plant.
Five containment barriers

A series of five successive containment barriers completely isolate the uranium and the highly radioactive fission products.

1. The uranium oxide is compressed into pellets.
2. The pellets are then packed into hermetically-sealed fuel rods.
3. These rods are then assembled into fuel elements and placed in the reactor vessel, whose steel wall is 25 cm thick.
4. A first inner containment prevents any radioactivity from being released outside the reactor building; it can withstand significant internal pressure.
5. A second outer containment made of reinforced concrete protects the facilities from external accidents. It is designed to cope with multiple incident and accident scenarios, such as explosion, fire, flooding, earthquake and impact of an aircraft. Under-pressure between the two containments ensures that there is no uncontrolled release of radioactivity into the environment.

The fuel is encased five times to prevent the release of radioactivity.
The human factor

The day-to-day operation of Doel power plant is undertaken by highly qualified personnel. Staff working in the control room must have a special licence (renewed every two years) proving their ability to run the plant. This licence is issued after a specific and intensive training program, as well as extensive simulator training, and after successfully passing an exam in the presence of an independent supervisory body. In addition, these staff members must undergo regular medical checks to prove their physical condition.

Every year, internal and external emergency plan exercises are organised with the involvement of the power plant’s personnel.
Staff from the many outside companies working at Doel must also undergo training to ensure that they meet the same basic knowledge requirements as the Doel’s personnel.

**Ten-yearly safety reassessment**

In addition to ongoing internal controls and regular reviews, a reassessment of the safety level is carried out every 10 years, in accordance with the operating licence.

**External audits**

Belgium’s nuclear facilities are subject to external audits carried out by the Federal Agency for Nuclear Control (AFCN/FANC) and its subsidiary Bel V.

Internationally, the nuclear industry is amongst the most heavily regulated of all sectors.

Doel nuclear power plant has its own training centre, including a full-scope simulator which can exactly replicate all aspects of the plant’s operation, down to the smallest detail.

The International Atomic Energy Agency (IAEA) and the European Atomic Energy Community (EURATOM) see to it that nuclear facilities are safe and that atomic energy is used exclusively for peaceful ends.
Humans are continually exposed to ionising radiation emitted by natural sources. The main sources are soil, building materials, foodstuffs and the cosmos.

Ionising radiation is also generated artificially, for example through the use of radioactive sources in medicine (such as X-rays) or in industry, or through electricity generation at nuclear power plants. The fission of an atomic nucleus into multiple fragments in a nuclear reactor not only produces heat but also gives off ionising radiation.

What is ionising radiation?

Ionising radiation is a form of energy emitted by a radioactive element. If it comes into contact with matter (air, water, a living organism), ionisation may occur. This may be harmful to the health of living beings because, at high doses, it can cause irreversible damage to body cells.

Measuring radiation

The unit of measurement of radioactivity is the becquerel (Bq). A quantity of matter in which one atomic nucleus desintegrates per second, i.e. changes in structure, has an activity of 1 Becquerel.

Another unit used to measure the radiation energy absorbed by living tissue, taking into account the degree of harm caused to the body by the radiation, is the sievert (Sv). As a sievert represents quite a large dose, the millisievert (one-thousandth of a sievert, mSv) or microsievert (one-millionth of a sievert, µSv) are often used as units.

Given the risk to health, statutory regulations on radiation are extremely strict. An ‘ordinary’ citizen may receive a maximum dose of 1 mSv of radiation per year. In an occupational setting, the legal norm is 20 mSv in any 12-month period and 100 mSv over a five-year period.

1. Ionisation is the process by which an atom (or molecule) loses or gains a charge, making it no longer electrically neutral. It is then known as an ion.
For its staff, Doel power plant applies target values below the legal limit:

- **10 mSv** whole-body dose/12-month period (dose absorbed at Doel power plant)
- **18 mSv** whole-body dose/12-month period (including doses absorbed at other facilities)

Source: www.dbcp.gov.hk
MANAGING RADIOACTIVE WASTE

Operating activities at a nuclear power plant generate radioactive waste, i.e. waste containing substances that emit ionising radiation (radionuclides). Such waste is grouped into classes according to its lifetime (after a certain time radionuclides lose their radiation energy) and level of radioactivity.

- **Class A** comprises low- and intermediate-level short-lived radioactive waste (half-life of less than 30 years). Examples include working clothes, gloves, safety footwear, masks, filters and laboratory waste.

- **Class B** consists of low- and intermediate-level long-lived radioactive waste (half-life of more than 30 years). Most of this waste comes from the manufacture, examination and reprocessing of fissile material, as well as filters and resins from primary circuit purification systems.

- **Class C** comprises highly radioactive waste. The majority of such waste comes from the reprocessing of spent fuel. It requires the greatest protection during removal, treatment and storage.

In Belgium, the National Agency for Radioactive Waste and Enriched Fissile Material (ONDRAF/NIRAS) and its subsidiary Belgoprocess are responsible for the management of radioactive waste originating from nuclear power stations, industrial and medical applications and research centres.

In 2006, the Belgian government decided that low-and intermediate-level short-lived waste should finally be disposed of above-ground in the municipality of Dessel. In 2013, ONDRAF/NIRAS requested permission for permanent storage of this class A waste.
Low- and intermediate-level radioactive waste

Electrabel has its own facilities on the power plant’s site for treating much of the waste it generates. Low- and intermediate-level liquid and solid waste is processed in the on-site effluent and waste treatment building. Water filters, low-level radioactive resins and sludge are stabilised in concrete in special barrels. The waste forms a compact whole with the concrete. This method of immobilising waste is called ‘conditioning’. The barrels are stored temporarily on-site before being transferred to Belgoprocess.

Solid compressible waste is compacted and removed for subsequent treatment at Belgoprocess. Another waste processing method is shredding. The shredded waste is then burnt in a specially designed incinerator at Belgoprocess. Low-activity liquid waste is treated and reused where possible, discharged after treatment or conditioned by evaporation for subsequent treatment.

Limiting the amount of low- and intermediate-level radioactive waste is an ongoing objective at Doel nuclear power plant. However, the quantities depend on scheduled maintenance activities and projects. In 2013, 125.9 m³ of low- and intermediate-level radioactive waste was produced at Doel.
Did you know?

SCK•CEN is conducting research with ONDRAF/NIRAS into the feasibility of burying highly radioactive waste in deep layers of clay. To assist with this research, the HADES underground laboratory has been built in Mol at a depth of 225 m.

Highly radioactive waste from spent fuel

When the fuel is removed from the reactor after 48 or 54 months, it has only released part of its energy. The spent fuel is first cooled in a deactivation pool and then transferred in containers to the on-site fuel storage building, pending a decision by the authorities on the status of spent fuel, i.e. whether it should be reprocessed or disposed of as radioactive waste.

In 2013, 32 nuclear fuel assembly elements were permanently discharged at Doel.
Environmental statement

Every year, Doel power plant issues an EMAS (Eco-Management and Audit Scheme) environmental statement containing the plant’s environmental results, including waste production and management. This report is available on the Electrabel website and can be obtained upon request from Doel power plant.
Doel power plant key figures

• Site: 80 hectares

• 4 nuclear reactors
  commissioned in 1975 (Doel 1 and 2), 1982 (Doel 3) and 1985 (Doel 4)

• Total capacity: 2,911 MW
  • Doel 1: 433 MW
  • Doel 2: 433 MW
  • Doel 3: 1,006 MW
  • Doel 4: 1,039 MW

• Annual generation
  21 billion kWh, equivalent to around 30% of Belgium’s power generation

• Employees
  • 900 direct
  • 665 indirect (average)

Doel nuclear power plant
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