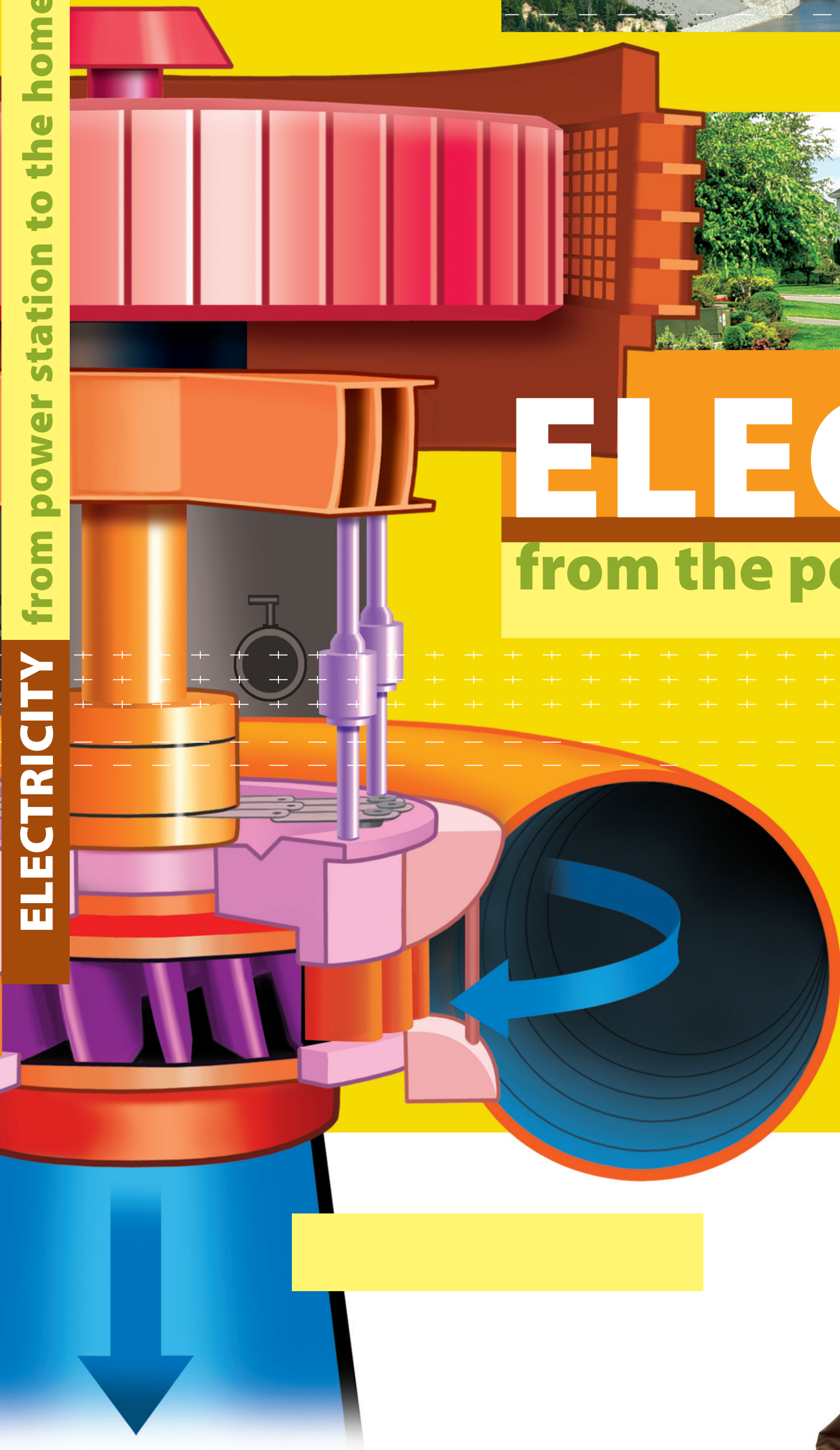
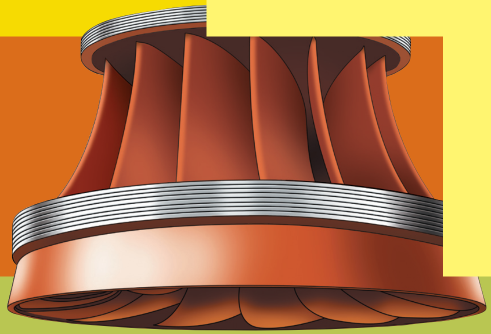


ELECTRICITY

from the power station to the home

ELECTRICITY from the power station to the home

Hydro Québec



Note: The figures and illustrations in this document are simplified representations designed to help the reader better understand certain concepts. They do not necessarily reflect the actual technical aspects of the phenomenon or equipment being discussed.

H_2O

"When water is harnessed with patience, skill and respect, it is indeed a precious and inexhaustible natural resource."

– Antoine de Saint-Exupéry,
French author and aviator

Electricity captures our imagination and leads us on a fascinating journey. Unexpected turning points, incredible vistas and many surprises await the reader of this guidebook. Welcome to an overview of our understanding of electricity, where you'll discover the world of electric power, including Québec's hydroelectric resources. Electricity, from the power station to the home … an energizing learning experience brought to you by Hydro-Québec.

Electricity travels thousands of kilometres

Contents

from the power station to the home!

question://

WHAT IS ELECTRICITY?

answer://

Electricity is an invisible phenomenon created by the movement of electrons in a conductor. This seemingly simple explanation leads us to a whole world of possibilities … and unknowns! Curiously enough, it is a challenge to define electrical energy. However, we understand its properties, how to generate it and transmit it from point A to point B and, especially, how to use it.

V
Volt

A
Ampere

Ω
Ohm

W
Watt

V / Volt, Standard unit for measuring the force of electricity, or voltage. Named after *Alessandro Volta*, inventor of the battery.

A / Ampere, Unit for measuring the amount of electric current. Named after *André-Marie Ampère*, the French inventor of the galvanometer.

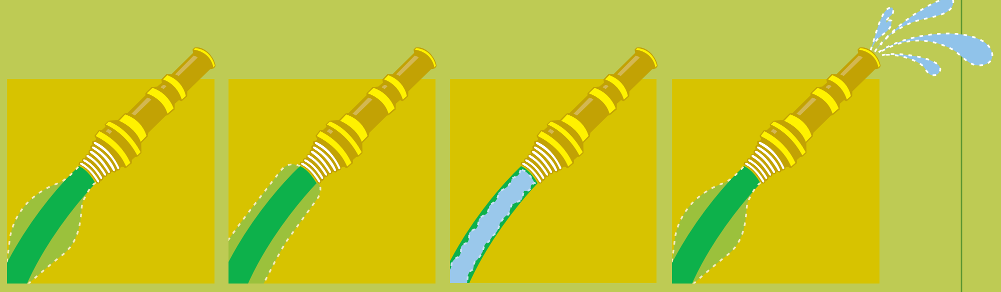
Ω / Ohm, Unit for measuring the resistance of a substance through which electricity flows. Named after *Georg Simon Ohm*, the German physicist and author of the law of electricity that bears his surname.

W / Watt, Standard unit for measuring power, including that of alternating current. Named after the Scottish inventor *James Watt*, renowned for his improvements to the steam engine.

Measuring electricity

An electric current can be compared to the water flowing through a hose. The pressure inside the hose, or the force with which the water flows, is like voltage (V). The hose's discharge, or the amount of water flowing, is like current intensity, measured in amperes (A). Friction along the hose's inner wall is similar to resistance (Ω). Power is what is produced by multiplying voltage by intensity, and is expressed in watts (W). Consumption is expressed in watthours (Wh) and indicates the energy used by a system or device over a given period of time.

Figure 1 – **Similarities between the water in a hose and an electric current**

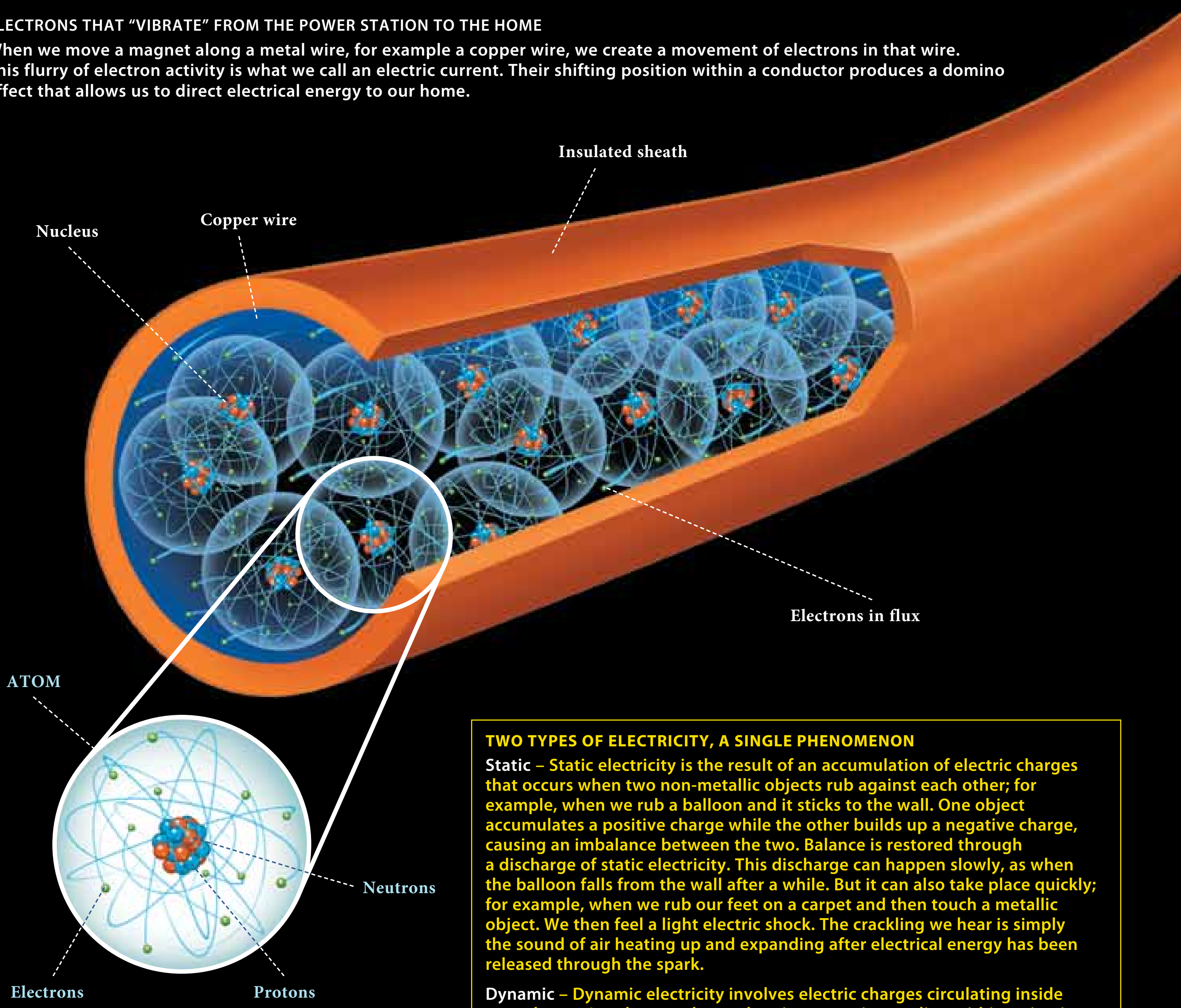


Pressure = Volt | Discharge = Ampere | Friction = Ohm | Pressure x Discharge = Watt

Figure 2 / Electrons in motion

ELECTRONS THAT "VIBRATE" FROM THE POWER STATION TO THE HOME

When we move a magnet along a metal wire, for example a copper wire, we create a movement of electrons in that wire. This flurry of electron activity is what we call an electric current. Their shifting position within a conductor produces a domino effect that allows us to direct electrical energy to our home.



At the atomic level

To better understand electricity, we must consider what happens at the atomic level. Air, water, living beings and matter are all made up of tiny atoms. To give you a sense of scale, the width of a single hair is equal to over a million atoms side by side! Atoms have a nucleus surrounded by electrons. An electron is a particle of negative energy that turns around its nucleus, as satellites do around the earth. The electrons of certain materials, such as copper, aluminum and other metals, can easily leave their orbit; these materials are called conductors. The electrons of other substances, like ceramics, cannot escape from their orbit; they are called insulators.

TWO TYPES OF ELECTRICITY, A SINGLE PHENOMENON

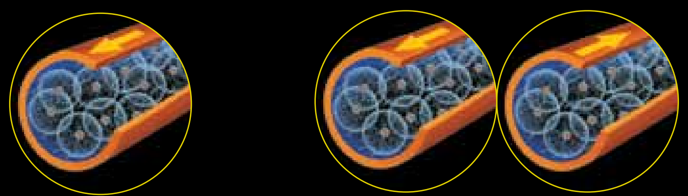
Static – Static electricity is the result of an accumulation of electric charges that occurs when two non-metallic objects rub against each other; for example, when we rub a balloon and it sticks to the wall. One object accumulates a positive charge while the other builds up a negative charge, causing an imbalance between the two. Balance is restored through a discharge of static electricity. This discharge can happen slowly, as when the balloon falls from the wall after a while. But it can also take place quickly; for example, when we rub our feet on a carpet and then touch a metallic object. We then feel a light electric shock. The crackling we hear is simply the sound of air heating up and expanding after electrical energy has been released through the spark.

Dynamic – Dynamic electricity involves electric charges circulating inside a conductor. In other words, an electric current is traveling within a circuit.

Electricity of electrochemical origin is generated through a chemical reaction that triggers a movement of electrons from the negative to the positive terminal of a battery, for example. This type of current is called *direct current*.

Electricity of electromagnetic origin is generated by the movement of electrons that is triggered when a magnet travels inside a coil of metal wire. In fact, electrons move back and forth between atoms, as the magnet alternately pushes electrons together and pulls them away from one another. This type of current is called alternating current. Magnetism is responsible for generating over 99% of all the electric power used in the world.

Figure 3 – **Direct current and alternating current**



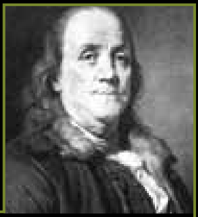
In direct current, electrons move in a single direction.

In alternating current, electrons move in both directions because they are attracted alternately by the north and south poles of a magnet. In fact, alternating current changes direction 120 times per second!

Historical overview of electricity

600 B.C.
Greek mathematician Thales of Miletus discovered that a piece of yellow amber, when rubbed against his tunic, could lift small objects. His description of the phenomenon pointed to the first obvious effects of static electricity. We can trace the origins of the word “electricity” to his observations. Indeed, the Greek word for yellow amber is elektron. However, this discovery remained dormant for nearly 2,000 years.

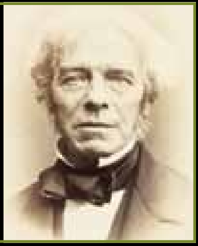
375 B.C.
Chinese general Huang Ti realized that magnetite, a natural magnet, aligned itself with the north and south poles when suspended from a string. He used his invention to lead his army in the right direction over long distances. The general’s discovery led to the creation of the first compass.



1747
American politician and inventor Benjamin Franklin was the first to refer to electricity’s positive and negative charges. A few years later, in 1752, he conducted his famous experiment with a kite during a thunderstorm to prove that lightning is of electric origin. Shortly thereafter, Franklin invented the lightning rod to protect buildings from the devastating effects of lightning.

1800
Italian physicist Alessandro Volta invented the first battery. His device demonstrated that when certain metals come into contact with certain chemicals, an electric current is generated. For the first time, electricity was described as being “in motion.”

1831
British physicist and chemist Michael Faraday discovered the phenomenon of electromagnetic induction. He generated an electric current by moving a magnet back and forth inside a coil of metal wire. The discovery snowballed as the fledgling electricity sector rushed to apply Faraday’s novel ideas to the manufacturing requirements of the industrial age. For example, the first electric generator, predecessor of today’s turbine-generator units, was based on Faraday’s principles. Moreover, Faraday’s experiments allowed other researchers to develop useful inventions, such as the first electric motor and the first transformer, an essential device for the transmission of electricity.



WATER + ELECTRICITY = DANGER

Electricity always takes the shortest path to reach the ground. When a person gets an electric shock, their body becomes that shortest route. Why? The body is made up of approximately 70% water, and water, like metal, is an excellent conductor of electricity. Tree branches can also conduct electricity because they have liquid, or sap, inside. Even low-voltage current can be lethal or very harmful to humans. However, in most cases, electricity-related accidents can be avoided. It’s simply a matter of taking the right precautions.

- Operate all electrical appliances (hair dryer, radio, etc.) as far away as possible from water, whether in the bathroom or near the pool.
- During a thunderstorm, stay away from water and large objects, such as isolated trees and transmission towers. Your best protection against lightning is to remain indoors.
- Always follow the proper safety rules concerning electrical appliances you are using or environments you are entering… When it comes to preventing electricity-related accidents, you can never be too cautious or alert.

Electric eels, *Electrophorus electricus*, which live in South American rivers, produce enough electricity to power a dozen 40-watt lightbulbs.

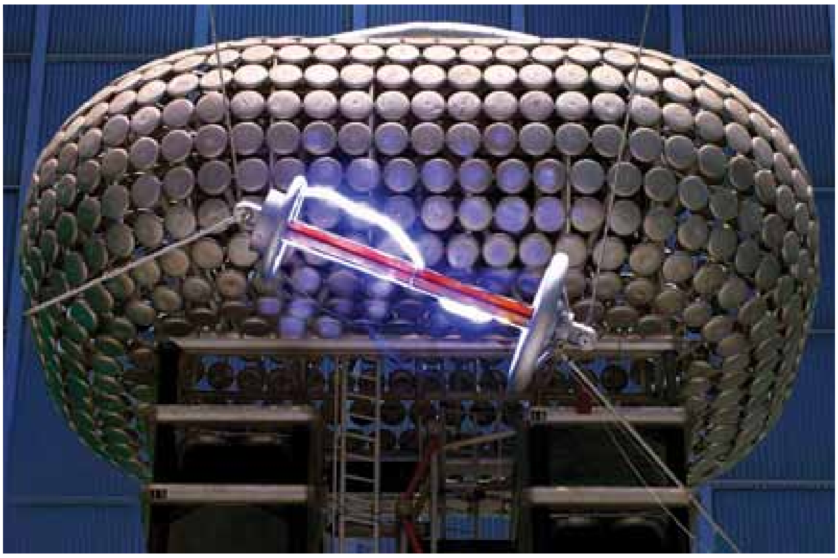
Electric fish

Certain species of fish, such as electric rays, electric eels and electric catfish, have special organs that emit electrical discharges designed to paralyze prey, defend themselves or locate objects.

Electricity in nature

Lightning

Lightning is basically static electricity caused by huge concentrations of raindrops rubbing against each other high up in the sky. Lightning and thunder happen simultaneously, but lightning travels near the speed of light while thunder moves at the speed of sound, approximately 866,000 times slower than the speed of light, which explains the time delay between the two phenomena.

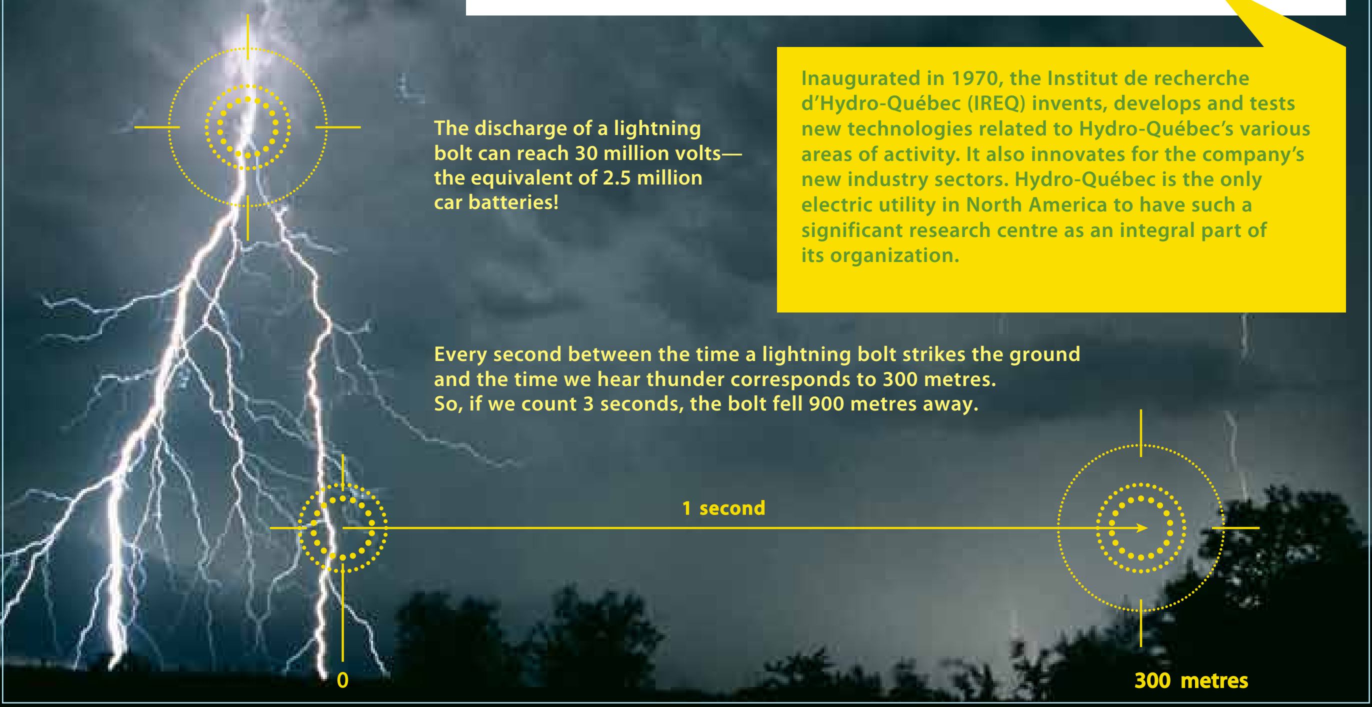


In the vast facilities of Hydro-Québec's research institute (IREQ) at Varennes, lightning can be recreated during high-voltage tests.

Inaugurated in 1970, the Institut de recherche d'Hydro-Québec (IREQ) invents, develops and tests new technologies related to Hydro-Québec's various areas of activity. It also innovates for the company's new industry sectors. Hydro-Québec is the only electric utility in North America to have such a significant research centre as an integral part of its organization.

The discharge of a lightning bolt can reach 30 million volts—the equivalent of 2.5 million car batteries!

Every second between the time a lightning bolt strikes the ground and the time we hear thunder corresponds to 300 metres. So, if we count 3 seconds, the bolt fell 900 metres away.



question://

HOW LONG HAVE WE HAD ELECTRICITY IN QUÉBEC?

answer://

Nearly 125 years have gone by since Quebecers began to enjoy the benefits of electricity. Here are some of the key events that have marked the growth and development of electricity in Québec. Of course, Hydro-Québec is a fundamental part of the history of electric power in this part of North America.

1879 – PUBLIC DEMONSTRATION OF THE ARC LAMP IN MONTRÉAL

On May 16, 1879, there was a public demonstration of the arc lamp at Montréal's Champ-de-Mars. According to the following day's edition of the newspaper La Minerve, several thousand spectators expressed their satisfaction. Later that year, American inventor Thomas Alva Edison improved the incandescent lamp, which he marketed successfully 10 years afterwards.

1889 – ELECTRICITY OVERTAKES GAS!

In the streets of Montréal, electricity finally succeeded in replacing gas as the method of choice for public lighting. By 1889, electric streetlights could be found all over the city.

1892 – ELECTRIC STREETCARS MAKE INROADS IN MONTRÉAL

The city saw its first electric-powered streetcars, which replaced horse-drawn streetcars that had existed in Montréal since 1861. Other cities in Québec also adopted this type of public transit, including the cities of Québec, Trois-Rivières and Sherbrooke.

Archives de la STM.

1901 – EMERGENCE OF A POWERFUL MONOPOLY: MONTREAL LIGHT, HEAT AND POWER COMPANY

The merger of the *Montreal Gas Company* and the *Royal Electric Company* laid the groundwork for what would become a vast industrial and financial empire: the *Montreal Light, Heat and Power Company*. The company sought to tap into the immense potential for expansion offered by the electricity market. It consistently refused any form of cooperation with commissions of inquiry and agencies established by the government in an effort to regulate the sale of electricity.

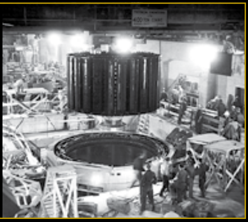
1908 – UNDERGROUNDING AND URBAN AESTHETICS

A growing number of companies tried to carve out a place for themselves in the lucrative public lighting market. More and more electric wires crossed overhead, and the Montréal cityscape grew increasingly ugly. Influenced by climate and urban aesthetics, Montréal became one of the first cities in North America to adopt a policy of undergrounding—burying power lines, a practice that improved the city's appearance and protected the distribution grid against bad weather.

A brief history of Hydro-Québec

1953 – FIRST MAJOR PROJECTS

Hydro-Québec undertook to develop the Rivière Betsiamites, in the Côte-Nord region. This first remote site servedto build two hydroelectric generating stations, Bersimis-1 and Bersimis-2. The project showcased innovative engineering, as Hydro-Québec improved and implemented 315,000-volt transmission line technology, a world first.



1944 – BIRTH OF HYDRO-QUÉBEC

Electricity companie were prospering but their public image was tarnished. Politicians and academics alike strongly denounced abuses perpetrated by the utilities: high rates, poor service, exorbitant profits, arrogance in the face of government attempts to regulate the sale of electricity. On April 14, the Québec government passed a law that expropriated the electricity and gas assets of the powerful monopoly, Montreal Light, Heat and Power Company Consolidated. Management of these assets was assigned to a provincial government-owned corporation, the Québec Hydro-Electric Commission, later to become Hydro-Québec. The new corporation inherited four hydroelectric generating stations: Chambly, Les Cèdres, Rivière-des-Prairies and Beauharnois, amounting to 696 megawatts of installed capacity.

1959 – BEGINNING OF LARGE-SCALE DEVELOPMENTS

In the fall of 1959, Hydro-Québec announced the start of development of the Manicouagan and Outardes rivers, in Côte-Nord. This hydroelectric project would become the most ambitious ever undertaken in Canada. As it stands today, the Manic-Outardes complex encompasses eight hydroelectric generating stations, one of which required construction of the only dam of its kind in the world. This complex was the setting for another technological feat: 735,000-volt transmission lines capable of delivering high volumes of energy over several hundred kilometres, from these remote generating stations to major urban centres.

1963 – SECOND STAGE OF NATIONALIZATION

On May 1, 1963, Hydro-Québec acquired the last eight private electricity generators and distributors. In its bid to achieve Québec-wide scope, the utility followed with several other offers, accepted by 45 of the 46 electricity cooperatives and by many municipal power system authorities. Suddenly, its generating capacity almost doubled, from 3,700 to 6,200 megawatts, and its customers had access to low, uniform rates throughout Québec. Elsewhere in the world, nuclear power increasingly became the darling of the international energy scene. But Hydro-Québec continued to put its faith in hydropower.

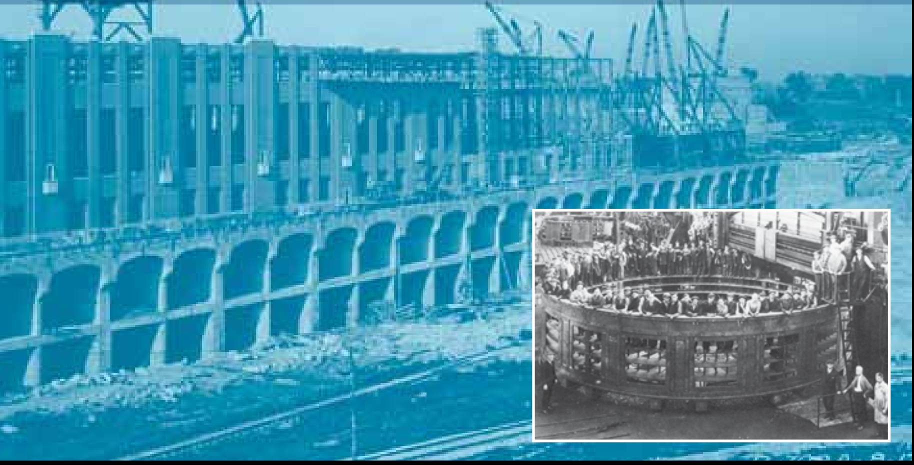
1971 – LAUNCHING THE "PROJECT OF THE CENTURY"

Hydro-Québec began work on the La Grande hydroelectric complex, in the Baie-James region. Project management was entrusted to the Société d'énergie de la Baie James, later to become a wholly owned subsidiary of Hydro-Québec. In 1996, with the commissioning of Laforge-2 generating station, the La Grande complex became the world's largest hydroelectric development. That same year, the La Grande-2 generating facility took on the name of former Québec Premier Robert Bourassa, a strong supporter of electric power derived from Northern Québec's immense water resources.

1929 – BEAUHARNOIS, AN ENERGY MEGAPROJECT ON THE ST. LAWRENCE RIVER

The sheer size of this hydroelectric development defied the imagination. It was often compared to the digging of the Panama Canal. A remarkable achievement in many respects, the construction of Beauharnois generating station, located just 40 kilometres from Montréal, made news around the world.

In 1961, Hydro-Québec commissioned the last of the generating station's 38 turbine-generator units; this phase marked the end of more than 30 years of construction activity. Beauharnois was then considered the most powerful generating facility in Canada. Today, it is still one of the largest run-of-river generating stations in the world.



1975 – SIGNING OF THE JAMES BAY AND NORTHERN QUÉBEC AGREEMENT

Hydro-Québec entered into a landmark accord that established the rights and responsibilities of Aboriginal peoples—Crees and Inuit—and other parties involved, and set guidelines for resource development in Baie-James

2002 – NEW WAVE OF DEVELOPMENT PROJECTS

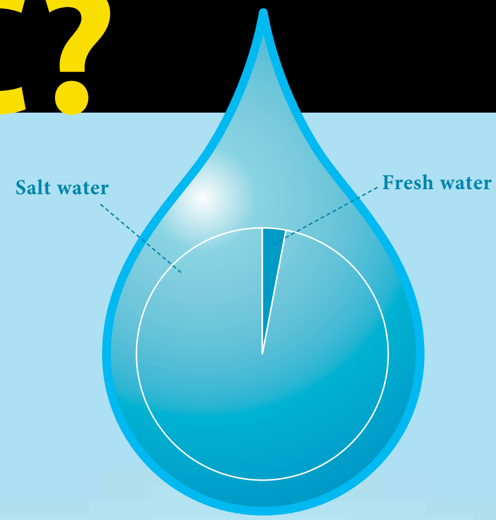
On February 7, 2002, the Québec government and the Grand Council of the Crees signed a historic agreement described as a "Peace Among Braves." The pact paved the way for construction of major new hydroelectric projects in Northwestern Québec, including Eastmain-1 and Eastmain-1-A generating stations.

question://

WHY DO WE USE HYDRO-ELECTRICITY IN QUÉBEC?

answer://

Québec takes advantage of hydroelectric power for three good reasons... There is an abundance of water on its territory. Hydroelectricity is clean energy that has very little impact on global warming. And then there is its efficiency. Indeed, hydroelectric generation entails fewer energy losses compared to other generating options that use different sources of energy.



THE WORLD'S SALT WATER AND FRESH WATER RESERVES

Water is the most abundant substance on earth. It covers three-quarters of the planet. Salt water accounts for 97.5% of total water resources. Of the remaining 2.5%, namely our fresh water reserves, only a third can be put to use.

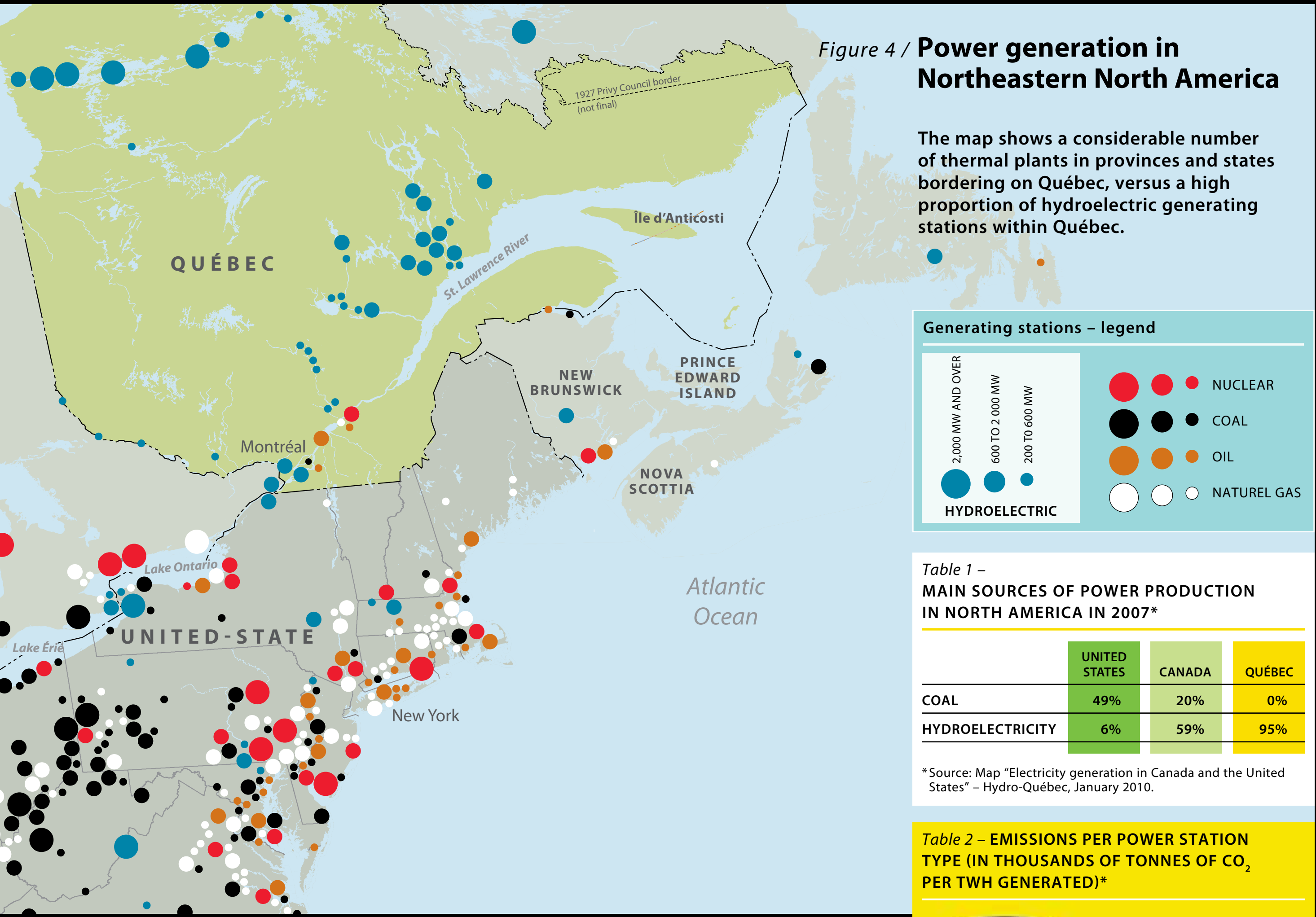


Figure 4 / **Power generation in Northeastern North America**

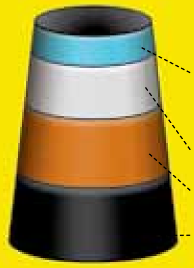
The map shows a considerable number of thermal plants in provinces and states bordering on Québec, versus a high proportion of hydroelectric generating stations within Québec.

Table 1 – MAIN SOURCES OF POWER PRODUCTION IN NORTH AMERICA IN 2007*

	UNITED STATES	CANADA	QUÉBEC
COAL	49%	20%	0%
HYDROELECTRICITY	6%	59%	95%

*Source: Map "Electricity generation in Canada and the United States" – Hydro-Québec, January 2010.

Table 2 – EMISSIONS PER POWER STATION TYPE (IN THOUSANDS OF TONNES OF CO_2 PER TWH GENERATED)*



0	NUCLEAR
15	HYDROELECTRIC (RUN-OF-RIVER *AND RESERVOIR)*
535	NATURAL GAS
748	HEAVY OIL
915	COAL

*Source: Map "Electricity generation in Canada and the United States" – Hydro-Québec, January 2010.

Greenhouse gas (GHG): Gases in the atmosphere that allow the earth to remain warm are called greenhouse gases, or GHGs. Overproduction of these gases accelerates the global warming of our natural "greenhouse" environment, an imbalance that can cause extreme weather events. Carbon dioxide (CO2), one of the main industrial pollutants, is the leading form of surplus GHGs.

Sustainable development: Development that meets the needs of people today without compromising the ability of future generations to meet their own needs.

1

Québec's plentiful water resources

Québec is one of the most water-rich regions in the world. It boasts over 130,000 rivers and streams, and over one million lakes. Over 40% of Canada's water resources are found in Québec. Surface water reserves in Québec (natural lakes and reservoirs) cover approximately 12% of its territory.

2

Low emissions

Energy systems produce high volumes of pollutants, including greenhouse gases (GHGs). However, hydroelectricity is one of the least polluting forms of energy. According to the table above, a hydroelectric generating station produces 94 times fewer GHGs than a coal-fired power plant. Because of its low GHG emissions, hydroelectricity represents an effective solution for preventing climate change while ensuring sustainable development.

3

Superior energy performance

Hydroelectricity, or the transformation of water power into electricity, involves fewer energy losses during the generation process. In comparison, the transformation of fossil fuels, such as oil, natural gas and coal, usually leads to substantial losses in the form of heat. For example, when coal is burned to generate power, two-thirds of its energy is wasted. Water, on the other hand, is used to the last drop, as it pushes against the blades of power station turbines.

Figure 5 / **Hydro-Québec power generation in 2009**

Hydroelectricity

60 hydroelectric generating stations
account for 98% of Hydro-Québec's total energy output.

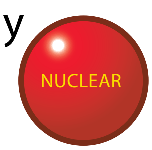
Other means of generation

28 thermal stations and 1 wind-power facility supply the remaining 2%.

THE GREEK TERM **HYDRO** MEANS **"WATER"**

Power generation

A refrigerator hums in the background, a computer screen suddenly comes to life… It all happens thanks to electric power. There is a great demand for it, so power stations must generate large quantities of electricity. Then that power must be delivered to its destination. Electricity is generated on a large scale using different methods, including water. Most high-performance generating stations create electricity by converting the energy of movement, or mechanical energy, into electrical energy.

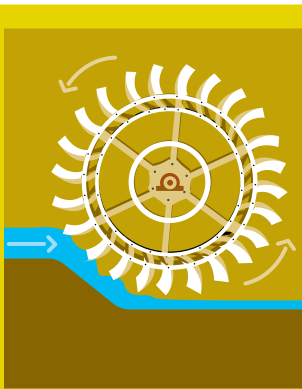


Hydroelectricity, the power of water

In Québec, we use the *driving force of water* to generate most of our electricity. Hydropower is clean, efficient energy that is abundantly available in Québec. What's more, hydroelectricity has the advantage of being renewable. In hydroelectric generating stations, water rushes down to huge turbines, making them turn and drive generators. These systems are called turbine-generator units.

Electricity by other means

Other forces can be used to propel a turbine and generate electricity, such as high-pressure vapor (thermal energy) from burning oil, gas, coal or nuclear fuel. Diesel engines can also make a generator spin. Even the wind and the tides can propel a turbine. Other potential sources of energy exist, notably the sun, geothermal sources (heat energy available in the earth's interior) and biomass (mostly methane derived from the breakdown of organic matter).



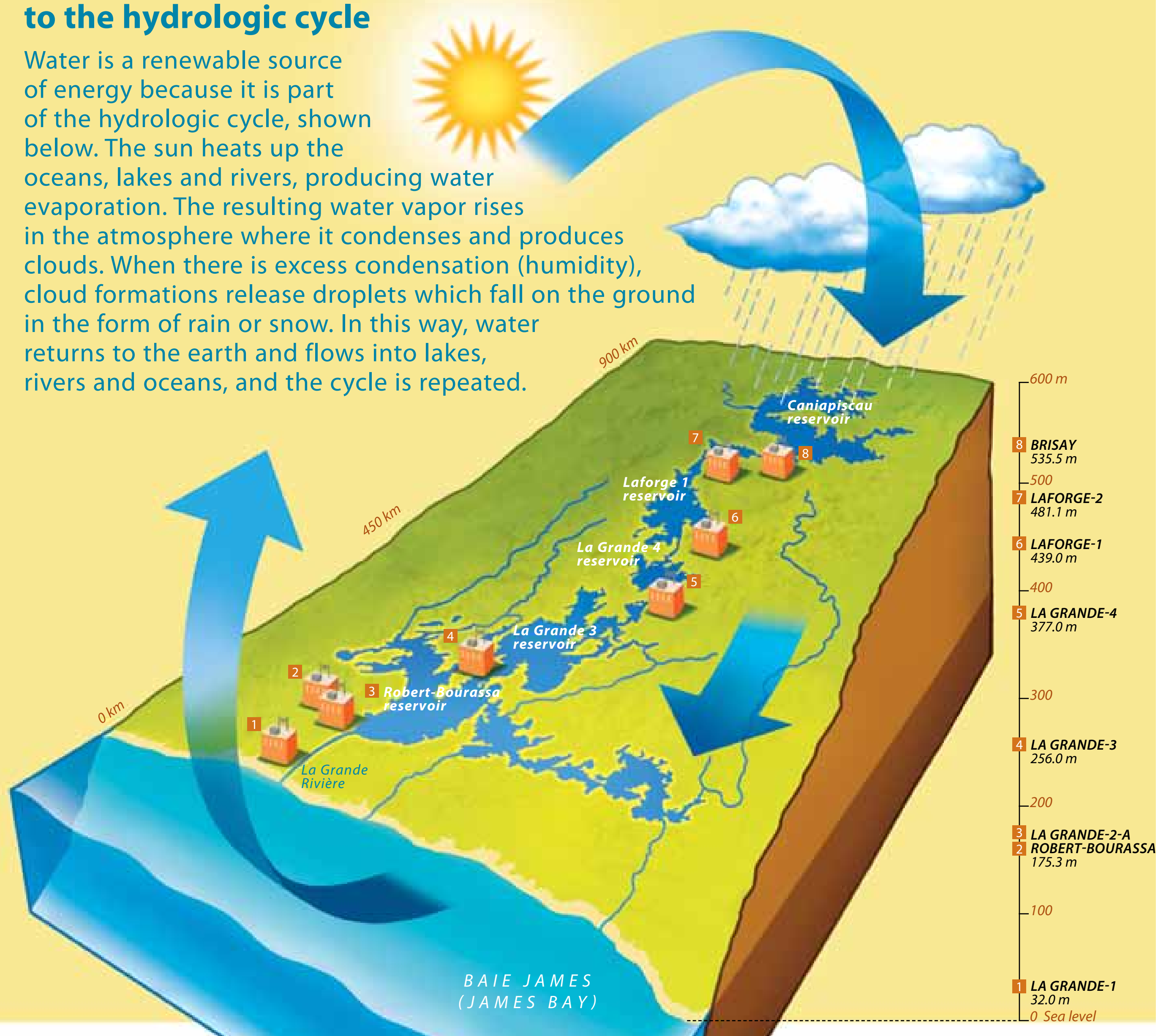
The driving force of water

The *driving* or *impelling* force of water can be converted into mechanical energy. Grain millers were among the first to harness this type of power several thousand years ago. Millhouses built along a river or stream featured a waterwheel that was propelled by the fall of water; in turn, the wheel rotated a millstone that crushed grain to make flour. For water to create a force capable of propelling turbines in a hydroelectric plant, the flow (volume of water running past a given point per unit time) must be strong enough and the head (how far the water falls) must be high enough. The head is the difference in elevation between a point upstream of a power plant (the water intake) and a point downstream (the water outlet). The higher the head, the farther the water falls and the more force it exerts on the turbine's blades. This explains why certain rivers require retaining structures to raise the head substantially.

Figure 6 / **The hydrologic cycle**

Water, a renewable source of energy thanks to the hydrologic cycle

Water is a renewable source of energy because it is part of the hydrologic cycle, shown below. The sun heats up the oceans, lakes and rivers, producing water evaporation. The resulting water vapor rises in the atmosphere where it condenses and produces clouds. When there is excess condensation (humidity), cloud formations release droplets which fall on the ground in the form of rain or snow. In this way, water returns to the earth and flows into lakes, rivers and oceans, and the cycle is repeated.



HYDROGRAPHIC PROFILE OF LA GRANDE COMPLEX

The Grande Rivière, Québec's longest waterway after the St. Lawrence and Ottawa Rivers, is home to Hydro-Québec's most extensive hydroelectric complex. Nearly half of all the electricity generated in Québec comes from the La Grande complex. Eight generating stations are located along this water-resource corridor, two of which are fed from the same reservoir. Rushing downstream through the stations' turbines, the same water is therefore able to generate power seven times before flowing into James Bay.

GMON KNOWS SNOW INSIDE OUT!

Invented at Hydro-Québec's research institute, in collaboration with external partners, the GMON (for gamma monitoring) sensor precisely measures the amount of water contained in snow. Since meltwater can account for 25 to 40% of the water powering generating stations, this technological innovation is a huge asset for Hydro-Québec's hydrology forecasters.

Retaining structures

One of the purposes of retaining structures is to create large bodies of water, or reservoirs, that have a variety of functions, including land irrigation, power generation, water supply and flood control. The retaining structures used to build reservoirs are called dams and dikes. A dam is constructed on the riverbed; it serves to restrict water flow and raise the water level of the resulting reservoir. Dikes are often built to increase a dam's effectiveness by preventing water from leaving the reservoir; for example, by overflowing into secondary valleys.

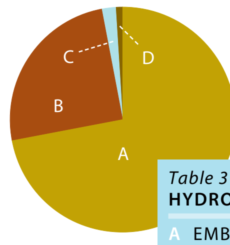


Table 3 /
HYDRO-QUÉBEC DAMS IN 2009

A	EMBANKMENT DAMS (EARTHFILL AND ROCKFILL)	73%
B	GRAVITY DAMS (CONCRETE)	24%
C	TIMBER DAMS	3%
D	ARCH DAMS (CONCRETE)	< 1%

Québec dams

There are close to 6,000 retaining structures of various sizes in Québec. Québec's Ministère du Développement durable, de l'Environnement et des Parcs (Department of Sustainable Development, Environment and Parks) 'owns most Québec dams. Hydro-Québec owns and operates only one out of 10 such facilities. Other dam owners, notably municipalities, outfitters and companies like aluminum smelters, are also involved in dam and dike operation, in addition to water management of the related reservoirs.

DAM INSPECTION

Hydro-Québec continually monitors the state of its facilities. However, certain underwater portions of its dams are difficult to inspect. Visual inspections of these dam facings are carried out by a diver or an underwater robot equipped with a camera.

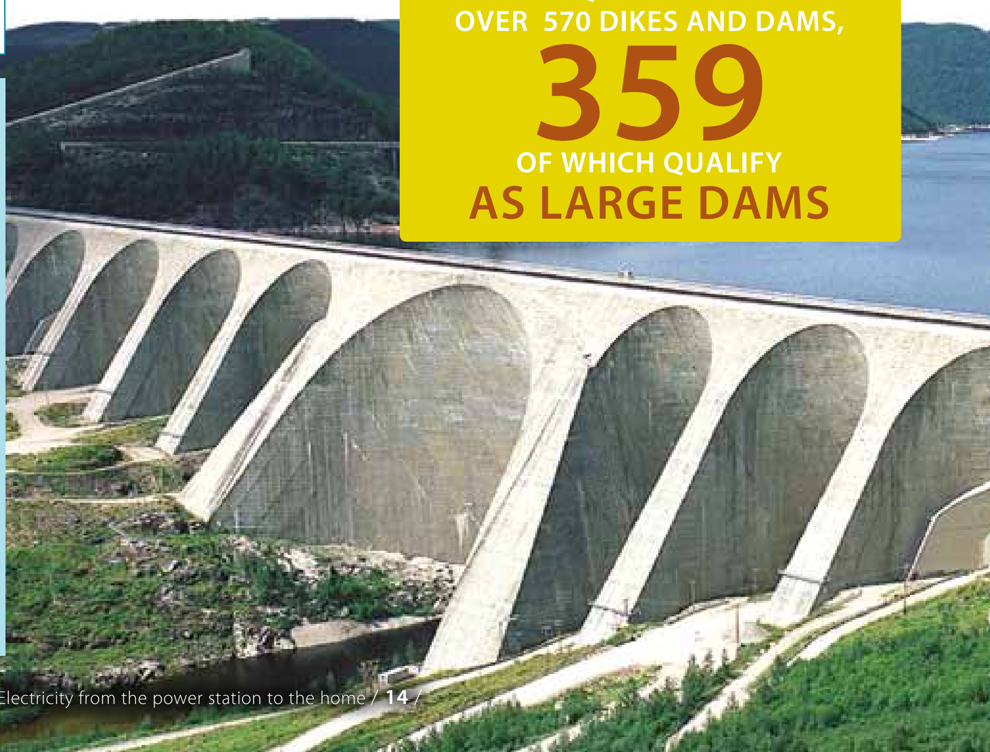
Hydro-Québec divers are sometimes required to perform dam inspections.

Large dams

According to the definition provided by the International Commission on Large Dams (ICOLD), the term "large dam" refers to:

- any dam of over 15 metres in height from the lowest point of the foundation to the crest, or
- any dam between 5 and 15 metres in height with a reservoir volume of more than 3 million cubic metres.

There are about 45,000 large dams in the world. Over half are used exclusively for irrigating agricultural land. About one out of four generate electric power. Of Canada's 793 large dams, just over one quarter are located in Québec.



HYDRO-QUÉBEC OPERATES OVER 570 DIKES AND DAMS, 359 OF WHICH QUALIFY AS LARGE DAMS

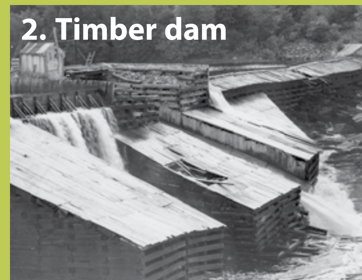
Developed by Hydro-Québec's research institute, MASKI is an underwater robot designed for inspecting submerged structures like Hydro-Québec's dams. It can dive as deep as 270 metres, even in turbid water or whitewater. The MASKI robot is of great help to divers, making their job easier and safer.

Figure 7 / Retaining structures used by Hydro-Québec

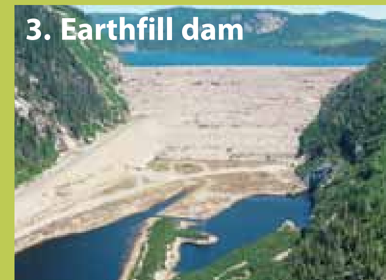
1. Dike

La Grande 4 reservoir is Hydro-Québec's largest dike, stretching over 2 kilometres and extending 92 metres in the air.

2. Timber dam



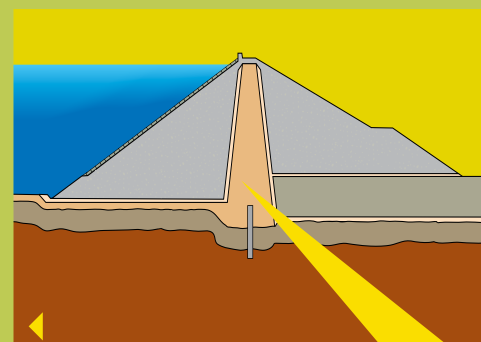
3. Earthfill dam



The storage capacity associated with the rockfill dam at Robert-Bourassa reservoir—61.7 billion cubic metres—ranks 11th in the world.

Rising 171 metres in the air, the rockfill dam at Sainte-Marguerite-3 hydroelectric generating station is the highest dam of its kind in Québec.

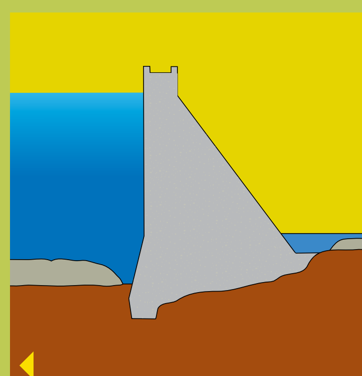
4. Rockfill dam



MORAINE: A CORE ADVANTAGE

Moraine is the perfect material for ensuring the impermeability of a dam. An accumulation of glacial drift, moraine consists of rocks and soil containing fine dust particles produced by debris resulting from glacier movement. It forms the core of most rockfill dams owned by Hydro-Québec, including certain retaining structures of the La Grande complex.

5. Gravity dam (concrete)



DANIEL-JOHNSON DAM: AN ENGINEERING FEAT

This multiple-arch-and-buttress dam is the largest of its kind in the world. Inaugurated in 1969, it was named after Québec's Premier at the time, Daniel Johnson. Its reservoir is four times the size of the Island of Montréal. Its construction, spread over a 10-year period, required 2.2 million cubic metres of concrete, the equivalent of a regular sidewalk linking the North and South Poles. In 2000, Canada Post issued a stamp in honor of this structure, which is used to supply water to Manic-5 and Manic-5-PA power stations.

Asphalt concrete core being built for Nemiscau-1 dam. This technique is well known in Europe, where it is used to make structures watertight when moraine is unavailable. Although there is no lack of moraine in the Nemiscau region, Hydro-Québec wants to master the technique for use in future projects in areas where moraine is scarcer, like around the Romaine complex.

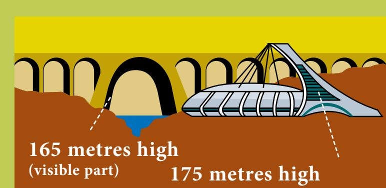


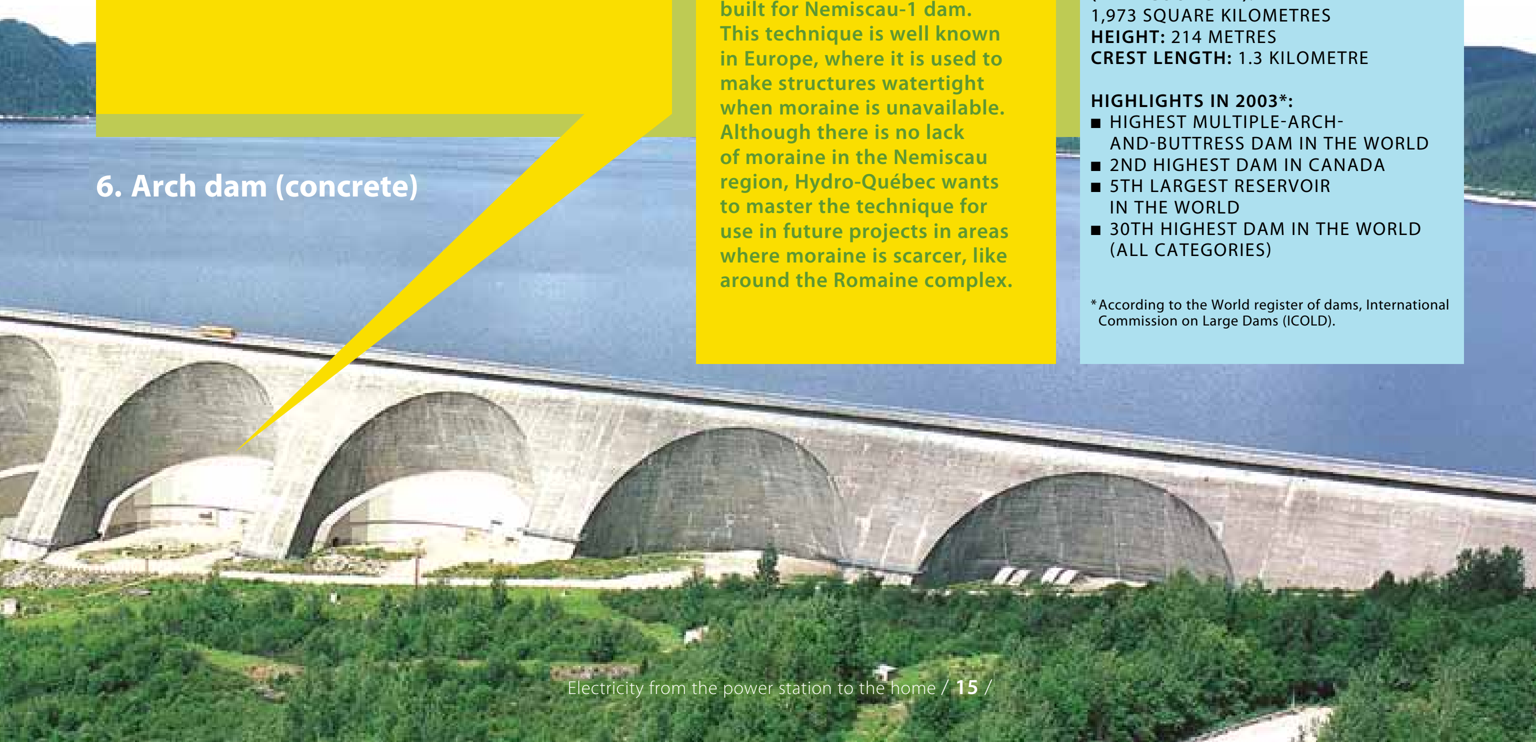
Table 4 /
OVERVIEW OF DANIELJOHNSON DAM, A COLOSSAL STRUCTURE

RESERVOIR SURFACE AREA (MANICOUAGAN): 1,973 SQUARE KILOMETRES
HEIGHT: 214 METRES
CREST LENGTH: 1.3 KILOMETRE

HIGHLIGHTS IN 2003*:
- HIGHEST MULTIPLE-ARCH-AND-BUTTRESS DAM IN THE WORLD
- 2ND HIGHEST DAM IN CANADA
- 5TH LARGEST RESERVOIR IN THE WORLD
- 30TH HIGHEST DAM IN THE WORLD (ALL CATEGORIES)

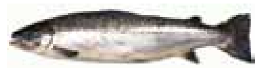
*According to the World register of dams, International Commission on Large Dams (ICOLD).

6. Arch dam (concrete)



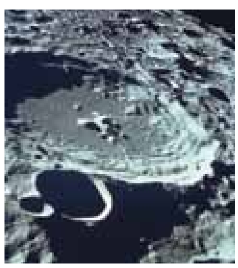
Water management

One of the purposes of retaining structures is to store water. Why build reservoirs to store water? Given that electricity consists of countless electrons in motion, it cannot be stored directly. However, storing water for future use allows utilities to meet the demand for electric power… demand that varies considerably according to the time of day and the season. We store wood in a dry place for the same reason: to be able to use logs when we need them, for example to heat our home.



The ability to turn the tap on and off

In Québec, the demand for electric power is very high on cold winter days and drops significantly during the summer. To ensure a year-round supply of water for its turbine-generator units, Hydro-Québec must effectively manage its water resources, which includes analyzing the impact of precipitation and forecasting future requirements.

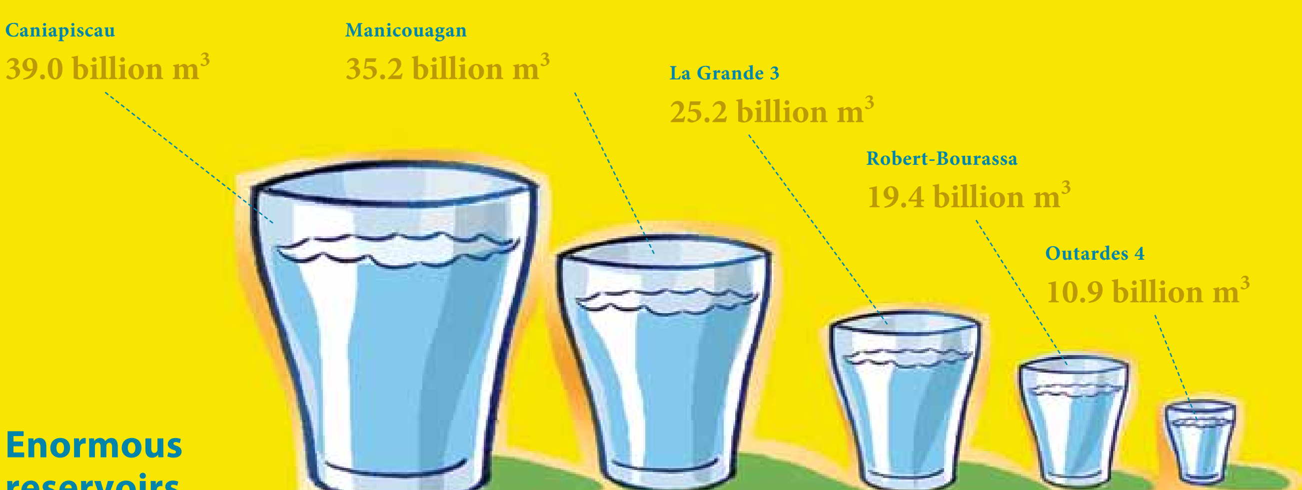



THE MANICOUAGAN RESERVOIR: ORIGINALLY A METEORITE CRATER

About 214 million years ago, a large asteroid fell to earth and created a huge ring-like formation now occupied by the Manicouagan reservoir. The origin of this unusual shape—a meteorite six kilometres in diameter—was determined only after the reservoir had been filled. The depression resembles craters found on the moon and rock samples from the site are similar to those brought back by astronauts.

HYDROELECTRICITY AND NATURE

Managing large bodies of water and harnessing all of a river's energy in harmony with people and nature requires in-depth knowledge of water resources and the environment. Hydro-Québec is keenly aware of the environmental impacts of its projects. Consequently, the company spares no effort to preserve natural habitats, while developing environment-friendly mitigative measures, such as the fish pass for migratory salmon shown above.



Enormous reservoirs of energy

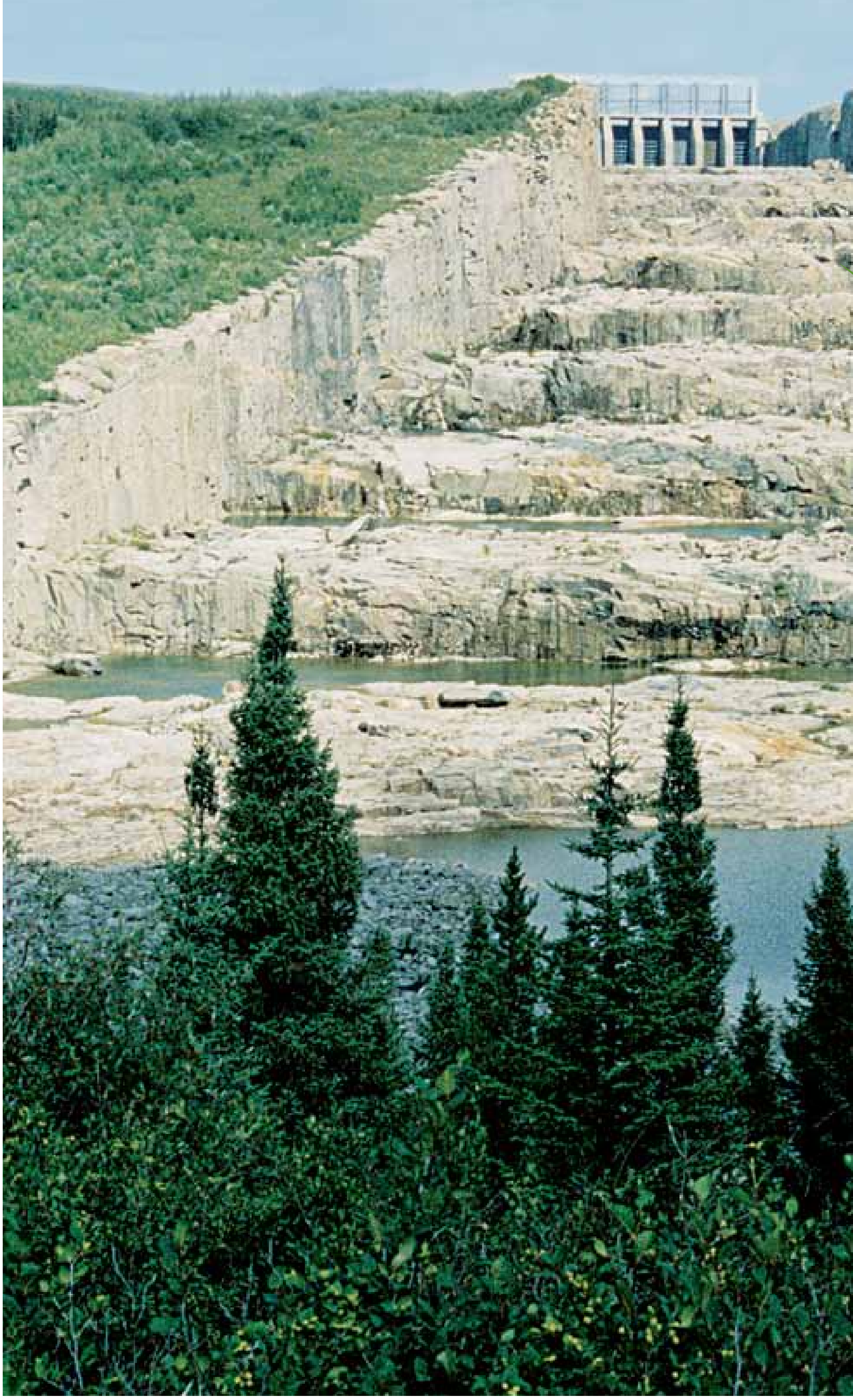
Hydro-Québec owns 26 large reservoirs. Véritables mers intérieures, ils offrent une capacité maximale de stockage de 175 milliards de kWh, soit assez pour combler les besoins de tout le Québec pendant un an.

Table 5 / HYDRO-QUÉBEC'S FIVE LARGEST RESERVOIRS IN 2009

RESERVOIR	HYDROELECTRIC COMPLEX	VOLUME AVAILABLE TO GENERATE ELECTRICITY (IN BILLIONS OF CUBIC METRES – KM^3)	RESERVOIR SURFACE AREA (km^2)
CANIAPISCAU	LA GRANDE	39.0	4,318
MANICOUAGAN	MANIC-OUTARDES	35.2	1,927
LA GRANDE 3	LA GRANDE	25.2	2,536
ROBERT-BOURASSA	LA GRANDE	19.4	2,815
OUTARDES 4	MANIC-OUTARDES	10.9	677

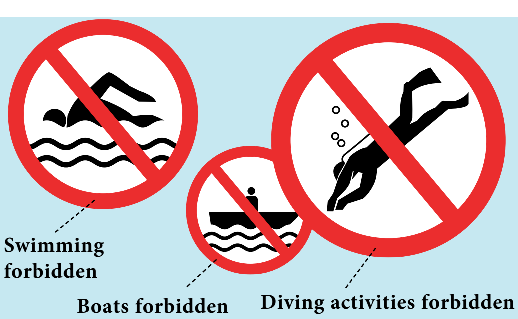
Spillways

Hydroelectric developments include flood-control structures designed to let excess water escape safely from the generating station reservoir. This “safety valve” prevents water from spilling over the dam crest. It takes the form of a spillway, a weir or sometimes a combination of both.



The spillway at Robert-Bourassa dam is called “the giant’s staircase.” The structure is named after its unique shape, which features 10 steps, each 10 metres high and 122 metres wide. The spillway has a discharge capacity of 16,280 cubic metres of water per second, about twice the flow of the St. Lawrence River at Montréal. This phenomenal capacity corresponds to an exceptional flood, likely to occur once every 10,000 years.

Spillways at La Grande-3 and La Grande-4 hydropower stations have a curved design that looks like a ski jump. The upward lip is designed to project the jet of water dozens of metres into the air, which dissipates part of its energy and prevents structural damage.



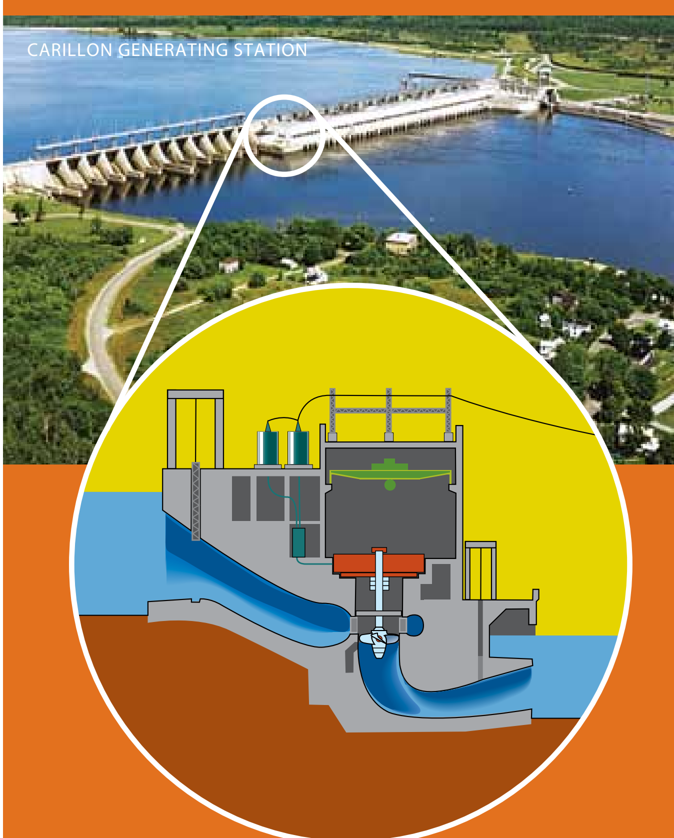
It is very important to follow safety regulations posted near water-control structures—dams, water intakes, generating stations and spillways—whether they are operated by Hydro-Québec or other parties. Even when a body of water appears still, danger may lurk below. Turbulence and strong suction can pull swimmers and boaters underwater. As well, the flow can increase suddenly with the operation of turbine-generator units or the opening of dam or spillway gates, depending on the particular action required at the power station.

Hydroelectric generating stations

A hydroelectric generating station is a plant that produces electric power by using water to propel turbines, which, in turn, drive generators. These power stations generate about a quarter of all the electricity used in the world. With its 51 hydropower stations and access to vast water reserves, Hydro-Québec uses water to generate almost all of its energy output—97% in 2002. In this way, the company contributes to reducing greenhouse gas emissions.

Run-of-river generating station

A power station fed by a river directly. It has little or no water storage capacity. Its head is usually not very high, so its generating output will depend on the flow of the river.



Generating station with reservoir

A power station supplied by the water that accumulates in a reservoir created by building a dam It is either underground or at the surface of the water, and its head is generally high. Since the amount of water intake from the reservoir can be regulated, this type of hydropower station offers increased flexibility in meeting variations in electricity demand.

PUMPED-STORAGE PLANT

This type of power station has two reservoirs. When demand is low, it drives turbines in reverse and pumps water from the lower reservoir back to the upper reservoir, located upstream from the plant. Water is then ready to be reused when demand is high.

TIDAL POWER STATION

This type of power station uses tidal waters to generate electricity. When the tide rises, seawater fills a retaining basin; when full, the basin gates close. At low tide, other gates open and seawater drives turbines on its way back to the sea.

Table 6 / QUÉBEC'S TOP 12 HYDROELECTRIC GENERATING STATIONS IN 2009 (BASED ON INSTALLED CAPACITY IN WINTER IN MW)

	Station	MW
1	ROBERT-BOURASSA	5,616
2	LA GRANDE-4	2,779
3	LA GRANDE-3	2,417
4	LA GRANDE-2-A	2,106
5	BEAUHARNOIS	1,903
6	MANIC-5	1,596
7	LA GRANDE-1	1,436
8	RENÉ-LÉVESQUE (MANIC-3)	1,244
9	BERSIMIS-1	1,178
10	JEAN-LESAGE (MANIC-2)	1,145
11	MANIC-5-PA	1,064
12	OUTARDES-3	1,026

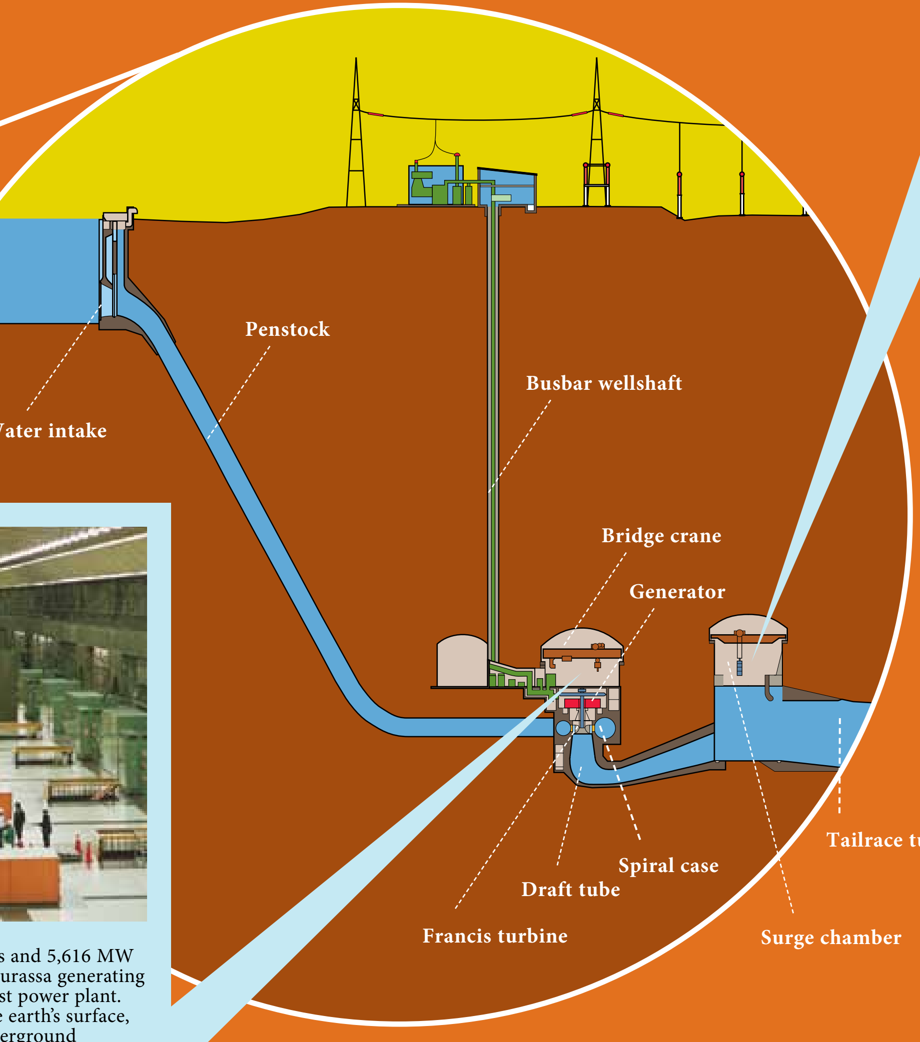
A head that's higher than the Eiffel Tower!

Sainte-Marguerite-3 generating station has a 330-metre head of water. That's 6 metres higher than the Eiffel Tower, antenna included.

THE SURGE CHAMBER AT ROBERT-BOURASSA GENERATING STATION

This gigantic granite cavern acts mainly as a shock absorber for the strong variations in pressure which occur when turbines are started up or shut down. Water rises in the chamber rather than surging back toward the turbines and damaging them.

Figure 8 / **Cross-section view of Robert-Bourassa underground generating station**



With 16 turbine-generator units and 5,616 MW of installed capacity, Robert-Bourassa generating station is Hydro-Québec's largest power plant. Located 137 metres beneath the earth's surface, it is also the world's largest underground power station.

Installed capacity:
The maximum generating capacity of all turbine-generator units in a power station at a given time. Expressed in watts, it is equal to the capacity of all the generators in winter operating conditions (water temperature at 5°C).

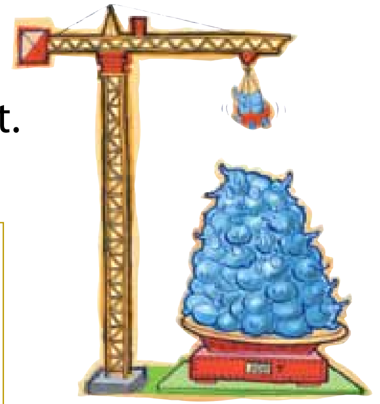
POWER TRADING, AN EXCITING PROFESSION

Hydro-Québec's brokers work around the clock to buy and sell energy at the most advantageous price. When they buy electricity at a low price, they allow generating stations with reservoirs to cut back production and store more water. When they sell electric power at a time when prices are high, for example during a summer heat wave to American customers, they optimize the profitability of Québec's hydroelectric facilities, since demand is comparatively low in Québec in the summer.

Hydro-Québec's trading floor in Montréal.

Turbine-generator units

Turbines convert the energy of rushing water, steam or wind into mechanical energy in order to drive a generator. The generator then converts the mechanical energy into electrical energy. In hydroelectric facilities, this assembly is called a turbine-generator unit, or a generating unit.



Installation of a Kaplan runner.

At La Grande-3 generating station, rotors have 32 pairs of electromagnets. To supply a 60-Hz alternating current, they must therefore rotate at a speed of 112.5 revolutions per minute (RPM). Here is the formula that was used by engineers: 32 pairs of electromagnets x 112.5 RPM = 3,600 RPM or 60 revolutions per second (60 Hz).

In North America, the standard alternating-current cycle is 60 times per second, but in Europe it is 50 times per second. This means that a clock designed to work at 60 Hz will be slower when plugged into a European socket.

TURBINES HAVE A CONSTANT ROTATION SPEED

All the generating units in a power system must be perfectly synchronized. Why? To ensure adequate power quality. Equipment that runs on electricity is designed to use alternating current of a specific frequency. This frequency depends on the generating unit's rotation speed, i.e. the number of times per second that rotor magnets travel past the stator's metal conducting bars. This frequency is expressed in cycles per second, or Hertz (Hz), named after the German physicist Heinrich Hertz, who proved the existence of radio waves.

A weighty matter

Each Kaplan turbine at Brisay generating station weighs 300 tonnes... That corresponds to 50 African elephants.

Table 7 / **TYPES OF HYDROPOWER TURBINES**

TURBINES ARE USED DEPENDING ON THE HEIGHT OF THE AVAILABLE HEAD, OR USABLE DIFFERENCE IN ELEVATION.

TURBINE TYPE	TYPICAL HEAD OF WATER
PROPELLER	UP TO 15 METRES
KAPLAN	UP TO 30 METRES
FRANCIS	10 TO 300 METRES
PELTON	300 METRES AND OVER

BULB-TYPE UNIT

This type of turbine has a horizontal axis and its alternator is housed in a watertight metal casing shaped like a bulb which lies under water. It has adjustable blades like the Kaplan turbine and is ideal for sites where there is a low hydraulic head and heavy flow.

Roue Francis

FRANCIS TURBINE

The most commonly used turbine in Hydro-Québec's power system. Water strikes the periphery of the runner, pushes the blades and then flows toward the axis of the turbine. It escapes through the draft tube located under the turbine. It was named after James Bicheno Francis (1815–1892), the American engineer who invented the apparatus in 1849.

Roue Kaplan

KAPLAN TURBINE

Austrian engineer Viktor Kaplan (1876–1934) invented this turbine. It is similar to the propeller turbine, except that its blades are adjustable; their position can be set according to the available flow. This turbine is therefore suitable for certain run-of-river generating stations whose river flow varies considerably.

PROPELLER TURBINE

Since they can reach very high rotation speeds, propeller turbines are effective for low heads. Consequently, this type of turbine is suitable for run-of-river power stations.

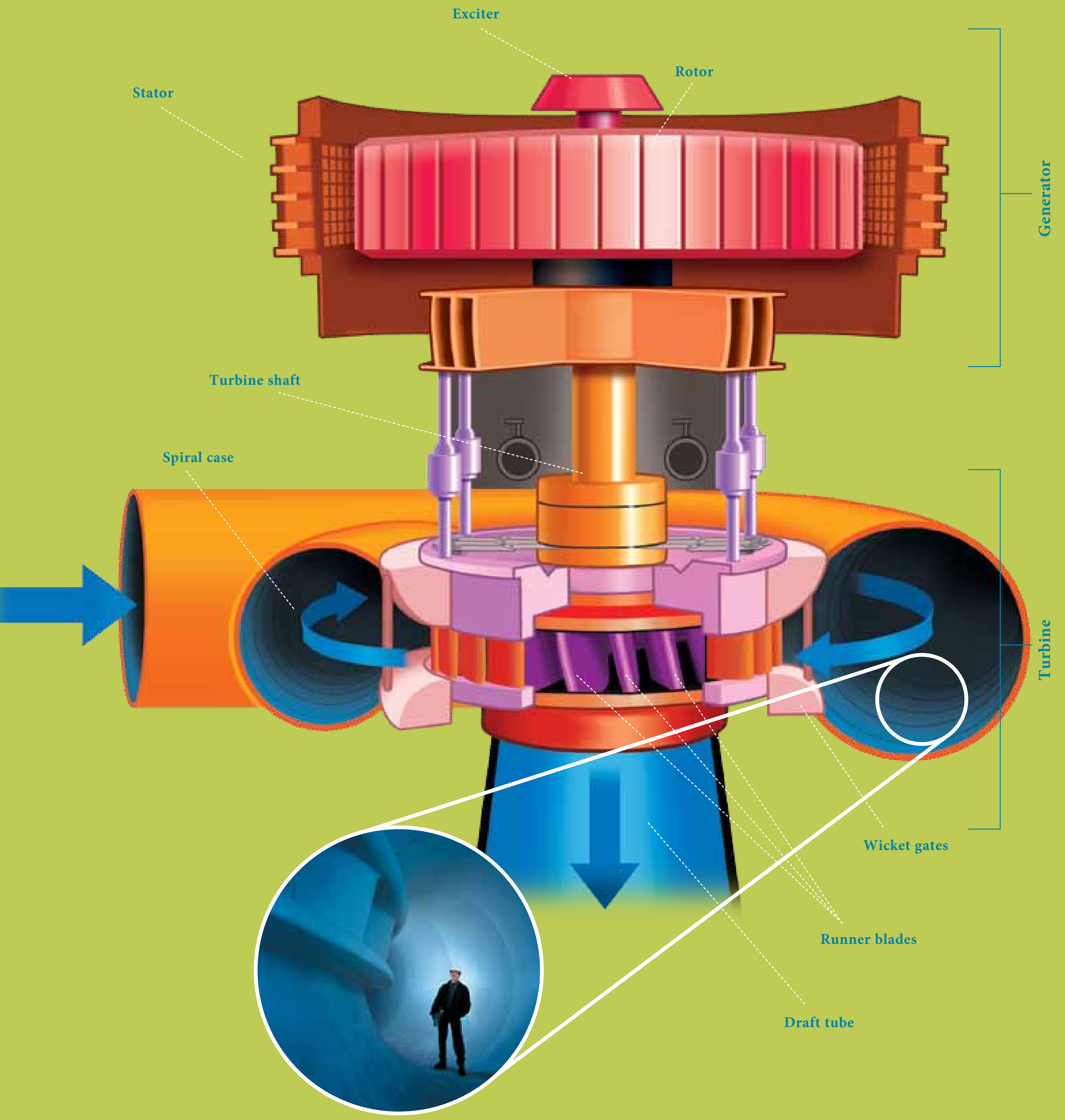
STEAM TURBINE

This turbine is used in conventional thermal generating stations and in nuclear power plants. Expanding steam pushes the turbine blades, making them rotate, just as the wind turns the blades of a windmill.

PELTON TURBINE

Named after its American inventor, Lester Pelton (1829–1908), this turbine uses spoon-shaped buckets to harness the energy of falling water.

Figure 9 / **Cross-section view of a generating unit**



Moving water makes the turbine spin

In this generating unit, water is carried from the penstock to the spiral case, and then rushes against the periphery of the runner to push the turbine blades. Drawn to the turbine's axis, water exits through the draft tube underneath. The energy of rushing water exerts a tremendous force on the turbine; this force is transmitted to the generator, which converts the mechanical energy from the turbine into electrical energy.

Driven by the turbine, the generator produces alternating current

The generator is connected to the turbine's driving shaft. It features a mobile component—the rotor—and a fixed component—the stator. The rotor's outer surface is covered with electromagnets. The stator's inner surface, or cylinder wall, is made up of windings of copper conducting bars. When the rotor turns inside the stator, electrons in the copper bars "vibrate." Their movement generates an electric current, similar to the one created by Michael Faraday in his 1831 experiment on electromagnetic induction, but on a much larger scale.

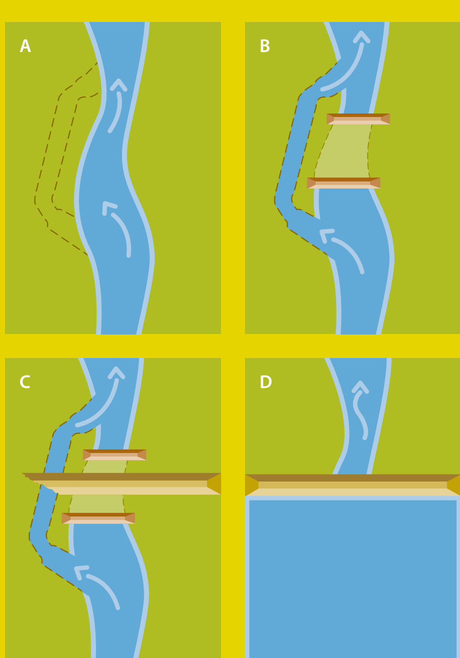
Three key conditions

Before proceeding with the construction of a hydropower station, Hydro-Québec is committed to meeting three key conditions:

1. the project must be profitable under current market conditions;
2. it must be environmentally acceptable and in keeping with the principles of sustainable development;
3. it must be well received by local communities.

Table 8 /
THE MAIN STAGES OF CONSTRUCTION

- SITE SELECTION.
- IN-DEPTH ENVIRONMENTAL IMPACT ASSESSMENT.
- EXCAVATION OF A DIVERSION TUNNEL TO BYPASS THE RIVER TEMPORARILY. (A)
- CONSTRUCTION OF COFFERDAMS (SMALL TEMPORARY DAMS) TO BLOCK THE RIVER UPSTREAM AND DOWNSTREAM. (B)
- LAYING OF FOUNDATIONS TO SUPPORT THE DAM.
- SPILLWAY CONSTRUCTION.
- POWER STATION CONSTRUCTION: WATER INTAKES, PENSTOCKS, MACHINE HALL, GENERATING UNITS, SURGE CHAMBER (IF APPLICABLE), TAILRACE TUNNELS, SWITCHYARD.
- ERECTION OF DAM (C)
- CONSTRUCTION OF DIKES TO CLOSE OFF SECONDARY VALLEYS AND FILLING OF THE RESERVOIR, IF APPLICABLE. (D)
- GRADUAL START-UP OF TURBINE-GENERATOR UNITS.
- ENVIRONMENTAL MONITORING ACTIVITIES.



Building a hydroelectric generating facility

The decision to build a power station is directly linked to the anticipated growth in demand for electricity. A utility must also take into account the fact that it takes about 10 years to complete a hydroelectric development.

Rehabilitating power stations: Another way to meet future needs for electric power

Hydroelectric facilities are generally designed to last 50 to 60 years. Regular maintenance can prolong the service life of a dam or power plant. But after a while, maintenance is not enough: the facility needs to be restored. Sometimes, it is more cost-effective to modernize a plant than to build a new one, as is the case with Beauharnois hydroelectric generating station. In other cases, it is preferable to start from scratch, as with the new facility being built next to Grand-Mère generating station.

In 1994, Hydro-Québec began carrying out rehabilitation work at Beauharnois generating station, located about 40 kilometres southwest of Montréal. The cost to extend its service life for another half century: approximately $2 billion. The project, spread over more than 15 years, has been organized so as to minimize generating-unit downtime. As a result, the power plant is almost fully functional during improvements, maintaining an operating factor of about 90%.

THE ENVIRONMENT, A PRIORITY

From the very start of a hydroelectric project, Hydro-Québec undertakes an impact study to assess the project's effects on the environment and determine the types of mitigation measures the company will implement. These initiatives are followed up with environmental monitoring activities during and after construction, combined with site-enhancement measures. Thanks to the valuable knowledge it has gained over the past 40 years—for example, concerning northern ecosystems—the company is able to identify precisely how new development projects will impact the environment.

Reservoirs at the La Grande complex promote wintertime migration of caribou. Thanks to these huge bodies of water covered with ice, herds avoid long detours in the snow.

Construction-site logistics, or the art of planning work in remote areas

Logistics experts must overcome significant challenges in planning a large-scale hydroelectric construction site. In addition to procuring vast quantities of materials, they must organize accomodations for the workers and other camp services. Roads and sometimes airports need to be built. These kinds of construction sites require huge investments. For example, $13.7 billion was pumped into Phase I of the La Grande complex, a major achievement of the 1970s and 80s. Here are some statistics that give an idea of the sheer magnitude of the project.

262,400,000 M^3 OF FILL WAS MOVED

DEVELOPMENT OF THREE POWER STATIONS WITH A TOTAL INSTALLED CAPACITY IN SUMMER OF **10,282 MEGAWATTS**

18,000 WORKERS WERE ON THE JOB AT THE PEAK OF CONSTRUCTION

$5.6 BILLION IN WAGES WERE DISTRIBUTED IN QUÉBEC

500,000 TONNES OF CONCRETE

$4.75 BILLION SPENT ON GOODS AND SERVICES PURCHASED IN QUÉBEC

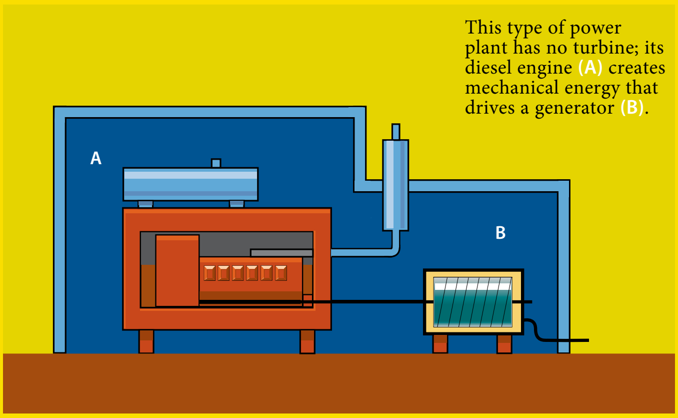
1,600,000 TONNES OF FUEL

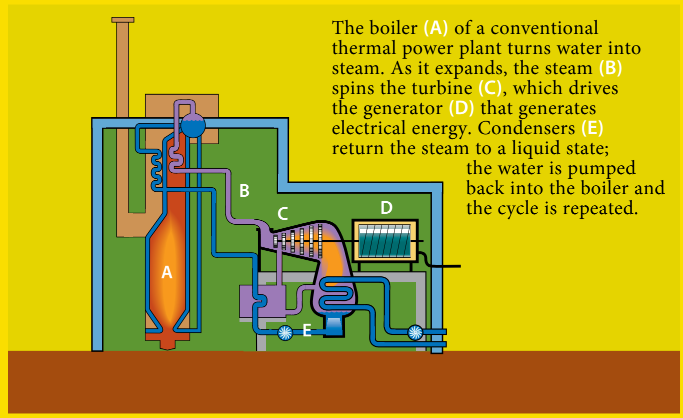
ERECTION OF **215** RETAINING STRUCTURES

110,000 TONNES OF FOOD

75,000 TONNES OF EXPLOSIVES

CONSTRUCTION OF **5** AIRPORTS, **5** VILLAGES AND **1 500** KILOMETRES OF ROADS





1. Diesel generating stations

Diesel-powered stations are used mainly in remote areas. For the most part, they supply electricity to isolated communities in the regions of Nunavik, Basse-Côte-Nord and Haute-Mauricie. Diesel generating stations power off-grid systems. The facility shown above is Hydro-Québec's largest diesel generating station, located on the Îles-de-la-Madeleine.

2. Conventional thermal generating stations

Conventional thermal generating stations burn coal or heavy oil. Hydro-Québec's power plant located near Sorel-Tracy uses heavy oil as fuel. The power station has a strategic role because it is operated when reservoir water levels are low or when demand peaks in winter months.

Thermal generating stations

Because they burn fossil fuels, thermal power plants cost more to operate and emit more pollutants in comparison to hydroelectric generating stations. While these facilities represent only a small portion of Hydro-Québec's overall generating capacity—about 2% in 2009—they play a vital role in meeting Québec's base-load and peak energy requirements. They are also useful in supplying power toremote, off-grid regions such as theÎles-de-la-Madeleine.

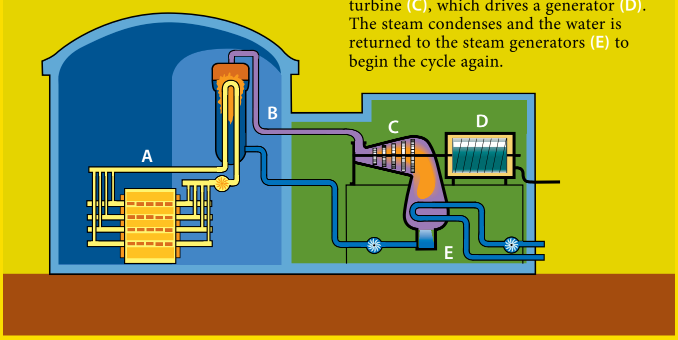
Tableau 9 / **THERMAL GENERATING STATIONS IN QUÉBEC**

TYPE DE CENTRALE	NOMBRE
À TURBINES À GAZ	3
NUCLÉAIRE	1
THERMIQUE CLASSIQUE	1
DIESEL	23

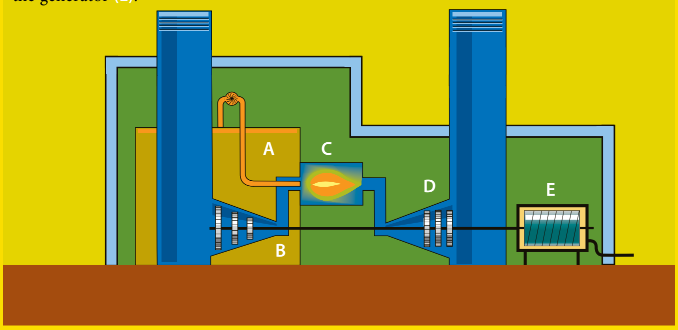
Role of thermal generation at Hydro-Québec

Some thermal power stations operate continuously to meet base-load energy needs; for instance, diesel generating stations and Gentilly-2 nuclear power plant. Other thermal generating stations, such as gas-fired facilities and the oil-fired conventional thermal generating station located near Sorel-Tracy, operate only when demand is high and hydroelectric facilities are working at maximum capacity.

The fission of uranium-235 atoms (A) creates heat that converts water into steam. Under pressure, this steam (B) spins a turbine (C), which drives a generator (D). The steam condenses and the water is returned to the steam generators (E) to begin the cycle again.



When diesel fuel is ignited (A) in combination with compressed air coming from the compressor (B), a high-temperature gas mixture is created (C) which will expand. The expansion of the gas is what strikes the blades (D) of the turbine which drives the generator (E).



3. Nuclear generating stations

Nuclear power plants generate steam through the fission of atoms; the steam then drives a turbine. These generating stations produce very few greenhouse gases. Hydro-Québec operates only one, Gentilly-2, since 1983. It is located near Trois-Rivières. With an installed capacity of 675 megawatts, it can meet the electricity needs of 100,000 residential customers. Operated continuously, Gentilly-2 is very efficient and it plays an important role within Hydro-Québec's generating fleet.

4. Gas-turbine generating stations

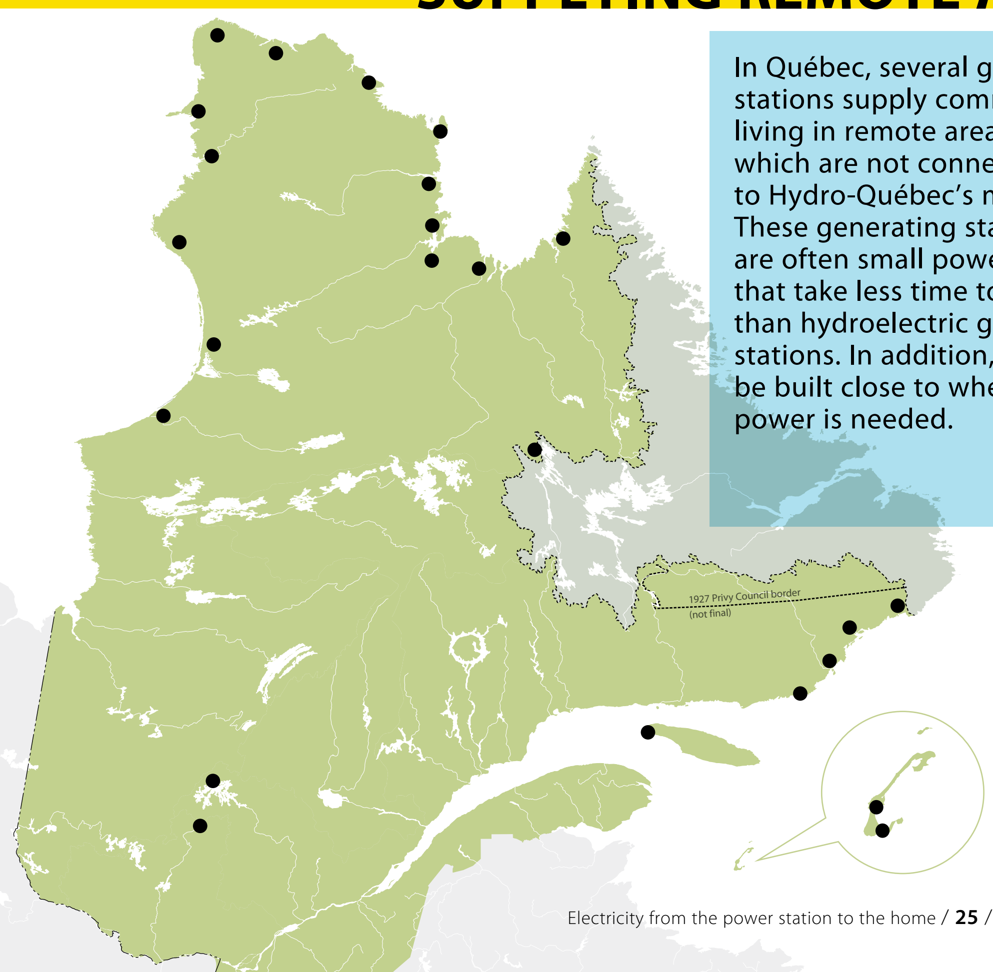
Gas-turbine generating stations generally burn light oil or natural gas. They are called "gas-turbine" because their combustion process produces gas that drives the turbine. Given the relatively high cost of fuel needed to run these facilities, they are used only to generate electricity during periods of peak demand. These generating stations have the advantage of taking only minutes to start and stop operations, compared to the longer time frames required by other thermal power stations.

SUPPLYING REMOTE AREAS

In Québec, several generating stations supply communities living in remote areas which are not connected to Hydro-Québec's main grid. These generating stations are often small power stations that take less time to build than hydroelectric generating stations. In addition, they can be built close to where the power is needed.

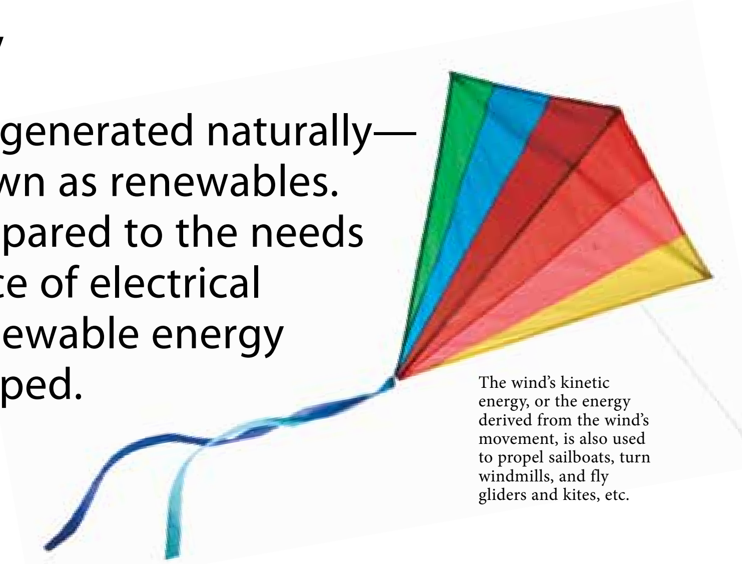
COMBINED-CYCLE GAS-FIRED GENERATING STATIONS: EFFECTIVE TECHNOLOGY

These power stations are named after their combined gas cycle and steam cycle. Each cycle generates electricity. The required fuel—natural gas—is used only to drive the gas turbine, which in turn propels the generator. Exhaust gas from the turbine is then used to produce steam without burning any other fuel; the steam then drives another turbine to generate even more power. All things considered, a combined-cycle generating station is more efficient than a gas-turbine facility. It is also the least polluting type of thermal generating station after nuclear power plants. In comparison, combined-cycle generating stations produce 2.5 times less greenhouse gases than conventional coal-fired facilities.



Renewable energy

Energy sources that are renewed or regenerated naturally—like water, wind or sunlight—are known as renewables. They are available in abundance, compared to the needs of humans. In Québec, the main source of electrical power is water, but other types of renewable energy sources are also being used or developed.



The wind's kinetic energy, or the energy derived from the wind's movement, is also used to propel sailboats, turn windmills, and fly gliders and kites, etc.

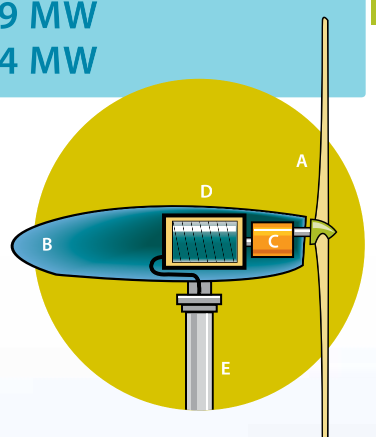
Wind power

Wind farms harness the kinetic energy of wind to generate electricity. Wind is a renewable source of energy that must be used in conjunction with other forms of power generation. Because of the intermittent nature of wind, wind farms are not able to meet demand all the time. At the end of 2009, Hydro-Québec was purchasing all the output from nine privately owned wind farms with a total installed capacity of 654 MW.

INSTALLED WIND GENERATING CAPACITY AT THE END OF 2009

IN CANADA	3,319 MW
IN QUÉBEC	654 MW

Since wind speed increases with elevation, wind turbines are installed on towers that are often as tall as a 26-storey building.



Wind turbines used in Québec have three fibreglass blades **(A)** connected to a nacelle **(B)** which holds the turbine **(C)** and the generator **(D)**. The nacelle is mounted on a steel tubular tower **(E)**.

Solar power

The sun is a natural and renewable source of energy. Hydro-Québec takes an active interest in solar energy which can be used either for heating or for power generation. In Québec, the number of solar energy applications is currently on the rise. It is being used more and more to heat water or power electronic road signs, for example. Photovoltaic panels capture the sun's light and transform it into electricity, turning solar energy into power we can use.

Passive or active?

Solar power is called passive when the sun's rays are used without being transformed, like when the windows of a home are strategically positioned to take advantage of daylight periods in winter. Active solar power is the energy generated through the use of equipment such as photovoltaic collectors which capture and concentrate solar power. These systems constitute an additional energy source that can supplement the energy provided by conventional equipment.

Source: http://www.mrnf.gouv.qc.ca/energie/innovation/innovation-solaire.jsp [In French only]

Biomass energy

Biomass refers to all materials derived from the decomposition of organic matter. The organic matter used can come from forest, urban or agricultural waste. Biomass is either burned directly or transformed into biogas to produce heat. It is used in many fields to meet various energy needs, including electricity production and heating. For many years, Hydro-Québec has been purchasing power from private producers of biomass energy.

Table 10 / **TYPES OF BIOMASS ENERGY FACILITIES**

BIOGAS GENERATING STATIONS
- GAS PRODUCED EITHER NATURALLY, IN LANDFILL SITES FOR EXAMPLE, OR ARTIFICIALLY, IN A METHANIZER

BIOMASS-FIRED THERMAL GENERATING STATIONS
- PLANT MATERIAL
- FARM-BASED ORGANIC WASTE
- ORGANIC RESIDUE FROM WATER TREATMENT PLANTS
- FORESTRY RESIDUE

The discovery of fire was the first use of biomass energy.

Geothermal energy

Geothermics is the study of the planet's thermal phenomena as well as of techniques for using the heat stored in the Earth.

THE GLOBAL INSTALLED CAPACITY FOR ELECTRICITY GENERATION FROM GEOTHERMAL ENERGY IN 2007 WAS

10,039 MW

Source: *Survey of Energy Resources Interim Update 2009*, World Energy Council, p. 59.

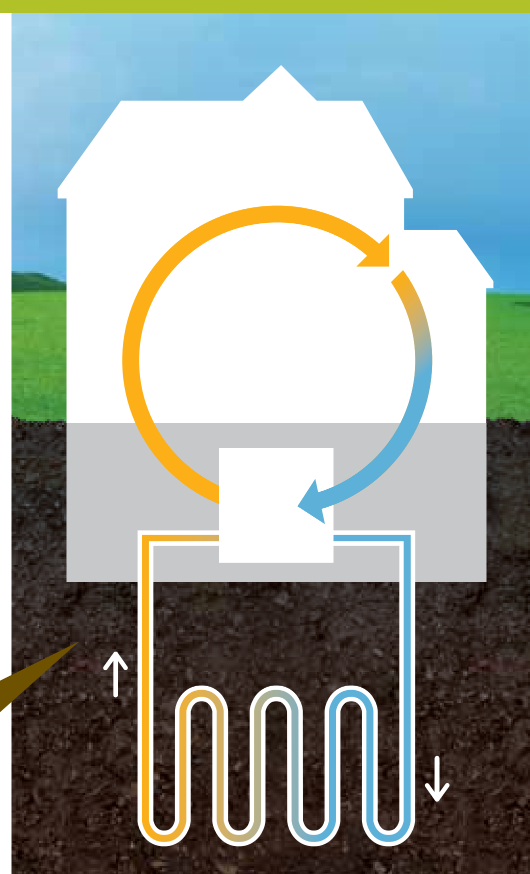
GEO COMES FROM THE GREEK AND MEANS "EARTH"

Deep or shallow?

Deep geothermal energy is generated by heat extracted at high temperatures from several thousand meters below the Earth's surface. Today, 24 countries use deep geothermal energy to generate electricity at a total of 350 geothermal generating stations. The global geothermal power output per year is more than 55 TWh, which is equivalent to 25 million barrels of oil.

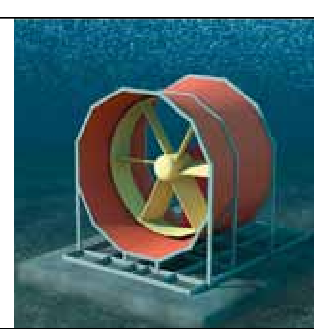
Shallow geothermal energy, which is the type used in Québec, is generated by applying various technologies to make use of the heat stored in the Earth's crust, up to 150 metres deep. In winter, heat pumps extract heat from the ground and use it to heat the building's air in. In summer, these same pumps can act as air-conditioners by sending the heat recovered from inside the buildings into the ground.

To heat buildings, heat pumps extract heat from the ground, at temperatures between 0°C and 10°C, and, through the use of exchangers, transfer it to the air at temperatures between 35°C and 45°C.



Hydrokinetic energy under study

Similarly to the way wind turbines capture the energy of the wind, a run-of-river submerged hydraulic turbine harnesses the kinetic energy of currents to rotate. In this way, part of a river's kinetic energy can be converted to electricity. Since there is no dam to regulate electricity generation, hydrokinetic turbines must be installed in sites meeting specific criteria, including a depth of several metres and a fairly strong current throughout the year. Hydro-Québec plans to assess the performance of submerged river turbines and study their integration into its grid.



question://

HOW DOES ELECTRICITY GET TO OUR HOME?

answer://

Does power from Robert-Bourassa generating station cook your pizza, while watts from Outardes-4 play your CD? Not quite. Once electricity leaves the power plant and hops on the transmission system, it blends in with other electric power generated elsewhere. Almost without exception, Québec residents use electricity generated from all of Hydro-Québec's power stations. At any rate, the electricity we use is wheeled through overhead cables that are attached to tall support structures called towers, which link generating station switchyards to power intersections called source substations. Power is then routed through satellite substations before running along the distribution lines to finally reach our homes. The fascinating thing is that we use electricity as soon as it is generated. The transfer of electricity therefore occurs at breakneck speed… Actually, it moves nearly as fast as light, which rushes along at 300,000 kilometres per second!

Figure 10 / **HYDRO-QUÉBEC POWER LINES IN 2009**

If all of Québec's power lines were placed end to end, they would circle the earth more than three and a half times.

144,449 KILOMETRES

OF TRANSMISSION AND DISTRIBUTION POWER LINES

Figure 11 / The transmission system, a pool of electrical energy

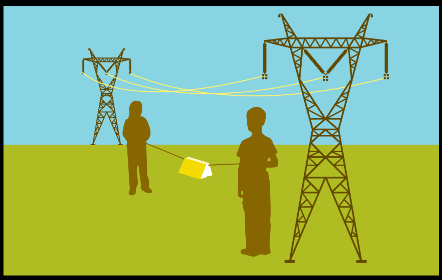
Hydro-Québec's transmission system could be compared to a swimming pool being filled by a number of faucets—the company's generating stations. If we drank some water from the pool, it would be nearly impossible to trace the faucet from which it came. If we pursue this analogy to explain how electricity reaches our home, imagine a set of pipes whose purpose is to empty the pool. The pipes immediately leaving the pool are very large. As they approach residential areas, they are split up at intersections (source substations) and their flow decreases. At the end of the line, only a small pipe enters each house.

WHY DO TOWERS CARRY SO MANY WIRES?

To stabilize power transmission and avoid energy losses, the alternating current transmitted on high-voltage cables is made up of three parts, or phases. Each phase includes between one and four wires, or conductors, depending on the voltage level. Phases with more than one conductor are called conductor bundles. In addition, to protect the tower from lightning, a ground wire is included.

WHY AREN'T POWER LINES STRAIGHT?

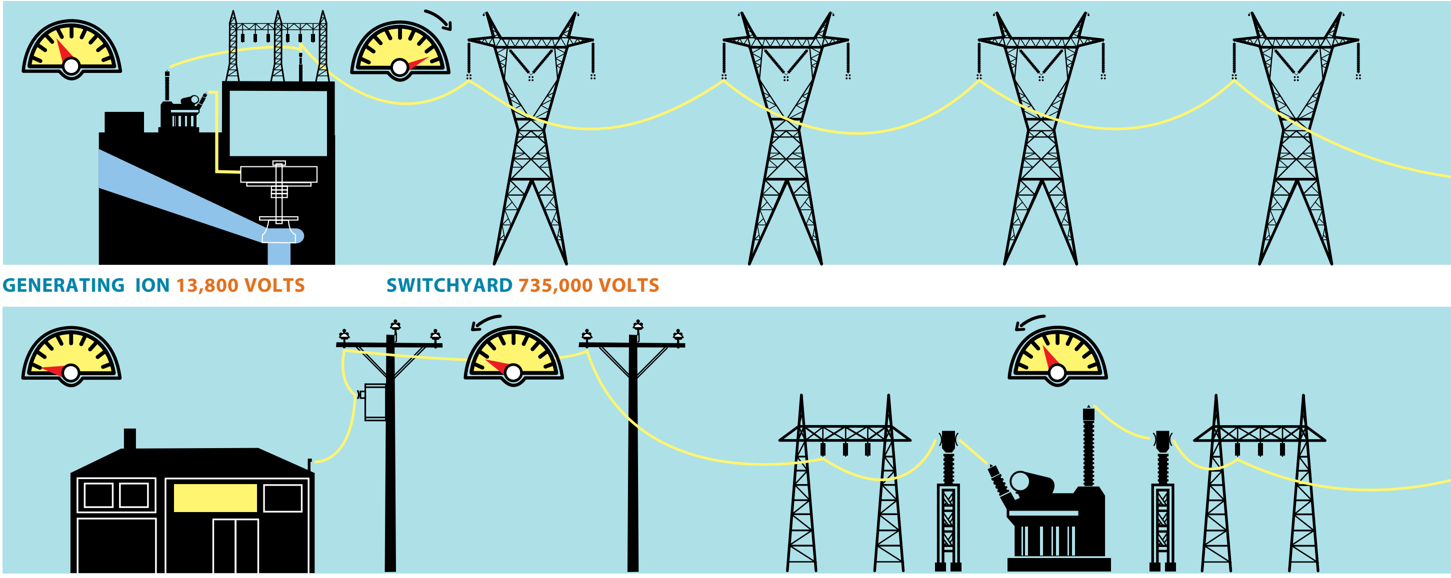
Wires strung between two transmission towers seem to sag in the middle. Electrical lines curve downward to reduce the force needed to hold them in place. Otherwise, towers would have to be built even stronger… and they would cost more. For example, grasping a dictionary with your hands is easy because all the force is concentrated vertically. However, when two people try lifting that dictionary using a rope, it's another matter: as the object is raised higher more horizontal force is required and we risk pulling the other person towards us.



WHAT CAUSES THE CRACKLING SOUND NEAR TRANSMISSION LINES?

This phenomenon, called the corona effect, is caused by electrons moving between the wires and the air. The back-and-forth movement creates a multitude of tiny electrical discharges a few centimetres from the wire, which we perceive as a crackling sound. The higher the voltage, the greater the chance this phenomenon will occur, and it intensifies when the air is humid or when impurities fall on the wires. Also, the crackling sound is louder when it snows or rains.

Hydro-Québec measures the impact of sound produced by its power transmission lines and other equipment.



GENERATING ION 13,800 VOLTS

SWITCHYARD 735,000 VOLTS

HOME 120/240 VOLTS

WOOD POLE 25,000 VOLTS

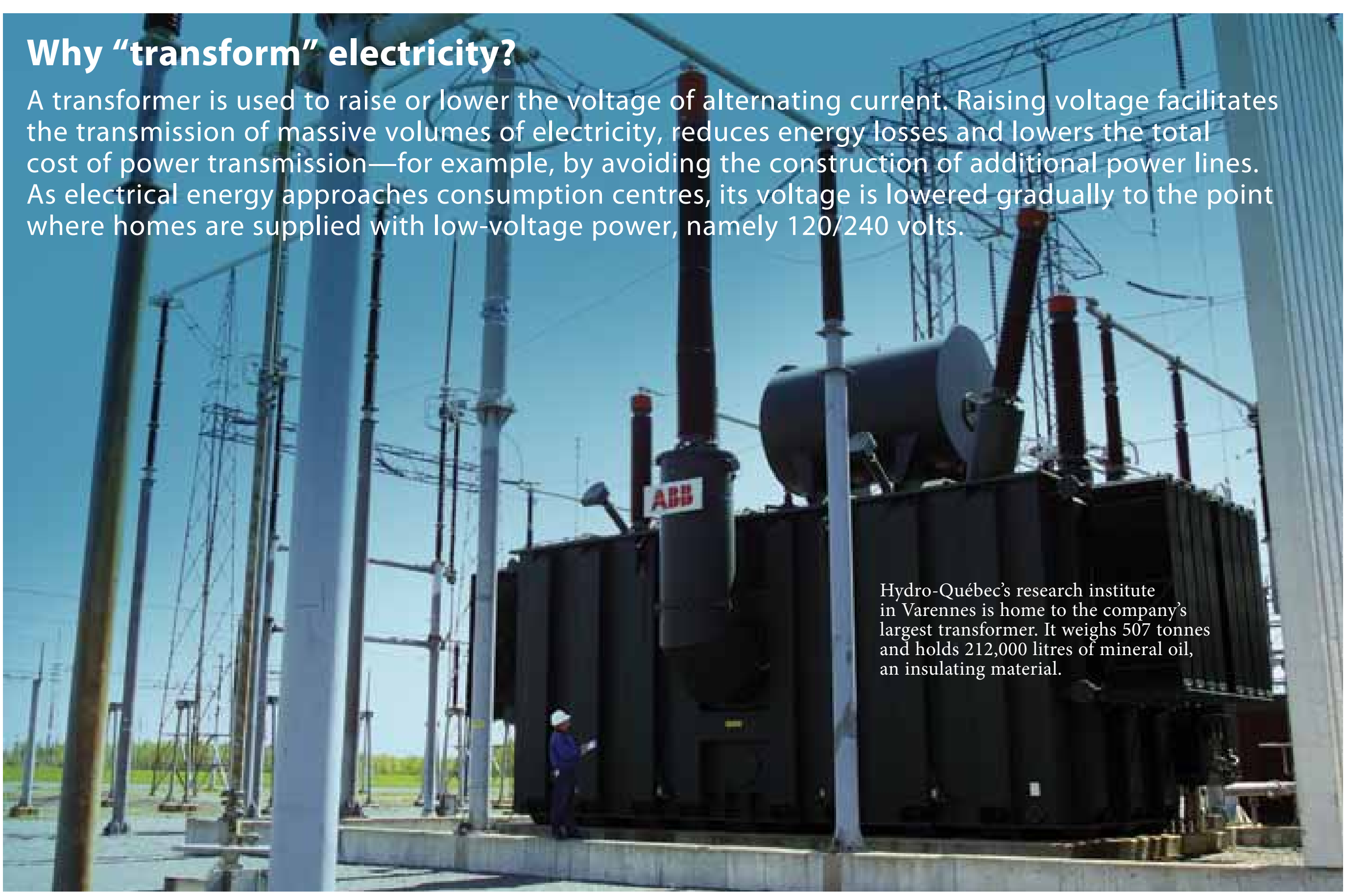
SATELLITE SUBSTATION 25,000/49,000 VOLTS

Power transmission

Using the driving force of water, we have set electrons in motion and generated alternating current. But electricity often must travel a very long distance to reach our homes. In fact, this power flow takes several detours before reaching its destination. The transmission of electricity involves a series of transformations, checkpoints and crossroads. These three basic functions are carried out along the way between the power station and the home.

Why "transform" electricity?

A transformer is used to raise or lower the voltage of alternating current. Raising voltage facilitates the transmission of massive volumes of electricity, reduces energy losses and lowers the total cost of power transmission—for example, by avoiding the construction of additional power lines. As electrical energy approaches consumption centres, its voltage is lowered gradually to the point where homes are supplied with low-voltage power, namely 120/240 volts.



Hydro-Québec's research institute in Varennes is home to the company's largest transformer. It weighs 507 tonnes and holds 212,000 litres of mineral oil, an insulating material.

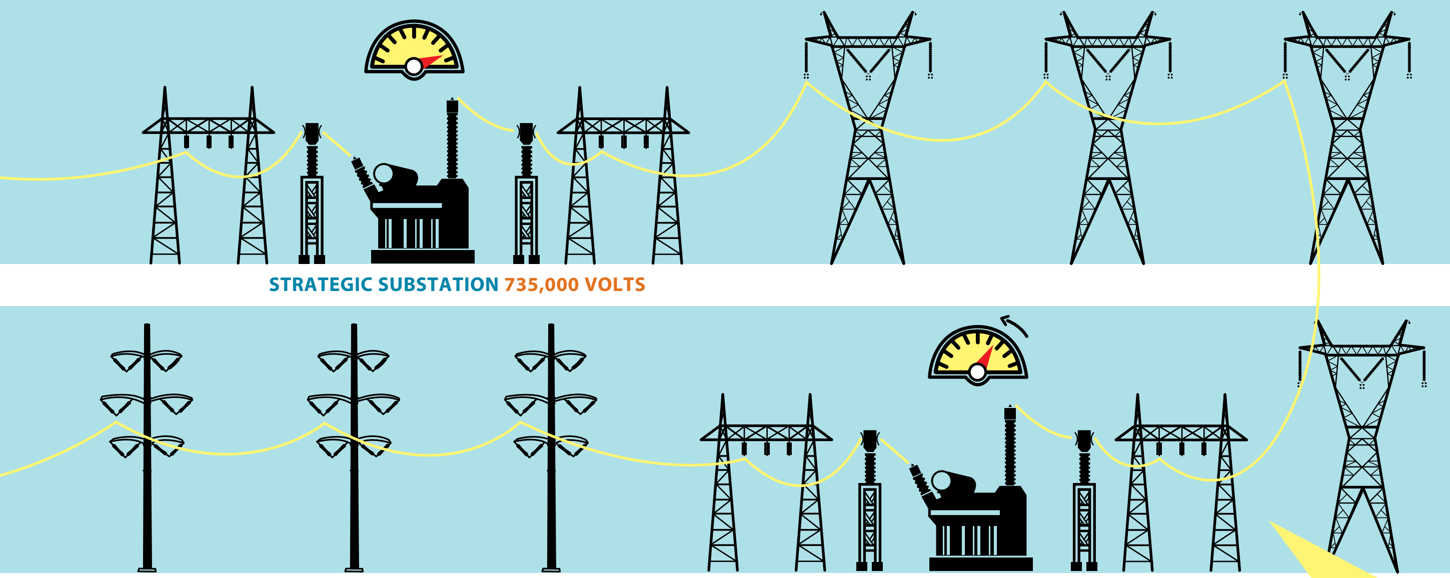


Table 11 / **HYDRO-QUÉBEC'S POWER TRANSMISSION SYSTEM IN 2009**

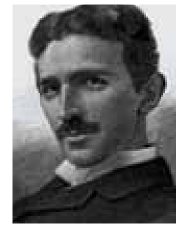
VOLTAGE (KILOVOLTS)	SUB-STATIONS	LINES (KILOMETRES)
735 AND 765	38	11,422
450 (direct current)	2	1,218
315	63	5,127
230	52	3,120
161	41	2,013
120	216	6,738
69 AND LESS	103	3,606
TOTAL	515	33,244

Figure 12 / **Power transmission: A typical roadmap**

Power plants can generate voltages of up to 13,800 volts, as is the case at Robert-Bourassa station. But transmission of electricity occurs at much higher voltages. The step-up voltage transformer in the power station switchyard raises the voltage to levels ranging from 44,000 to 765,000 volts. Then, the voltage will be reduced several times. In the home, we use 120-volt power for the television, radio and other common electrical appliances, or 240-volt power to operate equipment requiring more current, such as the clothes dryer and the stove.

THE RISE AND DOMINANCE OF ALTERNATING CURRENT

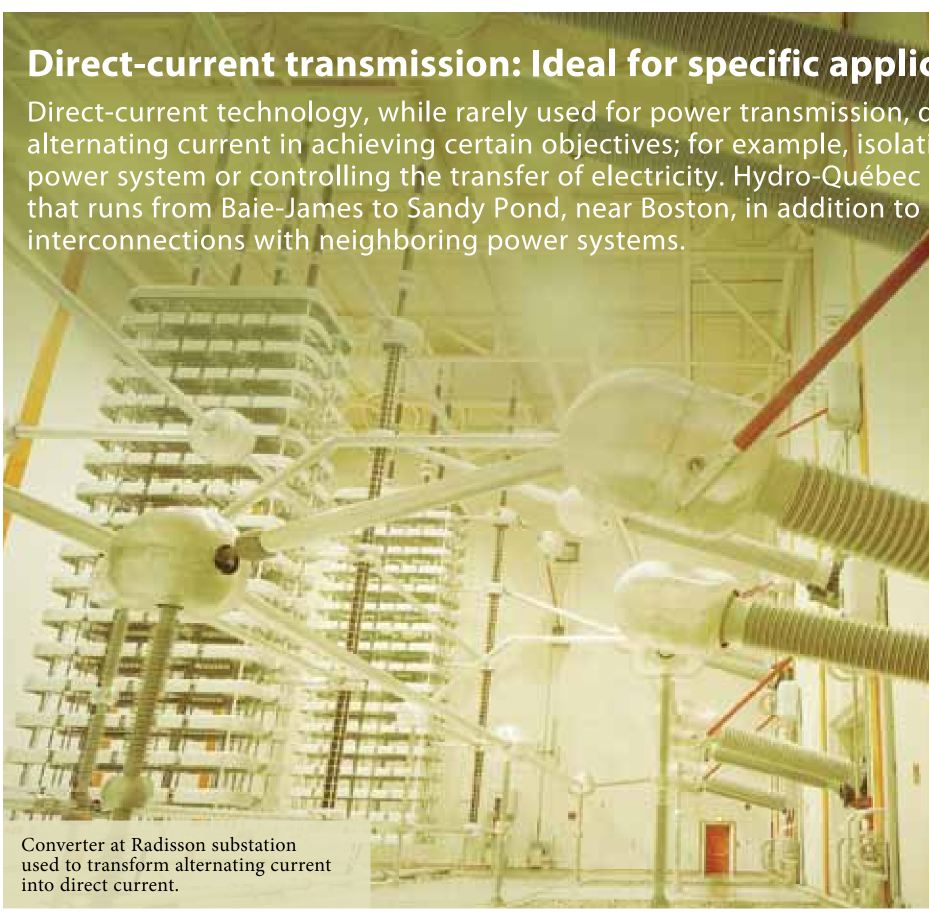
For transmitting power, alternating current is more effective than direct current. But this was not always the case. Just over 100 years ago, they were rival technologies. Alternating current supporters included George Westinghouse, while Thomas Alva Edison was among those backing direct current. This was the dawning of the age of electricity and American industrialists were seeking the best and cheapest way to bring this new energy from the power station to manufacturing plants. In 1887, Nikola Tesla bolstered the cause for alternating current by developing the first practical system for generating and transmitting alternating current.



Nikola Tesla (1856–1943) – Born in Croatia, he landed in New York in 1884 with only pennies in his pocket. Some three years later, he had already become one of the leading figures in the history of electricity. The tesla, a unit used to measure magnetic fields, was named after him.

Direct-current transmission: Ideal for specific applications

Direct-current technology, while rarely used for power transmission, does offer advantages over alternating current in achieving certain objectives; for example, isolating an alternating-current power system or controlling the transfer of electricity. Hydro-Québec operates a direct-current line that runs from Baie-James to Sandy Pond, near Boston, in addition to a number of direct-current interconnections with neighboring power systems.



Converter at Radisson substation used to transform alternating current into direct current.

Converter room at Outaouais substation.

Figure 13 / **Steel high-voltage transmission tower**

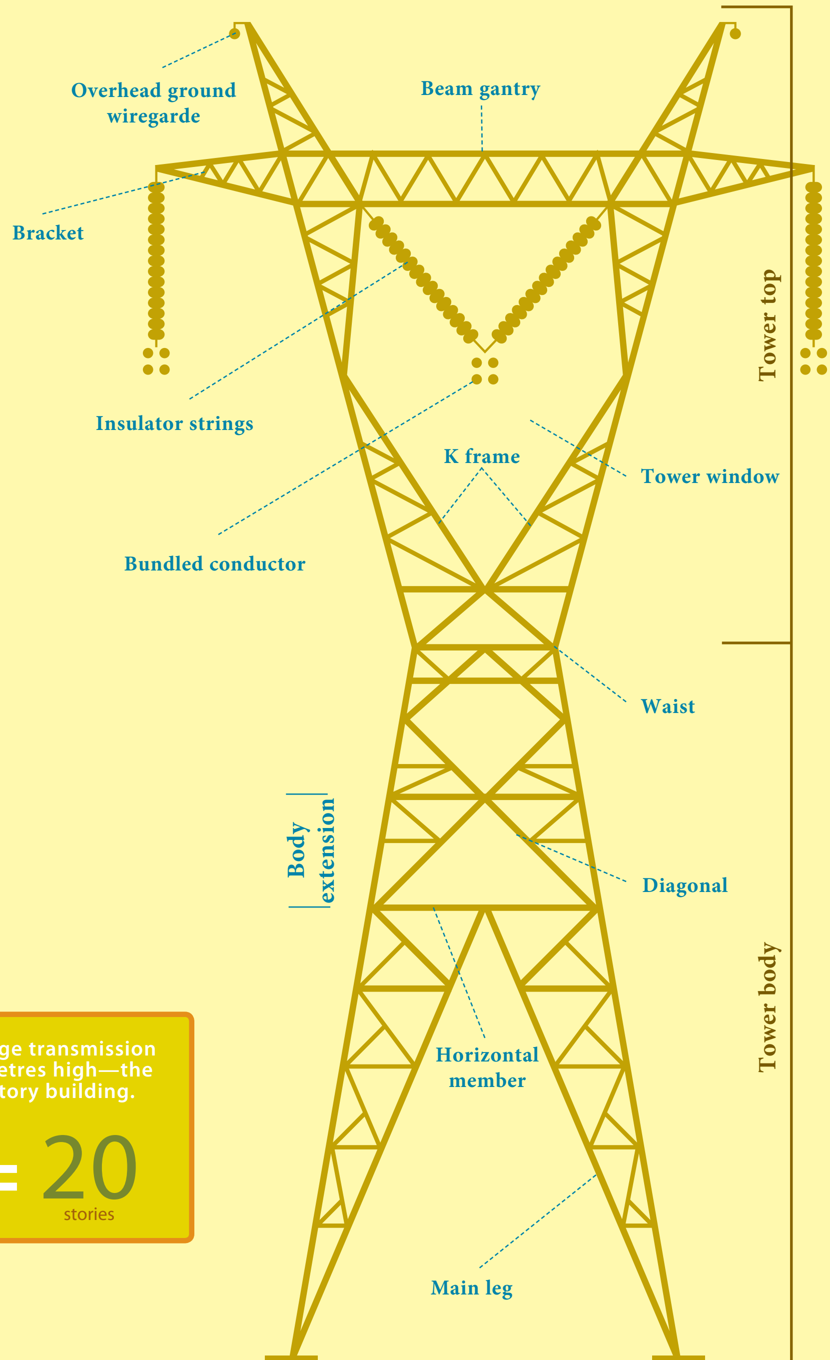


Table 12 / **OUTSTANDING TOWERS USED BY HYDRO-QUÉBEC**

THE LONGEST SPAN	**2,026 METRES**
THE HEAVIEST TOWER	**640 TONNES**
THE HIGHEST TOWER	**175 METRES**

1. Waist-type tower

This is the most common type of transmission tower. It is used for voltages ranging from 110,000 to 735,000 volts. Conductors are strung on a single horizontal plane. Because it is easily assembled, this rigid four-footed tower is suitable for power lines that cross very uneven terrain.

Some high-voltage transmission towers are 60 metres high—the same as a 20-story building.

60 = 20

metres stories

Towers

Transmission towers support the high-voltage conductors of overhead power lines, from the generating station's switchyard right up to source substations and satellite substations located near populated areas. Their shape, height and sturdiness (mechanical strength) depend on the stresses to which they are exposed. Towers do not transmit electricity themselves unless lightning strikes the ground wire strung along the top of the structure. This cable is designed to protect conductors by allowing a lightning discharge to reach the ground through the tower.

2. Double-circuit configuration tower

This rigid four-footed tower is used for voltages ranging from 110,000 to 315,000 volts. Its can be from 25 to 60 metres tall. Conductor bundles are placed one below the other.

3. Guyed-V tower

This guyed tower is designed for voltages ranging from 230,000 to 735,000 volts. It is used mainly for power lines leaving the La Grande and Manic-Outardes hydroelectric complexes. The guyed-V tower is more cost-effective than the double-circuit and waist-type towers. It is held in place by guy wires attached to anchors. Guy wires are metal cables or rods that stabilize the tower.

4. Tubular steel pole

Featuring a streamlined, aesthetic shape, this one-footed structure is less massive than other towers, allowing it to blend easily into the environment. It is used increasingly in urban centres. Between 27 and 45 metres high, it is suitable for voltages between 110,000 and 315,000 volts.

5. Cross-rope suspension tower

With its simple design, this guyed tower is easy to assemble. It is used for 735,000-volt conductors, in particular for certain power line sections leaving the La Grande complex. This type of structure requires less galvanized steel than the guyed-V tower, making it comparatively lighter and less costly.

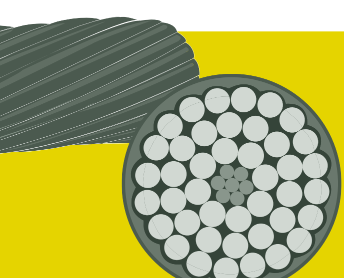
Spacer dampers separate bundled conductors and control vibrations caused by wind and ice buildup. Hydro-Québec designed its own heavy-duty spacer damper.

WATERWAY CROSSINGS

Hydro-Québec's most imposing towers are used when overhead power lines must cross large waterways, such as the Rivière Saguenay or St-Laurent near Île d'Orléans. However, there is another way to cross a waterway: using an underwater tunnel. Hydro-Québec operates such a tunnel, which runs from the north shore of the St-Laurent near Grondines to the south shore close to Lotbinière substation. The tunnel is a unique achievement. In fact, in 1990, Hydro-Québec was the first company in the world to use an 'underwater river crossing for a 450,000-volt direct-current power line.

POWER LINES, CABLES AND CONDUCTOR BUNDLES

What we call a *power line* is generally the route used by transmission cables and towers. Towers support different kinds of *cables*: conductors, which transfer electrical energy; ground wire, which protects the structure from lightning; and guys that anchor the structure and ensure its mechanical strength. A *conductor bundle* is a series of two, three or four conductors always kept apart thanks to a spacer. Bundled conductors are used on high-voltage power lines to help reduce energy losses (due to the corona effect), audible noise and radio interference. As a result, they improve the power transmission process. For example, four small conductors with a 3-cm diameter are just as effective as—and much lighter than—one single conductor with a 46-cm diameter. High-voltage towers carry three conductor bundles, one per current phase.



Most high-voltage conductors used by Hydro-Québec are made of aluminum with a steel core that gives the cable its required strength. Curiously, these conductors are bare: the air around them provides insulation. Each conductor is stranded, meaning it consists of several wires twisted together. This makes a conductor more flexible and more exposed to air, a feature that helps cool the conductor and therefore increase its conductivity. Indeed, electricity meets resistance when passing through hot metal, a phenomenon that transforms part of the electrical energy into thermal energy, a type of energy loss.

DANGER: HIGH VOLTAGE!

RADISSON SUBSTATION

Long distances

Electricity often travels over very long distances to reach urban consumption centres. For example, the distance between Baie James (James Bay)—where water from La Grande Rivière ends up after driving turbines in eight power stations—and Montréal is about 1,000 kilometres as the crow flies. However, the farther electricity travels, the greater the risk that some energy will be lost on the way. Since utilities invest heavily in the high-volume transmission of electrical energy over long distances, they take special steps to limit these transmission losses.

High-voltage transmission, a solution perfected by Hydro-Québec

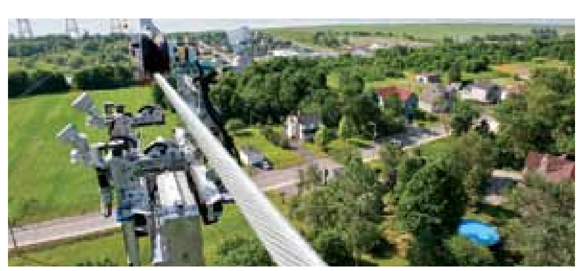
When moving large volumes of electricity, it is best to increase voltage to reduce energy losses and total cost of transmission. A large portion of the power generated by Hydro-Québec is transmitted using 735,000-volt lines. Without these high-voltage lines, the landscape would be cluttered with towers. One 735,000-volt line is equal to four 315,000-volt lines, the next voltage level down. In fact, Hydro-Québec is a pioneer in high-voltage power transmission: it developed the world's first commercial 735,000-volt line (see photo opposite), including the earliest equipment designed for that voltage.

WORLD FIRST IN POWER TRANSMISSION BY HYDRO-QUÉBEC

In 1965, the first ever 735,000-volt power line began operations, linking the Manicouagan and Outardes generating stations to the metropolitan areas of Québec and Montréal. This genuine breakthrough in the energy industry—a technology invented by Québecengineer Jean-Jacques Archambault—was key to developinghydroelectric projects in northwestern and northeastern Québec.

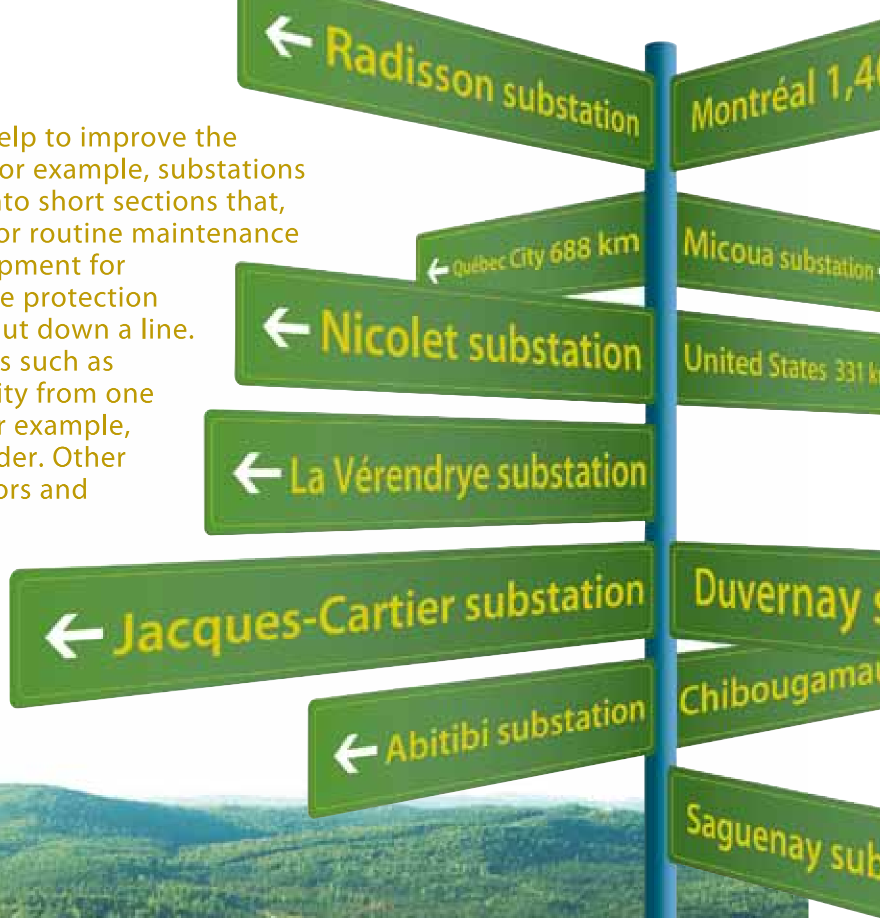
LINESCOUT, THE TIGHTROPE-WALKING ROBOT

Developed at Hydro-Québec's research institute, the Linescout robot is used to inspect and make some repairs on live transmission lines. Able to clear obstacles, the robot can inspect areas that are difficult for line workers to reach. This innovative technology provides Hydro-Québec with precise information on the condition of its transmission lines, and is used to correct anomalies where necessary.



Substations

Substations perform many functions that help to improve the dispatching and flow of electrical energy. For example, substations are essential in dividing long power lines into short sections that, when isolated, lessen the impact of a fault or routine maintenance on continuity of supply. In addition to equipment for measuring current and voltage, they include protection systems such as circuit breakers that can shut down a line. They are also equipped with control devices such as disconnecting switches that switch electricity from one line to another almost instantaneously—for example, when sections of a power line are out of order. Other equipment, such as shunt reactors, capacitors and compensators, also helps regulate voltage. Most substations are automated and subject to remote control. Only the more strategic substations have full-time technical staff; at most other substations, mobile teams perform maintenance.



LA VÉRENDRYE SUBSTATION

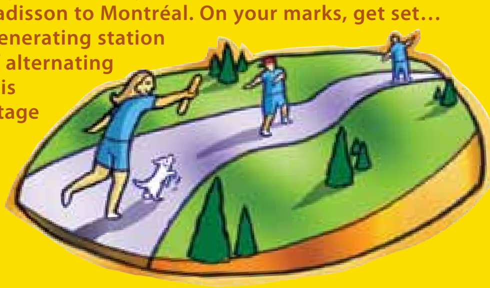
LIVE-LINE WORK: A POWERFUL OCCUPATION!

This technique consists of performing various maintenance tasks and repairs on high-voltage lines in totally safe conditions, but without de-energizing the lines. Since power transmission never ceases, utilities are able to avoid periods of equipment downtime and resulting loss of revenue.

735 kV anybody?
No problem! A lineman can work in a 735,000-volt environment, provided that he follows the proper safety procedures. For example, special protective equipment—insulated aerial buckets, insulating sticks, insulating gloves—must be used to prevent electricity from flowing through the technician's body to reach the ground.

Figure 14 / **Substations: Useful relays in power transmission**

As in a relay race, high-voltage power lines run through several substations to maintain the quality, reliability and stability of electric current—for example, the power lines running from Radisson to Montréal. On your marks, get set… To optimize transmission, the generating station switchyard raises the voltage of alternating current. Along the way, current is measured and adjusted, and voltage is gradually lowered before reaching the finish line in urban consumption centres.



ELECTRIC AND MAGNETIC FIELDS

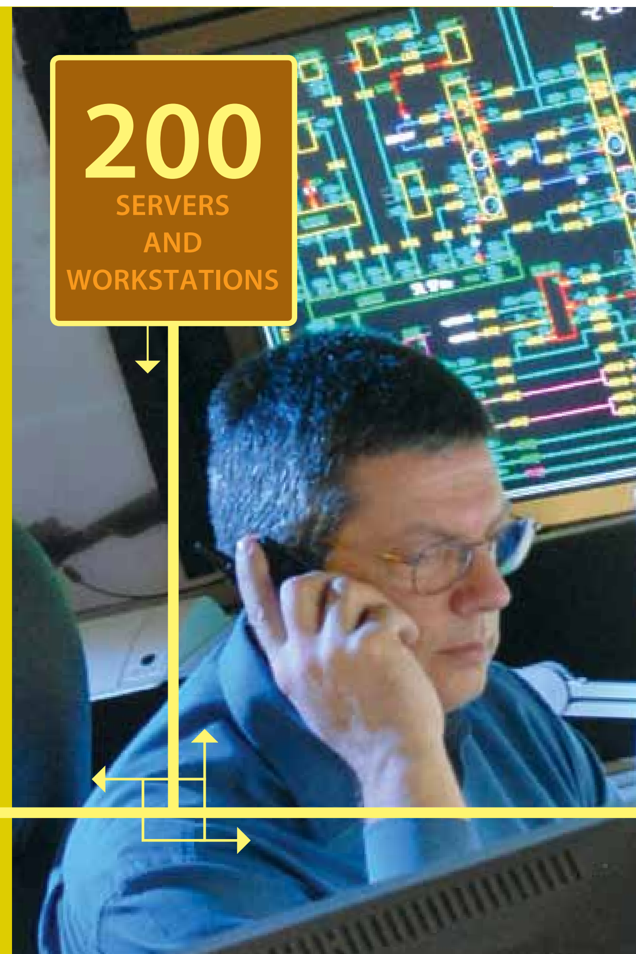
Everywhere there's electricity there are electric and magnetic fields (EMFs), whether around electrical appliances or near high-voltage lines. Since the 1970s, there has been increasing concern about the effects of EMFs on the health of human beings, animals and vegetation. Technical studies, laboratory research and epidemiological studies have been conducted throughout the world, but so far they have not proven that EMF exposure leads to harmful effects. The hunt for answers continues and Hydro-Québec is actively contributing to this research effort.

System operations

Remote automatic controls perform most of the tasks needed to ensure the flow of energy from the power station to the home. These advanced monitoring and command systems could be called the grid's "reflexes." However, human intervention is constantly required to make important decisions related to control and security, based on the most recent and relevant data available. This decision-making centre is at the heart of the energy-supply chain: it is the "brains" of the power system. At Hydro-Québec, it is called the System Control Centre, or SCC.

The strategic role of the SCC

The SCC operates round the clock and responds instantly to the power needs of Québec—its first priority—followed by those of its customers outside Québec. The SCC regulates the generation and transmission of power, as well as energy trading with neighboring power systems through interconnections (there are 16 of these border-crossing facilities creating a physical link with systems outside Québec). To improve the decision-making process, the SCC centralizes all the information required for system operations. Seven regional telecontrol centres implement SCC decisions regarding power generation and transmission, and power trading via interconnections. The SCC's multidisciplinary team includes about 150 experts, including planners, computer specialists and technical maintenance and troubleshooting units.



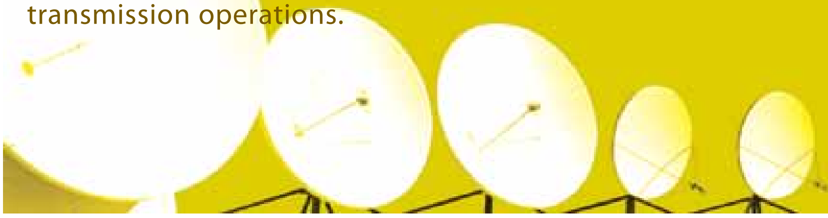
200
SERVERS AND WORKSTATIONS

THE HYDRO-QUÉBEC SYSTEM IS ONE OF **THE MOST AUTOMATED POWER GRIDS IN THE WORLD**

160
TELEMETERING AND TELESIGNALING STATIONS

A vast telecommunications network backs the power system

Hydro-Québec operates its very own telecom network. Its purpose is to transmit strategic data (e.g. for automatic control) and to enable verbal communications among utility staff. Whether they are located in urban centres or in remote areas, some 20,000 employees can connect with each other. In fact, the telecommunications network covers over half of Québec's territory. Network signals are transmitted over more than 16,000 circuits using fibre-optic links, microwave equipment and telephone cables. This network is like the "nervous system" of the utility's power transmission operations.

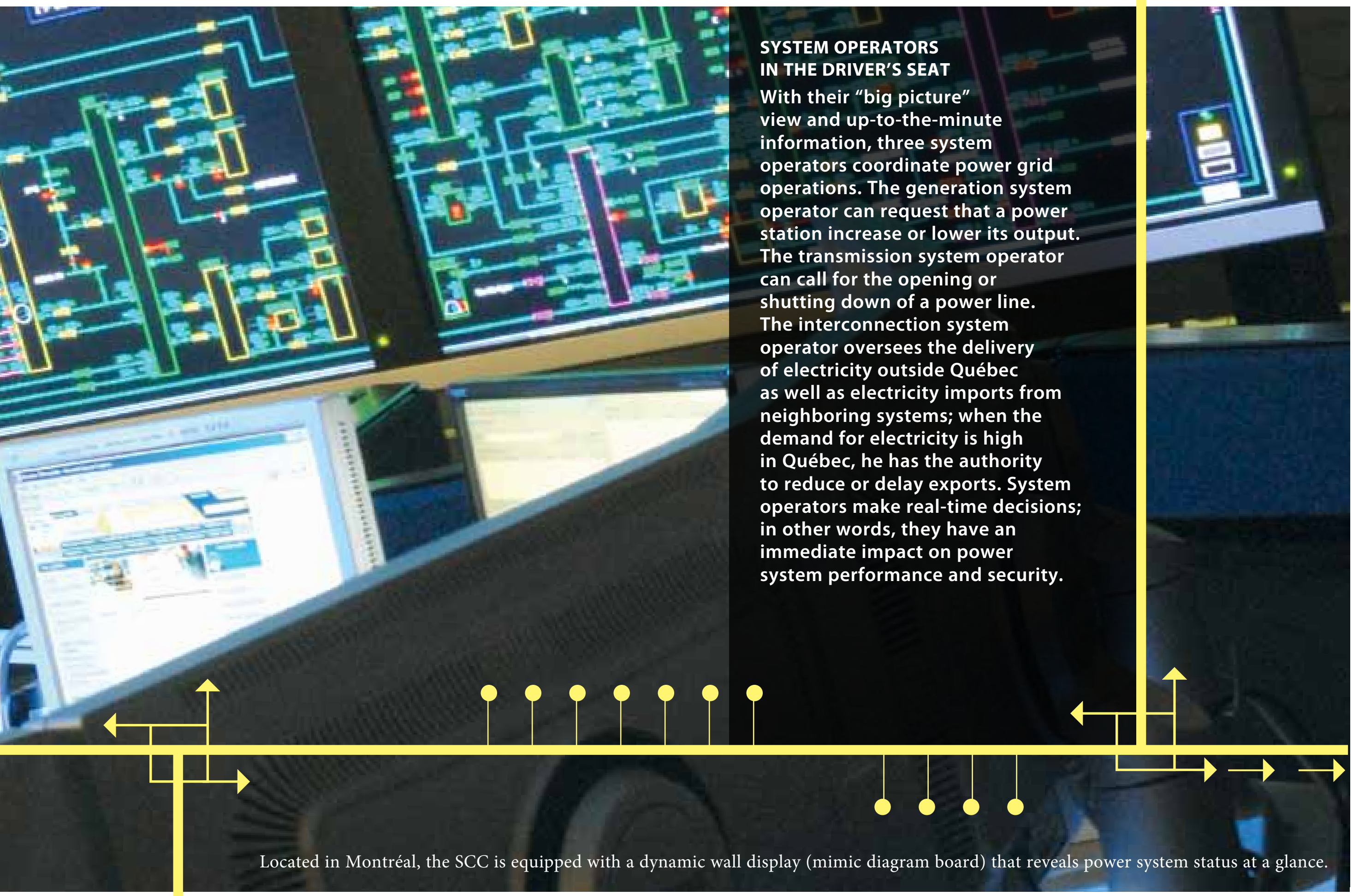


A FEW DEGREES MAKE A BIG DIFFERENCE

SCC decisions are also based on the latest meteorological data. The weather is indeed a factor in power generation (e.g. affecting water reserves) and in consumption patterns (e.g. cold snaps greatly increase demand). Major thunderstorms, ice storms and other extreme weather conditions can also have a direct impact on power transmission activities.

The buildup of ice on power lines, combined with strong winds, can lead to power failures. Québec residents are keenly aware of this fact... In January 1998, Québec was hit by one of the worst ice storms in its history. An unprecedented five days of ice accumulation dealt a blow to the power system and hundreds of structures collapsed. In the middle of winter, up to three million people were out of electricity for several days, and weeks in some cases. While its teams worked hard to rebuild lines and restore power, Hydro-Québec had already begun studying ways to prevent this situation from recurring. Solutions included developing new remote de-icing technology and anti-cascading towers. These towers are built especially strong and set between standard transmission towers to stop them from collapsing during extreme weather events, such as the 1998 ice storm.

5,500 DATA UPDATED EVERY 3 SECONDS



SYSTEM OPERATORS IN THE DRIVER'S SEAT

With their "big picture" view and up-to-the-minute information, three system operators coordinate power grid operations. The generation system operator can request that a power station increase or lower its output. The transmission system operator can call for the opening or shutting down of a power line. The interconnection system operator oversees the delivery of electricity outside Québec as well as electricity imports from neighboring systems; when the demand for electricity is high in Québec, he has the authority to reduce or delay exports. System operators make real-time decisions; in other words, they have an immediate impact on power system performance and security.

Located in Montréal, the SCC is equipped with a dynamic wall display (mimic diagram board) that reveals power system status at a glance.

22 500 DATA ACQUISITION POINTS

OSPREYS AND HIGH-WIRE NESTING...

Also known as the fish hawk, this bird of prey can cause power failures when it nests on Hydro-Québec structures. The nest is built using many dry branches and it can easily measure one metre in diameter. A single branch touching a cable is enough to create an electric shock and destroy the bird and its brood, not to mention causing system outages and fires. Hydro-Québec developed a solution in conjunction with McGill University: a pole with a platform on top is installed near the inhabited transmission tower and the osprey nest is simply moved over by helicopter! This measure is used especially in the Malartic region, in Western Québec, where the bird is fairly common.

question://

WHAT HAPPENS WHEN WE TURN ON AN ELECTRICAL APPLIANCE?

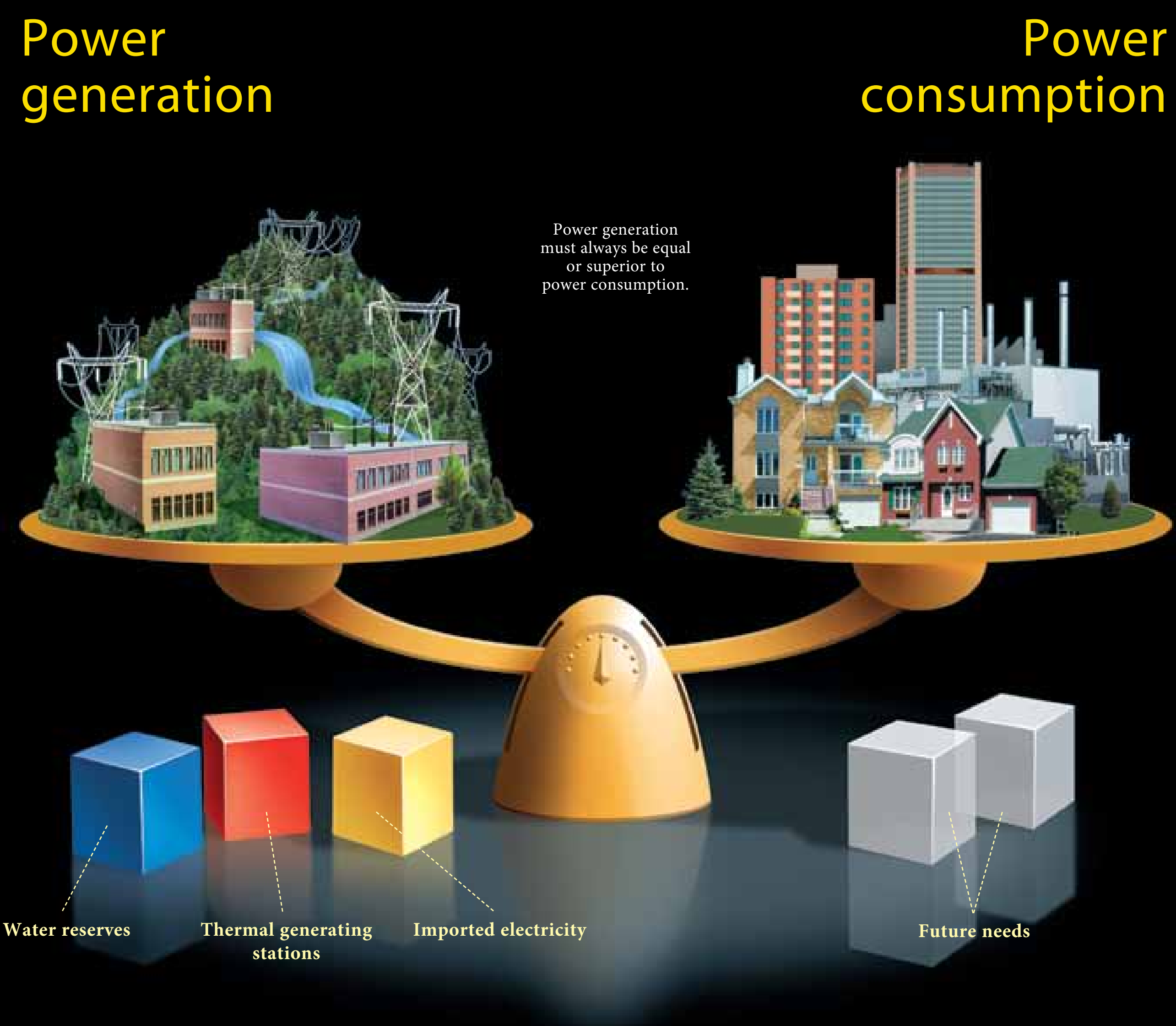
answer://

When we press on a switch—and the source of electricity is hydropower, as in Québec—we are in effect requesting that more water drive a turbine in order to generate moreelectricity and transmit a greater power flow fromthe generating station to our home. Turning on a single television set will not make a big difference. But if everyone in Québec were to turn on their set at the same time, demand would increase significantly! And yet, this is exactly what happens every day, for example, when we all turn on the kitchen stove to get supper ready around 6 p.m.

Beware of electric shocks!

We sometimes forget that electricity can be dangerous. The inappropriate use of an electrical appliance or the use of a damaged appliance can create an electric shock. As a result, a person's body becomes a path for electric current to reach the ground. The human body is a good conductor of electricity, but when current travels through the body it can cause serious injury: severe burns or even death. When a person gets an electric shock, the current passing through the body generates great heat, especially at the points where electricity enters and exits the body. However, by following effective safety measures, some of which are listed in this section, you can prevent electric shocks.

Figure 15 / **Supply-demand balance at Hydro-Québec**



Balancing supply and demand

Distributing electric power is like distributing water: it is always better to have too much to be sure tohave enough. As soon as a current is generated, it must be used. The reverse is also true: as soon as we turn on an appliance, power must be available. Regardless of the quantity required, electricity suppliers must meet demand instantly! Their capacity to respond quickly and effectively to variations in demand will depend on the flexibility of their generation facilities. If demand rises substantially—for example, because of a cold Québec winter—the supplier must distribute more electricity. When demand drops, as it does during Québec summers, power generators like Hydro-Québec use less water to drive turbines and can therefore store water in their reservoirs.

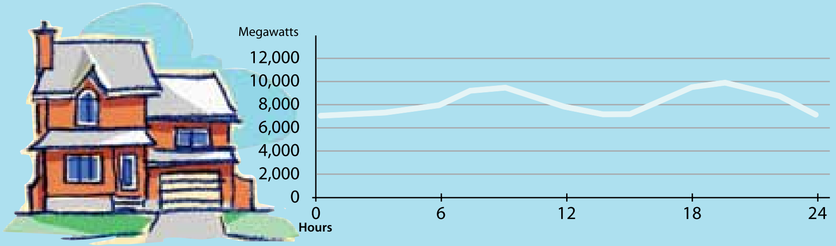
Table 13 / **CONVERTING UNITS FOR MEASUREMENT OF ELECTRICITY**

THE FOLLOWING PREFIXES LIST THE MOST COMMONLY USED DECIMAL MULTIPLES FOR MEASURING ELECTRICITY CONSUMPTION AS WELL AS OTHER ASPECTS OF THE ENERGY-SUPPLY CHAIN, INCLUDING KILOWATTHOURS (KWH), MEGAWATTS (MW), KILOVOLTS (KV), ETC.

	PREFIX	SYMBOL
1,000 = 10^3	KILO	k
1,000,000 = 10^6	MEGA	M
1,000,000,000 = 10^9	GIGA	G
1,000,000,000,000 = 10^{12}	TERA	T

Table 14 / **DAILY POWER-DEMAND VARIATIONS IN 2008**

RESIDENTIAL CUSTOMERS – AVERAGE CONSUMPTION IN WINTER



Power distribution

At last, we're getting close to home! Voltage has been lowered at a source substation, and again at a satellite substation.Only two steps remain before we can use this power: medium-voltage distribution and low-voltage distribution.

Electricity above

As a rule, medium-voltage three-phase alternating current leaves a satellite substation at 25,000 volts via underground power lines that become overhead lines some distance away. An overhead distribution system is made up of three bare phase conductors attached to insulators at the top of electricity poles. The bare neutral conductor, located a few metres beneath those three wires, is connected to a grounding system and contributes to occupational and public safety. The distribution grid also includes transformers, which are mounted on electricity poles; their purpose is to lower voltage from 25,000 volts to 120/240 volts—voltage intended for domestic use. This low voltage travels from pole to house on insulated conductors that can be overhead or underground.

Shocking news about live wires…

Birds and squirrels do not get electrocuted on a bare live overhead wire because they are not touching the ground, nor are they in contact with an object on the ground. However, if an animal or a person touches an electric wire while on the ground, on a ladder or on a roof, they may suffer an electric shock. Electricity would pass through their body to reach the ground. Even an insulated conductor can present a risk because birds and squirrels can peck and gnaw at its sheath, allowing electricity to reach the ground… through the person or animal that receives the shock.

Electricity below:

Overhead lines are not the only way of bringing power to homes. Neighborhoods that are free of electric wires and poles have underground power lines. When low-voltage lines are underground but transformers and medium-voltage lines are overhead, this is called a hybrid overhead/underground distribution system. When the system is entirely underground, medium-voltage lines are also buried, while transformers are mounted on a ground-level foundation pad or in an underground vault. The latter system is more common in densely populated areas and in certain housing developments.

Pad-mounted transformer

Montréal in the 1920s… Utility poles were everywhere. Today, over half the city's distribution grid is underground, which means that more than 4,000 kilometres of power lines have been buried.

In addition to improving the visual environment, undergrounding protects electrical equipment from bad weather and vegetation. It also helps create more open space in neighborhoods. In Québec, about 10% of distribution lines are buried beneath the surface. These numbers are consistent with undergrounding rates elsewhere in Canada. Undergrounding a power system is more expensive than building overhead lines; the decision is up to municipal and government authorities, not utilities.

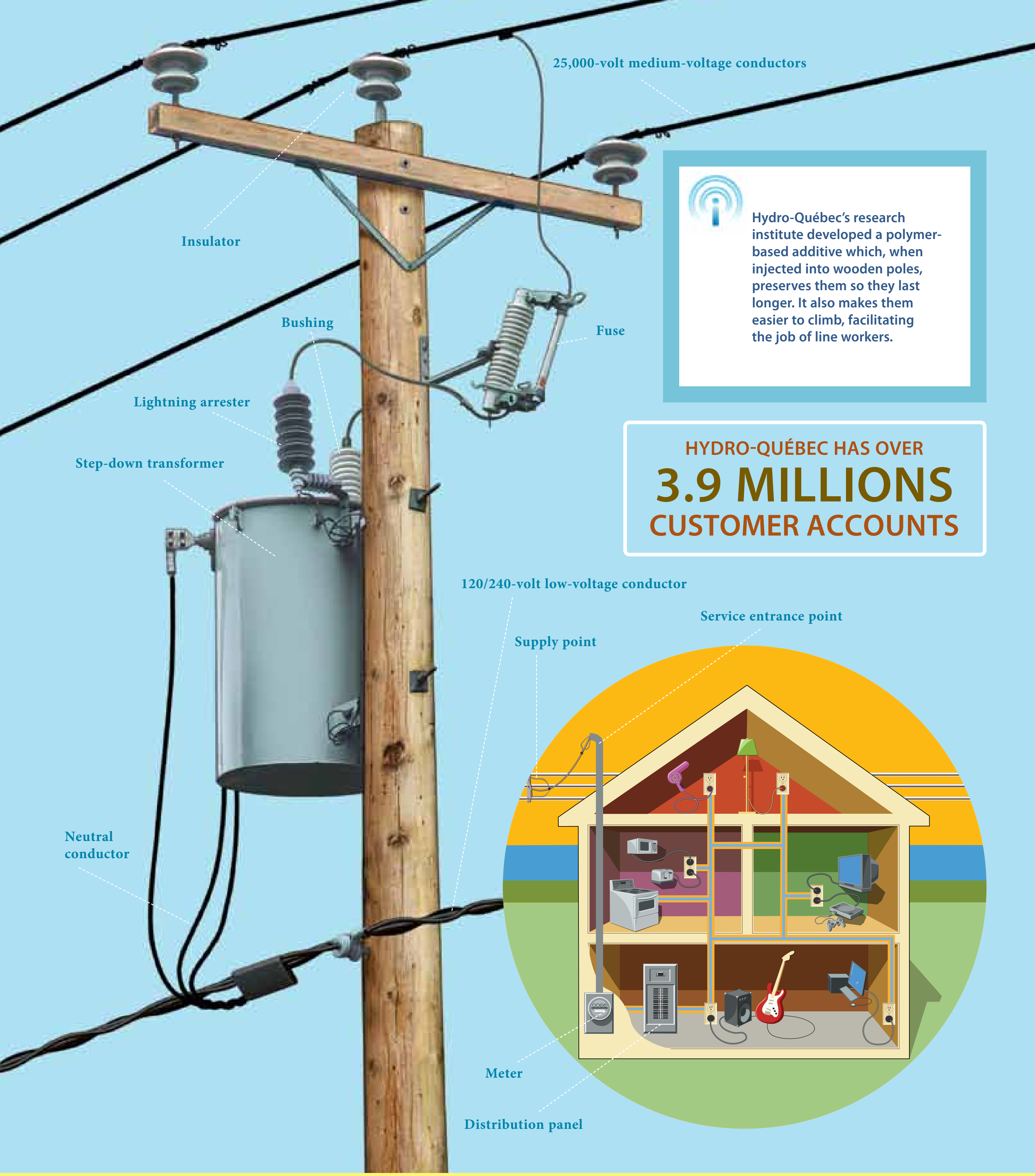
Table 15 / **HYDRO-QUÉBEC DISTRIBUTION EQUIPMENT IN 2009**

EQUIPMENT	QUANTITY
POLES (99% WOOD)	2,500,000
OVERHEAD LINES	100,000 KILOMETRES
UNDERGROUND LINES	11,200 KILOMETRES

CONTROLLING VEGETATION: THE WAY TO CUT DOWN ON POWER FAILURES

Electric utilities must periodically trim trees that grow near power lines to prevent vegetation from coming in contact with conductors and causing power outages. In Québec, more than 40% of power outages are caused by fallen branches or trees near overhead distribution lines. In certain areas, that percentage is much higher.

Figure 16 / **The wooden pole**



Hydro-Québec's research institute developed a polymer-based additive which, when injected into wooden poles, preserves them so they last longer. It also makes them easier to climb, facilitating the job of line workers.

HYDRO-QUÉBEC HAS OVER
3.9 MILLIONS
CUSTOMER ACCOUNTS

SAFETY AROUND THE HOUSE

Whether you are playing or puttering around the house, keep in mind the location of power lines; they always pose a risk of danger. These basic safety guidelines can prevent accidents and save lives, including your own... Play it safe!

- Never try to trim trees planted near power lines; many people have been injured or have died from doing work around power lines.
- Never climb a tree that is close to power lines; it is best to play far away from power lines, when flying a kite for example.
- Always check the power cord before using an electric lawnmower, and use it only when the grass is dry.
- Beware of power lines when doing chores around the house—on the roof, for example, or when cleaning the pool using a long-handled tool; never spray water on power lines or touch power lines with your hand or a tool.
- Never attempt to climb or hang a clothesline on an electric utility pole; it is dangerous and illegal.

Electricity consumption

Every time we use an electrical appliance, we are consuming power. The resulting need for electricity from a utility is called demand. When you flick a switch, the required power leaves the distribution system for use in your home. Since there's a cost to consuming this power, meters record precisely the amount of electricity that flows into a building. As well, certain devices and procedures can help promote safety when using electricity.

From the meter to the breaker

Hydro-Québec's power system stops at the electric meter in your home. This highly accurate instrument records the volume of power used by a customer. The meter is connected to a distribution panel, also known as the breaker panel. This apparatus includes a main switch that can cut power to the entire house and contains as many circuit breakers as there are circuits in the house.

From the breaker to the user

Breakers are switches that automatically cut electric current when an overload or some other anomaly occurs. They prevent circuits from overheating, for instance because of a wiring problem or a defective appliance. To form a circuit, each breaker is linked by three wires to a series of outlets or electrical boxes. Some dedicated circuits have only a single outlet or electrical box—for example, the refrigerator and the water heater. Other circuits are wired to outlets with a ground fault circuit interrupter, such as bathroom outlets, to provide added protection against electricity-related accidents in the home.

ELECTRICITY RATES IN QUÉBEC ARE AMONG THE LOWEST IN NORTH AMERICA

FOR EXAMPLE, IF A BILL FOR MONTREALERS* WAS FOR **$100*** IN 2009,

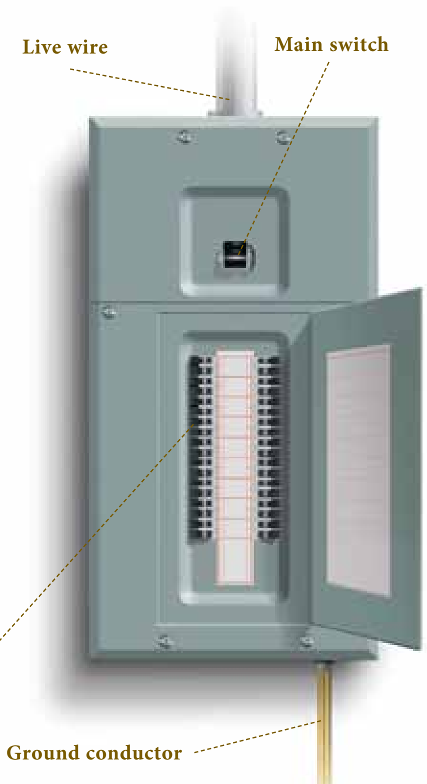
THE SAME ONE FOR CHICAGO RESIDENTS WOULD COME TO **$219** …MORE THAN DOUBLE,

WHILE THE SAME ONE FOR NEW YORKERS REACH **$369** …MORE THAN TRIPLE!

*According to electricity prices for residential customers effective in 2009 and based on a monthly bill (before taxes) for consumption of 1,000 kWh. Source: Hydro-Québec – *Comparison of Electricity Prices in Major North American Cities 2009.*

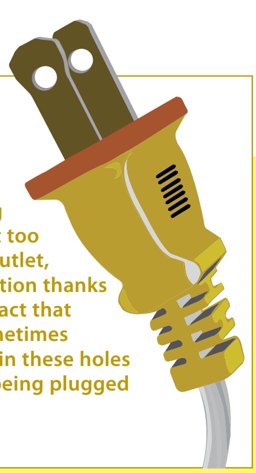
Figure 17 / Electrical distribution panel

The live, or "hot," wire delivers electric current. The neutral conductor, also called "return" because it returns current at zero voltage to the source of electric power, and the ground wire help protect users. The neutral and ground wires are hooked up to the same breaker terminal, which is connected to the ground conductor of the distribution panel.



WHY DO THE PLUGS OF MANY ELECTRICAL APPLIANCES HAVE A HOLE IN EACH PRONG?

These holes prevent the plug from coming out of an outlet too easily. When inserted in an outlet, prongs are wedged into position thanks to small bulges on each contact that fit snugly in these holes. Sometimes a plastic tie-wrap is inserted in these holes to prevent appliances from being plugged into an outlet.



SAFETY TIPS AT HOME

Circuit breakers cut power when a problem is detected. But occupants also have a role to play in ensuring personal safety in the home.

- Unplug the toaster before trying to remove a slice of bread that is stuck inside, and never insert utensils in a toaster.
- Never plug an appliance into a bathroom outlet unless the outlet has a protective device (ground fault circuit interrupter) that automatically deactivates the electric circuit to avoid a shock.

Figure 18 / **Electric meter**

Counting kilowatthours

An electric meter is equipped with a disk and four small dials showing the numbers 0 to 9. When an electric current passes through the meter, the disk rotates and drives a tiny sprocket wheel, which in turn drives the pointer on the units dial. After one complete turn, this pointer drives the pointer on the tens dial, and so forth for the hundreds dial and the thousands dial. To determine your consumption, a Hydro-Québec meter reader records the exact position of each pointer when he or she calls at your home. Your bill is based on the difference between the previous reading and the current reading.

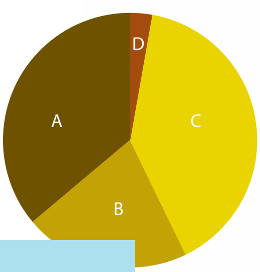


Table 16 / **BREAKDOWN OF ELECTRICITY CONSUMPTION IN QUÉBEC IN 2008**

A	RESIDENTIAL AND FARM	36%
B	GENERAL AND INSTITUTIONAL	21%
C	INDUSTRIAL	40%
D	OTHER	3%

RADIO-FREQUENCY METERS

Since 1997, radio-frequency meters have been making their way into Québec households. Today, Hydro-Québec's fleet includes more than 650,000 of these appliances.

Within the next few years, Hydro-Québec plans on replacing the 3.7 million existing models with next-generation meters. The new meters will communicate the customer's consumption data remotely.

- **When unplugging an appliance from an outlet, always pull on the power plug rather than the supply cord.**
- **Unplug a kettle, iron or coffee machine before filling it with water.**
- **Avoid circuit overloads and fire hazards by spreading the load over several outlets, by unplugging unnecessary appliances and by using a power bar.**
- **Never break off or fold back the rounded grounding prong of a three-prong plug, or circumvent the problem by using a three-hole, two-prong adapter.**
- **Use outlet covers to prevent children from inserting objects or fingers in outlets.**
- **Keep electric wires out of the reach of children.**
- **Unplug appliances that need repair or lamps that require a new lightbulb.**
- **Cut all power at the main switch before hitting nails or drilling holes in the wall, and before trimming wallpaper around outlets and light switches.**

Energy efficiency

We can save energy fairly easily on a daily basis by doing small things that, when multiplied on a large scale, can make a big difference. By lowering our electricity consumption, not only do we reduce our electricity bill, we also stand to gain collectively in terms of the environment. In fact, the electricity we save can be used for other purposes, such as the electrification of transportation, which contributes to reducing greenhouse gas emissions.

Energy-wasteful or energy-wise?

There are many ways of wasting energy. An appliance that consumes a lot of electricity can be described as energy-greedy. A person can also be energy-greedy if his or her behavior patterns are energy-inefficient. By using power carefully and responsibly, we can curb overconsumption. It may simply be a matter of adopting new habits that are less energy-intensive or choosing appliances for their lower power consumption. Here are a few energy-wise facts and tips…

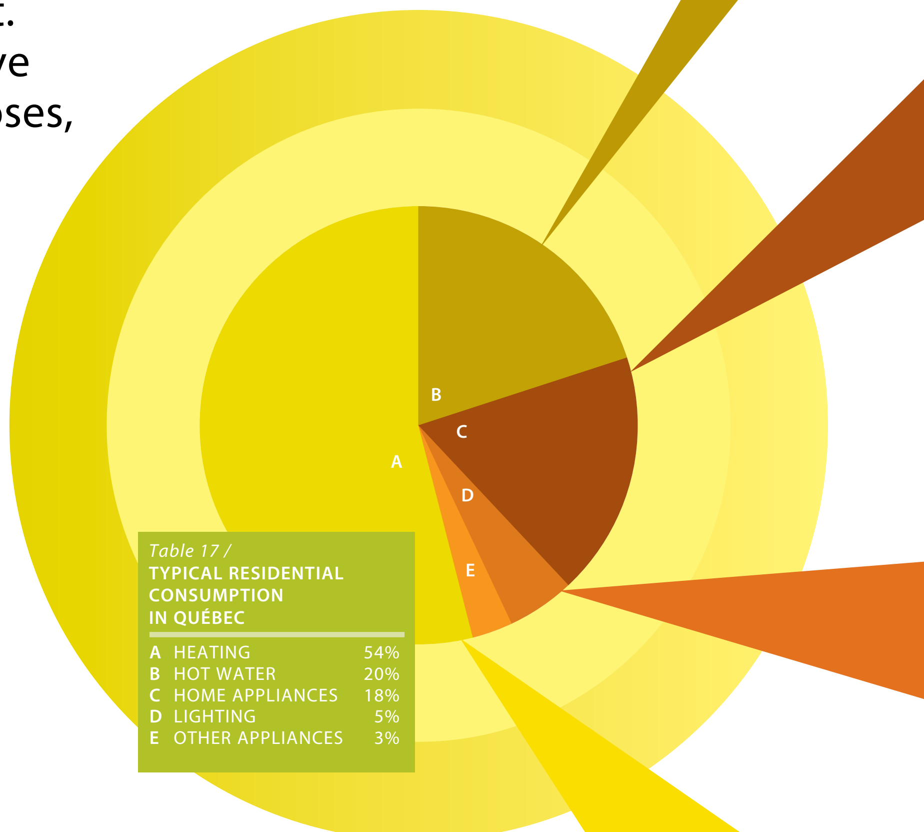
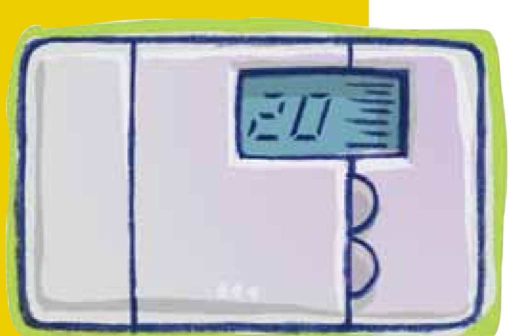


Table 17 /
TYPICAL RESIDENTIAL CONSUMPTION IN QUÉBEC

A	HEATING	54%
B	HOT WATER	20%
C	HOME APPLIANCES	18%
D	LIGHTING	5%
E	OTHER APPLIANCES	3%



Heating

Heating costs alone account for more than 50% of your electricity bill. You can save a great deal just by changing a few of your habits.

- **Carefully caulk all openings to the outdoors (pipes, ducts, doors and windows) to eliminate heat loss and therefore reduce heating costs while increasing your comfort.**
- **Set the temperature in occupied rooms at 17°C at night or when you're away, and at 20°C when you are home during the day; set the hallway thermostat at 15°C and unoccupied rooms at 10°C (make sure to keep the doors closed).**
- **If you use electric baseboard heaters, replace your regular thermostat with an electronic thermostat that you can program.**
- **Insulate the basement or improve existing insulation.**

54%

Hot water

The second major electricity expense in your home is hot water. It accounts for 20% of your bill. A 180-litre (40-gallon) hot-water tank is generally sufficient for three people.

- Avoid heat loss by covering your water heater with an insulating jacket and wrapping the hot-water pipes with insulation, especially any long pipes running across unheated areas.
- Set your water heater to 60°C and take shorter showers.
- Repair leaky faucets; one drop per second wastes 27 litres of hot water per day.
- Operate your washing machine only with a full load and wash with cold water whenever possible.
- Run your dishwasher only with a full load, preferably without the drying cycle.

20%

Home appliances

Many other appliances (e.g. kettle, kitchen stove, clothes dryer, air conditioner, microwave oven, etc.) can consume a lot of power if not used carefully.

- Use an electric kettle with only as much water as you need; it's the least expensive way to boil water.
- For cooking small quantities of food, use the microwave instead of your regular oven, and defrost your food in the refrigerator rather than in your microwave oven.
- Use pots with well-fitting lids; do not preheat your oven for more than 10 minutes, and turn it off a few minutes before your food is ready… the accumulated heat will finish the cooking process.

18%

Lighting

While it only represents a fraction of your electricity bill, lighting can nonetheless provide substantial savings.

- Replace incandescent bulbs with compact fluorescent bulbs, which use 75% less power to produce the same amount of light and last up to 10 times longer.
- Turn off the lights when you leave a room.

5%

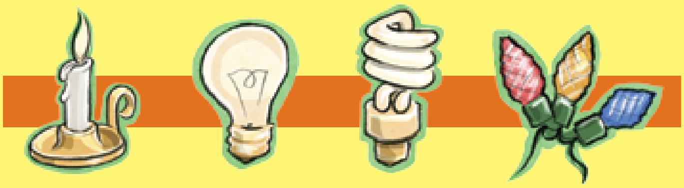
IF QUÉBEC'S 7,500,000-ODD RESIDENTS SIMULTANEOUSLY TURNED ON

A 100-WATT LIGHTBULB,

THE DEMAND WOULD SOLICIT THE ENTIRE OUTPUT OF CARILLON GENERATING STATION, NAMELY 752,080 KW!

SUPPORTING INDUSTRIAL ENERGY EFFICIENCY

The energy technologies laboratory (LTE)—part of Hydro-Québec's research institute—developed a diagnostic tool to help industrial customers improve their energy efficiency. Based on a questionnaire filled out by the customer, this tool automatically generates a consumption profile featuring tailored recommendations linked to Hydro-Québec's energy efficiency programs. A technological innovation that will help industrial customers be energy wise!



LIGHTBULBS: FROM INCANDESCENT TO LED

Until 1879, the only way to light up a house was to use gas lamps, oil lamps or candles. And yet, much was already known about electricity. For example, people knew that it could power a light source; an electric current passing through a filament in a vacuum created resistance that made the filament glow. The problem was finding a filament that would not disintegrate when heated to incandescence. After extensive research and tests involving over 6,000 substances from all over the world, American inventor Thomas Alva Edison deduced that a filament made simply of carbonized cotton thread was the most effective solution. On October 21, 1879, his incandescent bulb glowed continuously for some 40 hours, a breakthrough at the time. Nowadays, all over the globe, incandescent bulbs are being replaced by compact fluorescents, which are more efficient and save energy. Light-emitting diode (LED) bulbs, which are becoming increasingly popular in holiday lights, may start being used more and more, even for general lighting, since they consume very little electricity.

question://

WANT TO KNOW MORE ABOUT ELECTRICITY?

answer://

Many other reference works can provide in-depth information on electricity. You can also find out more about Hydro-Québec's activities from a variety of sources.

- **www.hydroquebec.com**
  The world of electricity is constantly evolving, especially at Hydro-Québec! Tour our website to see what's up, including the latest developments in Québec's hydroelectric sector.

- **Taking care of the environment**
  Hydro-Québec's commitment translates into concrete actions that range from useful mitigation measures to sound environmental management.
  www.hydroquebec.com/sustainable-development

- **Overview of construction projects**
  A brief look at Hydro-Québec projects under construction and under study in Québec.
  www.hydroquebec.com/projects

- **Transportation electrification**
  Electricity will be playing an increasingly important role in ground transportation. Find out how it could change personal and public transportation.
  www.hydroquebec.com/transportation-electrification

- **Guided tours of our facilities**
  Explore the world of electricity, discover a rich heritage and admire our large-scale achievements! Hydro-Québec offers free tours of generating stations, dams and other facilities.
  www.hydroquebec.com/visit

- **Advancing science**
  With its broad range of R&D projects, Hydro-Québec's research institute is a leader in technological innovation, an economic issue of prime importance to Hydro-Québec.
  www.hydroquebec.com/innovation/en

Flash Facts

1. Which home appliance consumes the most electricity?
2. How many hours must you operate a 60-watt lightbulb to use the same amount of electricity needed to heat water for a bath?
3. True or false? Using a 1,190-watt microwave oven for 4 minutes consumes as much electricity as a 60-watt lightbulb over one hour.
4. True or false? If 15 people held hands and the first person got an electric shock, the last person would also feel the shock.
5. I demonstrated that lightning is static electricity. My name is...
6. I am credited with developing 735-kilovolt power transmission. My name is...
7. My name is Alessandro Volta and in 1800, I invented...
8. At what time of day do we consume the most electric power?
9. Placed end to end, Hydro-Québec power transmission and distribution lines would circle the earth how many times?
10. How many watts are there in a megawatt?
11. In what year did the Québec government create Hydro-Québec?
12. The term *electron* comes from a Greek word that means...

1. Water heater - 2. 60 hours - 3. True - 4. True
5. Benjamin Franklin - 6. Jean-Jacques Archambault
7. The battery - 8. Around 6:30 p.m. - 9. Over three and a half times - 10. 1,000,000 - 11. 1944 - 12. Yellow amber

HYDRO-QUÉBEC'S TOP FACILITIES

THE WORLD'S FIRST 735-KILOVOLT POWER TRANSMISSION LINE

THE ONE LINKING THE MANIC-OUTARDES COMPLEX TO THE CITY OF QUÉBEC AND TO MONTRÉAL, BUILT IN 1965

THE LARGEST POWER PLANT

ROBERT-BOURASSA GENERATING STATION

5,616 MEGAWATTS

It generates enough electricity to supply 1.4 million people, which amounts to the combined population of Québec City, Longueuil, Laval and Sherbrooke!

THE HEAVIEST WATER FLOW DRIVING A TURBINE

THE ONE AT LA GRANDE-1 GENERATING STATION

496 cubic metres/second

THE TALLEST ROCKFILL DAM

Sainte-Marguerite-3 dam

171 METRES HIGH

THAT MATCHES THE HEIGHT OF A 56-STORY BUILDING!

THE WORLD'S TALLEST MULTIPLE-ARCH-AND-BUTTRESS DAM

Daniel-Johnson dam

214 METRES HIGH

ITS MAIN ARCH COULD HOLD MONTRÉAL'S PLACE VILLE MARIE BUILDING!

THE HYDROPOWER PLANT WITH THE TALLEST HEAD

SAINTE-MARGUERITE-3 GENERATING STATION

330 METRES

THAT'S 6 METRES HIGHER THAN THE EIFFEL TOWER, INCLUDING ITS ANTENNA!

THE TALLEST HIGH-VOLTAGE TRANSMISSION TOWER

The one near Tracy generating station, used to cross the Fleuve Saint-Laurent (St. Lawrence River) between Berthierville and Tracy

174.6 METRES HIGH

THAT'S AS TALL AS MONTRÉAL'S OLYMPIC STADIUM!

SAINTE-MARGUERITE-3 GENERATING STATION OPERATES THE TWO MOST POWERFUL TURBINE-GENERATOR UNITS

441 MEGAWATTS EACH

THE WORLD'S LARGEST UNDERGROUND POWER PLANT

Robert-Bourassa generating station

483 METRES LONG, 137 METRES DEEP

THE POWERHOUSE IS BIGGER THAN FOUR SOCCER FIELDS PLACED END TO END!

THE LARGEST RESERVOIR

(VOLUME OF WATER AVAILABLE TO GENERATE POWER)

CANIAPISCAU RESERVOIR

39 BILLION CUBIC METRES

THE FASTEST-SPINNING TURBINE-GENERATOR UNITS

LA CITIÈRE, TRACY AND BÉCANCOUR GENERATING STATIONS:

3,600 RPM

THE LARGEST RESERVOIR (SURFACE AREA)

Caniapiscau reservoir

4,318 SQUARE KILOMETRES

ITS SURFACE IS JUST OVER FOUR TIMES THE AREA COVERED BY LAC SAINT-JEAN.

The turbine-generator unit with the highest output

THE ONE AT GENTILLY-2 NUCLEAR POWER PLANT

675 MEGAWATTS

IT CAN SUPPLY POWER TO 100,000 RESIDENTIAL CUSTOMERS.

THE LARGEST RESERVOIR (TOTAL VOLUME)

Manic 5 reservoir

139.8 BILLION CUBIC METRES

IT RANKS AMONG THE WORLD'S 10 LARGEST ARTIFICIAL RESERVOIRS IN TERMS OF VOLUME!

LEARN WHILE HAVING FUN!

Discover more about the world of electricity using entertaining, hands-on learning tools. Here is an overview of Hydro-Québec pages on the Internet aimed at energizing the learning process.

- Games for learning about electricity, including games to:

  Build a power system from the generating station to Catshock's home!

  Go hunting for hazards with Catshock as your guide!

- History of electricity in Québec, from 1878 to the present day
- What you need to know and do about safety
- Understanding your consumption
- Guided tours of Hydro-Québec facilities

OTHER SOURCES OF INFORMATION

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Hydro-Québec: After 100 Years of Electricity, André Bolduc, Clarence Hogue and Daniel Larouche, Éditions Libre Expression, 1989.

La libéralisation des marchés de l'électricité, Henri Lepage and Michel Boucher, Éditions Saint-Martin, Institut économique de Montréal, 2001.

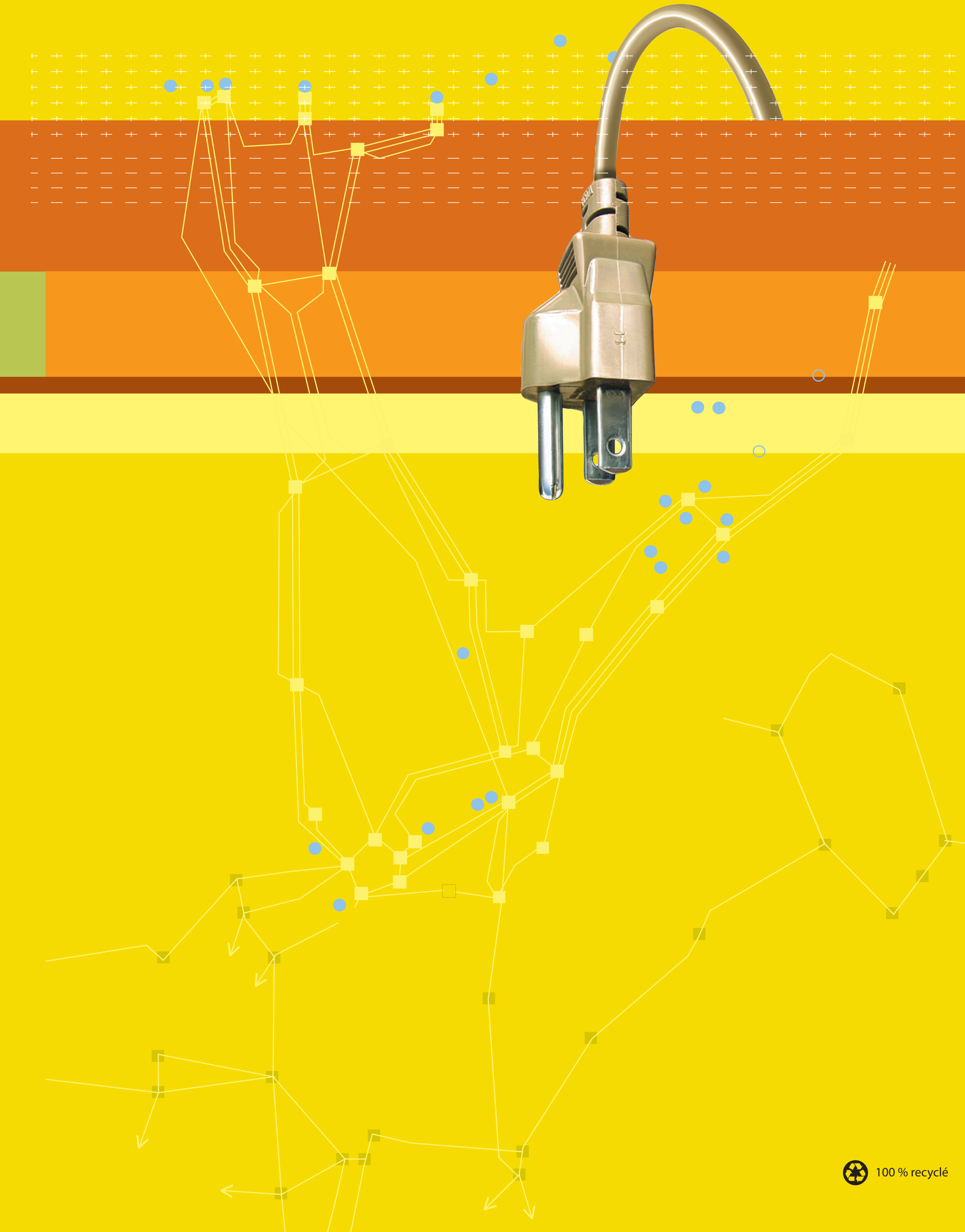
www.hydroquebec.com/learning

index://

The following is an inventory of key words used in this document, along with lists of figures and tables.

/ LIST OF TABLES

/ LIST OF FIGURES



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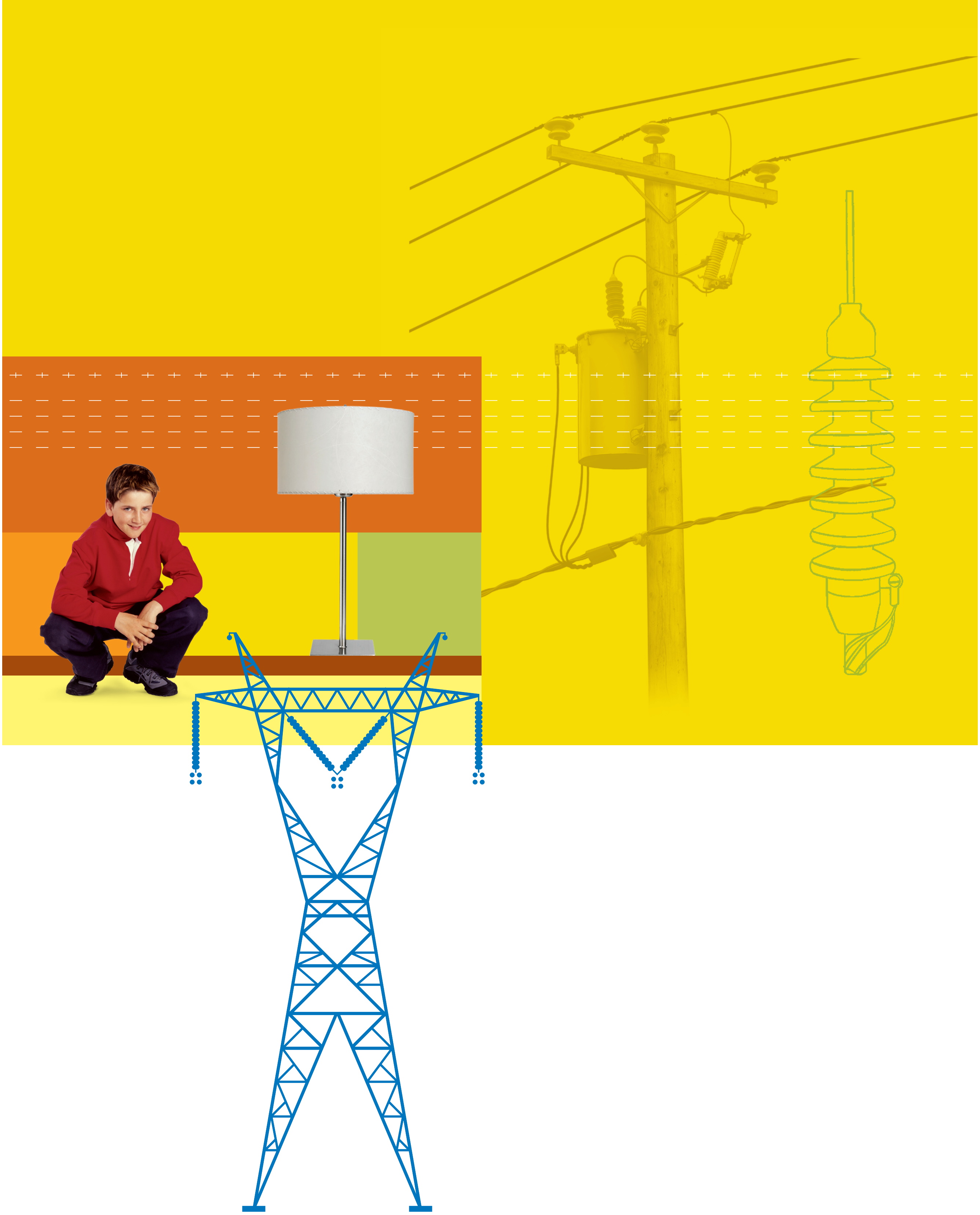

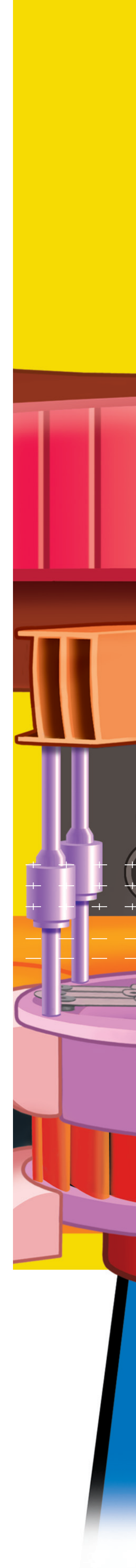

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