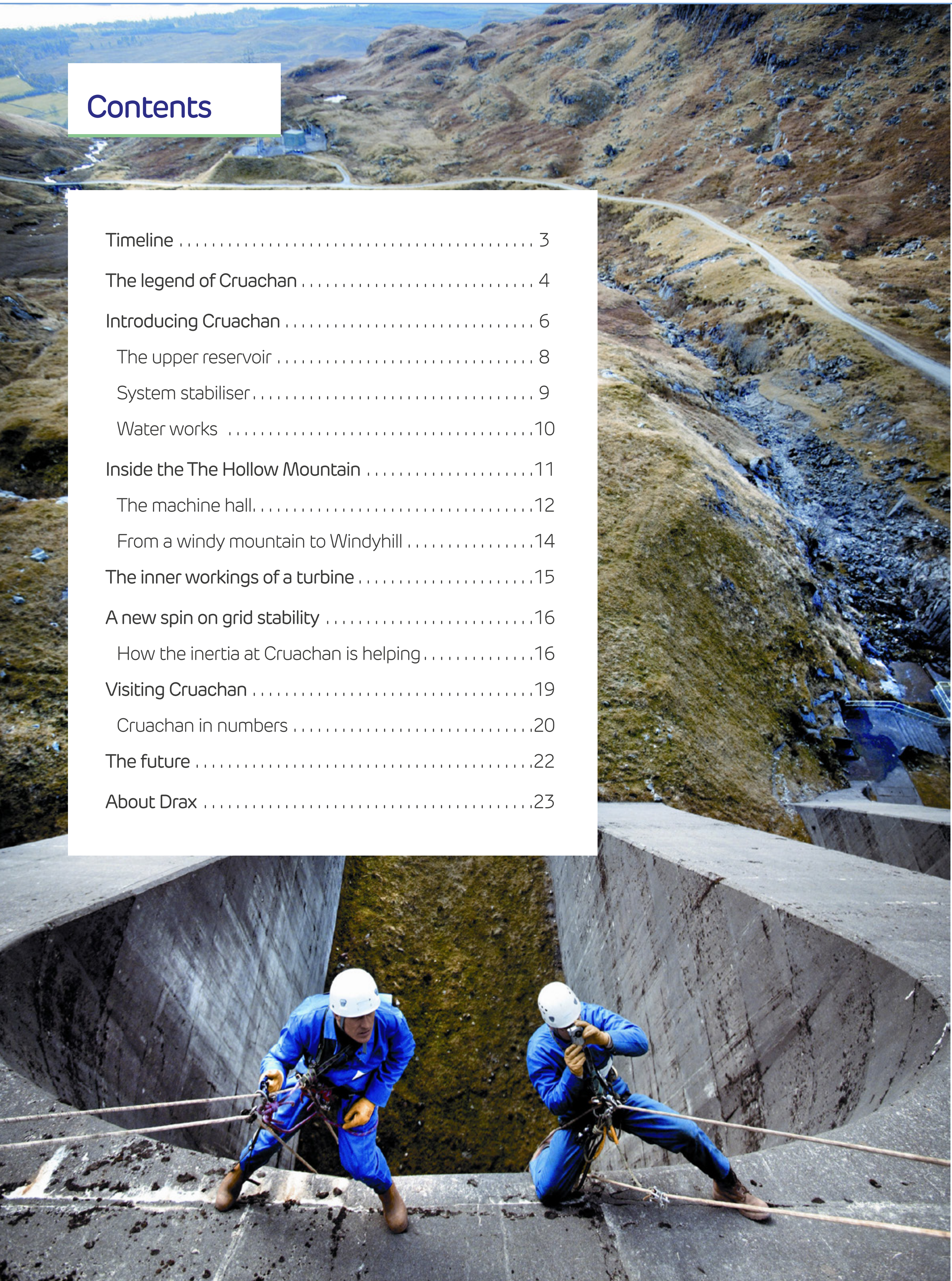
Cruachan

The Hollow Mountain

Discover the secrets hidden inside
the mountain that never sleeps



Contents

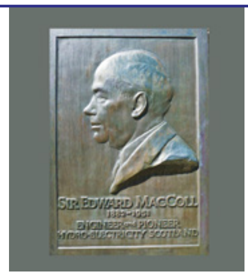
Timeline

1921

The final report of the Water Power Resources Committee, set up to investigate potential sources of hydro power in Britain, describes schemes for Loch Awe and Loch Nant.

1930s

Sir Edward McColl, a pioneering hydro power engineer comes up with the idea of bringing hydro-electricity to the Highlands.

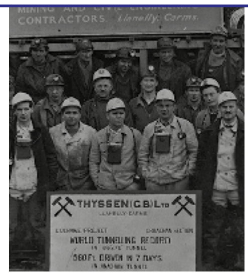


1947

Tom Johnston, wartime Secretary of State for Scotland and an advocate of hydro-electric power, helps The Hollow Mountain scheme get through Parliament.

1959

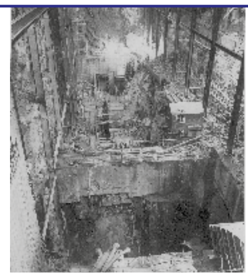
Construction at Cruachan begins with the excavation of the access tunnels and adits (horizontal passages, also for access or for drainage).



1960

A 275,000volt (V) transmission line is built to carry power from the top of the cable shaft to Dalmally substation, then on to Windyhill near Glasgow.

1960 - 65

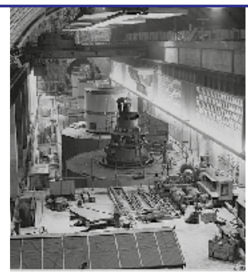


Work starts on the large caverns that will house the main machinery and transformers, and the two-year construction of the massive buttress dam begins.

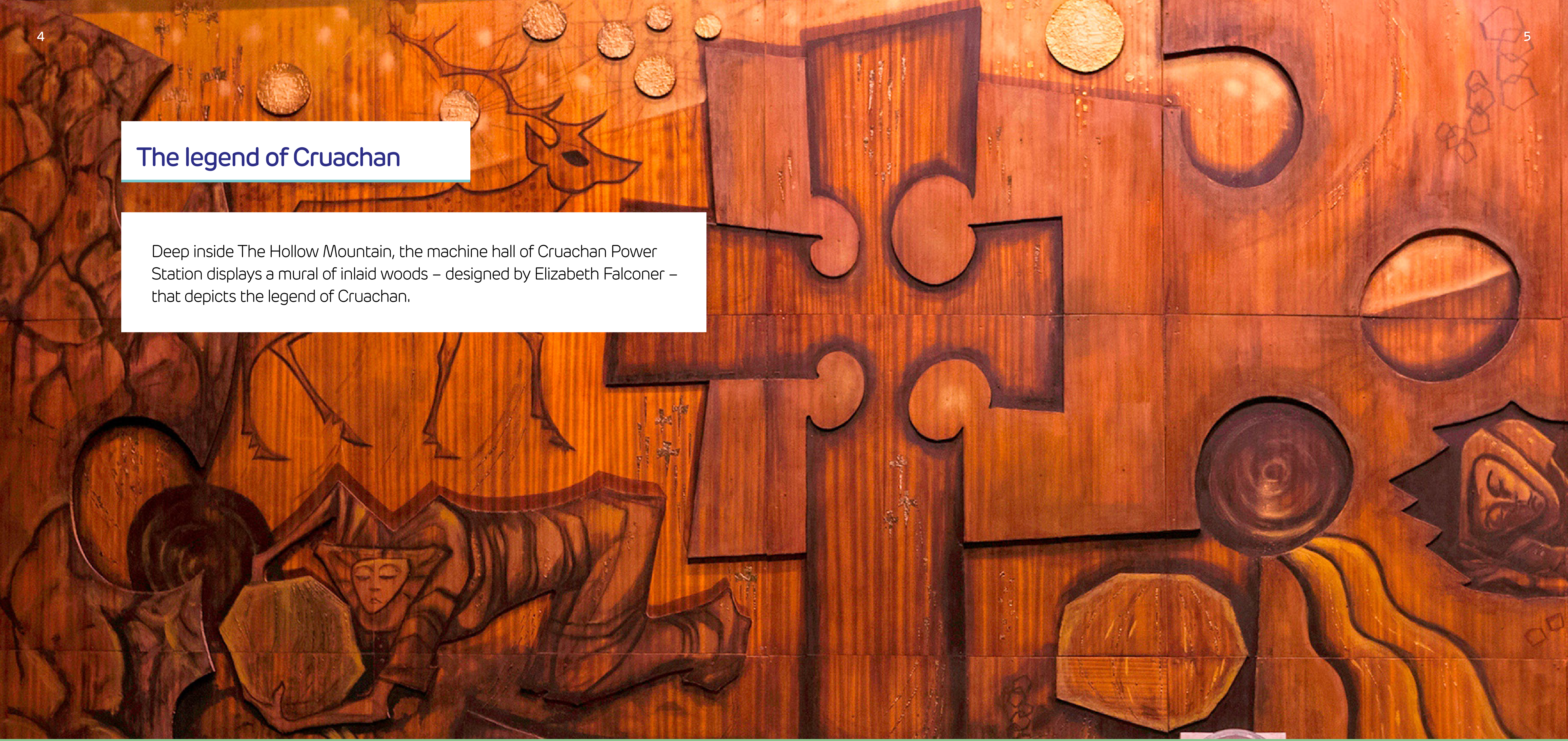
1965

Work concludes on two of the generator/turbine sets. On 15 October, Her Majesty Queen Elizabeth II officially opens Cruachan Power Station.

1967



The last of the four generator/turbine sets comes into service.



The legend of Cruachan

Deep inside The Hollow Mountain, the machine hall of Cruachan Power Station displays a mural of inlaid woods – designed by Elizabeth Falconer – that depicts the legend of Cruachan.

The Cailleach Bheur (the Old Hag of the Ridges) was the guardian of a spring at the peak of Ben Cruachan. It was her duty at sundown to cover the spring with a slab of stone and then lift it away at sunrise.

One evening, she fell asleep and the spring overflowed before rushing down the mountainside. Before she awoke, the water flooded the wide valley below and drowned all the people and their cattle. The flood created both Loch Awe and the River Awe, which burst open a new outlet to the sea through the Pass of Brander.

The Cailleach was turned to stone and, to this day, sits high on the mountain above the Pass of Brander.

Introducing Cruachan

Owned and run by Drax, a renewable energy leader and biomass pioneer, Cruachan is a reversible pump-storage power station in Argyll and Bute, Scotland. The plant's capable of producing 440 megawatts (MW) of electricity enough capacity to power more than 90,000 homes.

The Drax generation assets in Scotland and England make it the UK's largest source of renewable electricity by output.

As well as generating power, Cruachan stores it too - it's one of only four pump-storage facilities in Britain. Pumped storage is one of the oldest forms of large-scale energy storage, requiring two reservoirs close to each other and at different altitudes.

Rising steeply from the banks of Loch Awe (acting as a lower reservoir), Ben Cruachan also has an upper reservoir. In addition, the area's one of the wettest in Europe – a combination of factors that make it a perfect location for this type of power station.

A hidden gem

Because the power station sits deep within the heart of Ben Cruachan, there's little visible evidence of its existence from the outside. The only clues are the high storage dam on the mountain's slopes and the administration building beside Loch Awe. Cut deep into the mountain, almost 400 metres (m) below the upper reservoir there are several huge chambers housing an underground generation facility.

The plant's capable of producing 440MW of electricity, enough capacity to power more than 90,000 homes.

System stabiliser

Cruachan's third main purpose – after generation and storage – is to provide stability to the UK's national electricity grid. Across the electricity system, generation involves turbines spinning – yet some can do more than produce power; they can add something called inertia to the system.

System inertia is energy stored in spinning plant and it slows down the rate at which the electricity frequency changes. Rapid changes in frequency can create system instability, so inertia helps to make it stable, safe and efficient.

The upper reservoir

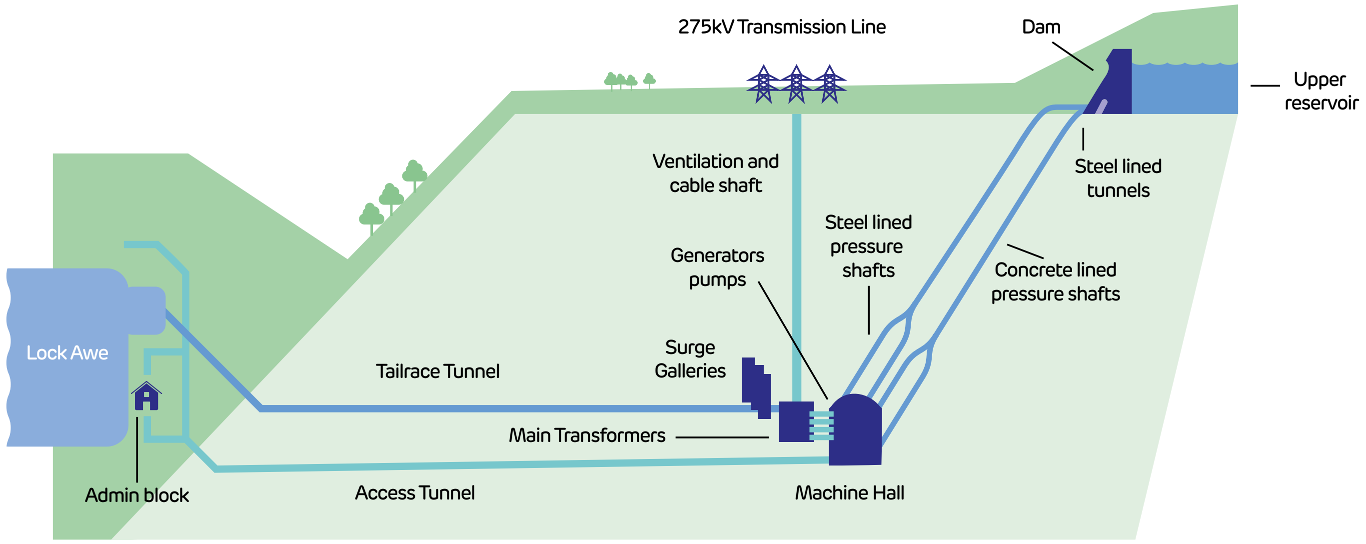
The upper reservoir sits high on the flanks of Ben Cruachan. A gravity buttress dam – 316m long and 46m high – holds back the water as it stretches across a windswept, basin-shaped hollow.

The dam houses two intakes that feed water to the power station. It's possible to close each intake with a 3.7m x 4.9m control gate, backed up by a 3.8m x 5.9m bulkhead gate.

There are 19 kilometres (km) of tunnels and piped aqueducts diverting water from streams around the mountain (an area where annual rainfall is 292cm) into the upper reservoir. This effectively increases its catchment area from 8km² to 23km² and supplements the water that's pumped up to it from Loch Awe.

Ben Cruachan's gravity buttress dam is 316m long and 46m high

This guidebook takes you inside The Hollow Mountain to reveal its secrets. You'll discover how it was built and works today, why it's so vital in Britain's electricity system, and what Drax has planned for its future.



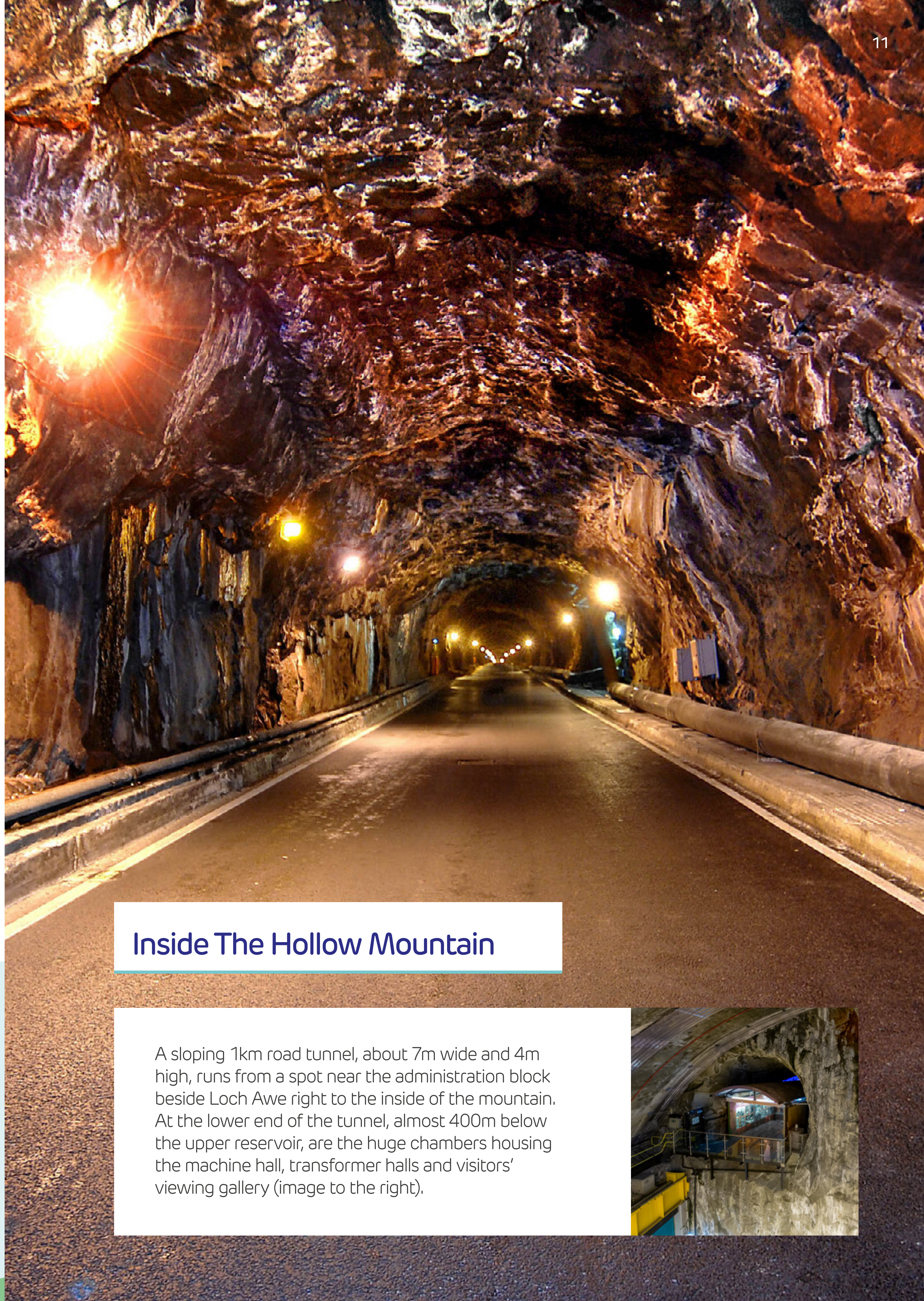
Water works

When electricity demand rises, water released from the upper reservoir flows through a turbine and into the lower reservoir (Loch Awe). The flow of water rotates the turbine, which spins a generator to produce the power needed.

At times of low demand, the turbine can use electricity from the grid to drive itself in the opposite direction. This pumps water up from the loch into the upper reservoir although, due to the loch's large surface area, the power station's operations have little effect on its water levels.

For a more detailed explanation of how Cruachan Power Station works, see **Inside The Hollow Mountain** on pages 11-17.

A sloping 1km road tunnel runs...
right to the inside of the mountain.



Inside The Hollow Mountain

A sloping 1km road tunnel, about 7m wide and 4m high, runs from a spot near the administration block beside Loch Awe right to the inside of the mountain. At the lower end of the tunnel, almost 400m below the upper reservoir, are the huge chambers housing the machine hall, transformer halls and visitors' viewing gallery (image to the right).

The machine hall

About 90m long and 36m high, the machine hall that houses the turbine and generator sets is the power station's largest chamber. In fact, it's big enough to contain a seven-storey building erected on a full-size football pitch.

There are four more levels below the machine hall floor, stretching down to the turbine runners 50m beneath the level of Loch Awe.

The four generator/motor sets within the machine hall each absorb around 110MW of electricity when pumping; together, they generate 440MW. The total weight of each combined generator/pump and turbine/pump is 650 tonnes; on each machine, the rotating parts alone weigh 250 tonnes.

The part of each machine that's visible from the visitors' viewing gallery is called the pony motor (or induction motor). Rated at 10,000 horsepower, each pony motor's purpose is to spin the machine from a resting position to synchronous speed (see A new spin on grid stability on page 16). The pony motor disengages once the main rotor has started to drive the pump, which lifts the water to the upper reservoir.

About 90m long and 36m high, the machine hall's big enough to contain a seven-storey building erected on a full-size football pitch.

Producing the power

From standstill, each machine can reach full generating output in two minutes and full pumping load in eight minutes. And it's possible to go even faster.

To speed up the generation process, the operators use compressed air to lower the water level in the turbine casing and clear the turbine runner. The turbines can then spin freely in air, without any water, to reach full output in seconds and provide immediate standby generating capacity.

Two of the machines connect to a 230 megavolt amperes (MVA) transformer, the other two each connect to a 150MVA transformer. Housed in large chambers near the main machine hall, these oil-immersed, water-cooled transformers convert the generated voltage of 16,000 volts (v) to the transmission voltage of 275,000v.

The need for speed

The speed of response that's possible at Cruachan is a major advantage over conventional forms of generation, such as using gas or nuclear for fuel.

In those cases, the power stations must increase their output and bring on additional generating sets to meet demand when it peaks. During periods of low demand, they must switch off the generator sets or run part loads. Either way, varying output to match demand is inefficient.

In contrast, pumped-storage power stations like Cruachan can minimise these changes in output. By always generating at full output, even when demand is low, they maximise energy efficiency and reduce the need to turn on any additional conventional generating sets.

What's more, Cruachan can use its reservoir to – in effect – store any excess electricity generated. By releasing the water to turn the turbines again, it helps meet the peaks in demand.

254 steel towers carry the power line

From a windy mountain to Windyhill

The transformers near the machine hall connect to its switchgear, and to the cable shaft, via busbars (metallic strips that both ground and conduct electricity) and cable tunnels.

The concrete-lined, vertical cable shaft (4m in diameter) houses the main power connections from the station to the transmission grid: six 275 kilovolt (kV) oil-filled cables.

The cables emerge from the shaft near the foot of the dam and connect to the terminal tower of a dual circuit 275kV transmission line. Then, 254 steel towers – 550m above sea-level at the highest point – carry the power line to the local switching substation at Dalmally then to Windyhill near Glasgow.

Going with the flow

When the machines within The Hollow Mountain are generating, water flows from the upper reservoir through two concrete-lined shafts known as penstocks.

Each penstock splits into two steel-lined pipes 2m in diameter that enter the machine hall, where a 1.8m diameter main inlet valve terminates their journey. Each valve allows the water to flow into the turbine; it opens and closes every time the machine operates.

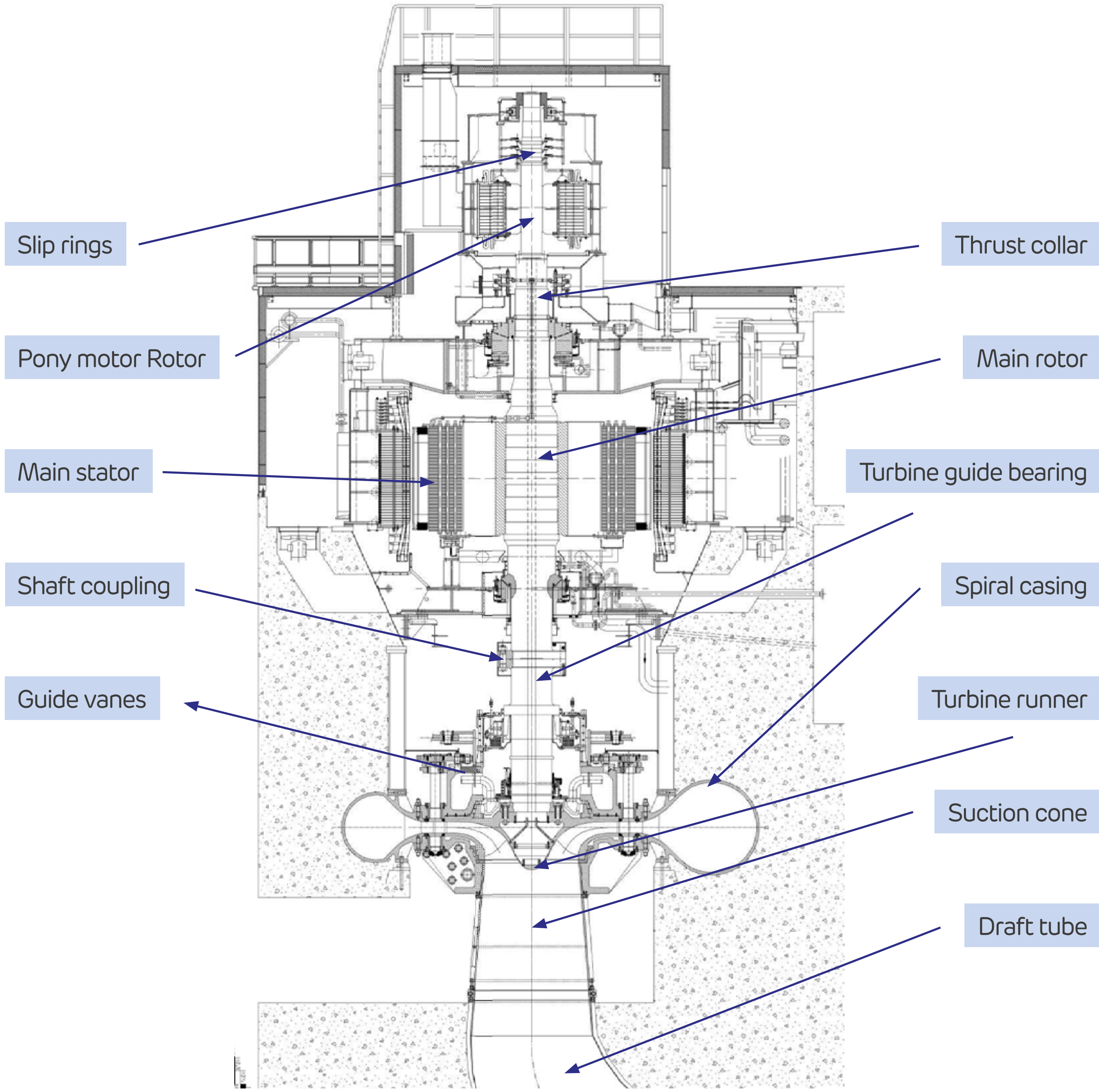
After passing through the four turbines, the water runs through a steel-lined draft tube pipe and up to a single, rectangular surge chamber. From here, the water flows to Loch Awe along a 975m long, 7m diameter, concrete-lined tailrace tunnel.

Shaped like a horseshoe in section, this tunnel enters Loch Awe at the forebay next to the visitor centre (see **Visiting Cruachan** on page 19). The forebay encloses the tunnel exit with screens to prevent fish being drawn into the power station.

When the machines are pumping, the flow of water reverses, moving it up from Loch Awe and through the mountain to the upper reservoir.

The inner workings of a turbine

Here's a cross-section diagram of a turbine, showing that most of the workings sit below the floor of the machine hall.



A new spin on grid stability

The level of inertia is falling on the electricity systems of Great Britain and other countries. That's because the world's moving away from coal and gas to renewables such as wind turbines, solar panels and interconnectors.

However, the renewable power generated from wind and solar sources isn't synchronised to the grid. So the industry refers to the machines producing these kinds of renewable electricity as asynchronous generators. What's more, these asynchronous generators have no readily-accessible stored energy (inertia) and don't contribute to system stability.

Due to the UK's ongoing transition to renewable electricity, the grid's system operator (the National Grid ESO) contracted several third parties to provide inertia when needed. At the start of 2020, it awarded Cruachan a six-year contract to support the system and help maintain secure supplies. This means one of the plant's four turbines will stop generating power and instead only provide the system services needed.

How the inertia at Cruachan is helping

Electricity generators that spin at 3,000 revolutions per minute (rpm) are called synchronous generators because they're in sync with the UK grid's frequency of 50 Hertz (Hz). Although most spin at 3,000 rpm, some go more slowly (e.g. 750 rpm). However, thanks to their design, they all synchronise together at the same, higher speed.

It's important to keep Great Britain's whole grid within 1% of the 50Hz frequency, otherwise the voltage of electricity starts to fluctuate. This damages equipment so it becomes less efficient, even dangerous, and can result in blackouts.

Cruachan Power Station is already capable of running its units in synchronous condenser mode (see image, right, of a unit open for maintenance).

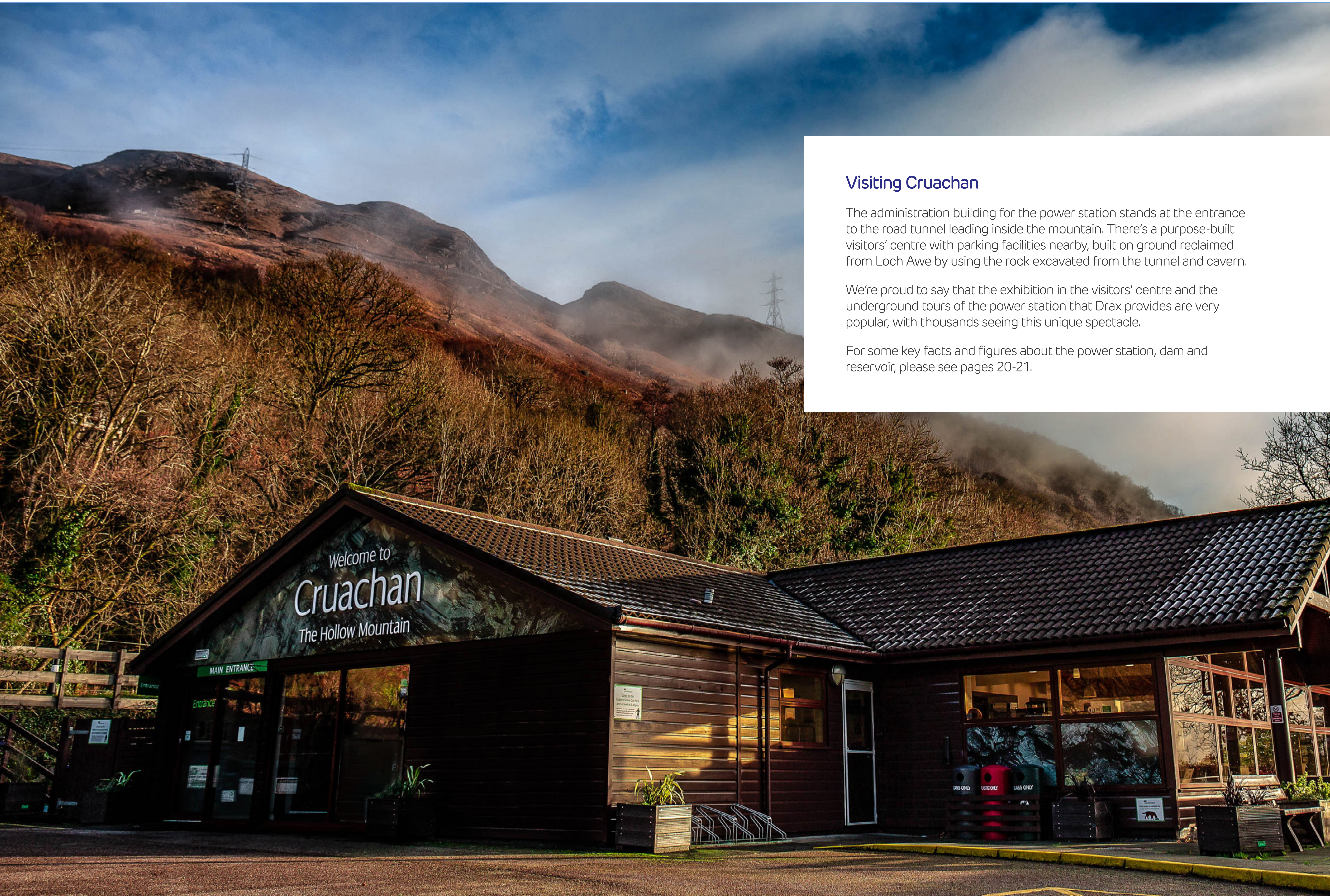
In this mode, an alternator acts as a motor, offering inertia to the grid without generating unneeded electricity. By continuing to turn, these big spinning machines give the grid valuable milliseconds to react, often automatically, before the potential damage of a fluctuating frequency becomes more widespread.

Visiting Cruachan

The administration building for the power station stands at the entrance to the road tunnel leading inside the mountain. There's a purpose-built visitors' centre with parking facilities nearby, built on ground reclaimed from Loch Awe by using the rock excavated from the tunnel and cavern.

We're proud to say that the exhibition in the visitors' centre and the underground tours of the power station that Drax provides are very popular, with thousands seeing this unique spectacle.

For some key facts and figures about the power station, dam and reservoir, please see pages 20-21.



Cruachan in numbers

Construction
At its peak, this major civil engineering project employed around 1,500 workers who excavated 220,000m^3 of rock and soil

Generators/pumps
Units 1&2 – 120MW, 500 revolutions per minute (rpm)

Units 3&4 – 100MW, 600rpm

Ventilation and cable shaft
335m high, 4m diameter

Access tunnel
1100m long, 6.7m wide

Tailrace tunnel
975m long, 7m diameter

Surface area of Loch Awe
38.85km^2

Upper reservoir capacity
7 gigawatt hours (GWh)

Dam
316m long, 46.6m high

Steel-lined tunnels
48m long, 5m diameter (x2)

Concrete-lined shafts
304m long, 5m diameter (x2)

Steel-lined pressure shafts
152m long, 2.7m to 2.4m diameter (x4)

Machine hall
91m long, 37m high, 23m wide

Main transformers
SGT1 – 230MVA, 16kV/275kV (x1)

SGT2 – 150MVA, 16kV/275kV (x2: a & b)

Cruachan dam
Gravity buttress type, containing 200,000 tonnes of concrete, with free spillway intakes 316m long, 46m high

Aqueducts
14.4km of tunnel, 2.6m x 2.1m and 3m by 2.4m sections

4.5km of piped aqueducts diverting water from the catchment area of 16.8km^2

Reservoir
23m operating range provides 10 x 106m^3 of storage, equivalent to 6.9 million units of electricity

Low pressure penstocks
5m diameter steel pipes encased in concrete (x2)

Shafts
Concrete-lined and inclined at a 55° angle (x2)
304.8m long, diameter 5m

Each shaft divides into two steel-lined tunnels – 152.4m long, 2.7m to 2.4m diameter

Tailrace surge chamber
21.9m long, 30.5m high, 7.6m wide

Two expansion galleries – 88.4m long, 7.6m horseshoe

Tailrace tunnel
Concrete-lined

975.3m long, 7m equivalent diameter

Motor generators
100,000kW, 0.9 P.F as generators

110,000kW, 0.79 P.F as motors
Two sets run at 600rpm, the other two at 500rpm

Voltage 16000V

Estimated annual output 350 million units (of which an average of 40 million units are from natural catchment)

Pump-turbines
134,000 H.P vertical reversible Francis

Maximum net head 362.7m generating, 367.6m pumping

Discharge approximately 28.3m^3/second

Main inlet valves 1.83m diameter

Setting of runner 9.75m O>D> (i.e. 45.7m below level of Loch Awe)

Main transformers
1x 230 MVA, 2x 150 MVA (16Kv/275Kv)

Oil-filled, water-cooled

On load tap changers + or – 10% site assembled

Switchgear
16kV SF6 6300A

Station transformers
1x 5 MVA 16/3.3kV,
1x 7.5 MVA 16/3.3kV

Standby station transformer
1x 5MVA 33/3.3K

Main cable/Ventilation shaft
335.3m vertical, 3.96m diameter

Sectionalised lining

Drainage/dewatering pumps
4-200 gallons per minute (gpm) (0.91m^3/min)/4-2500 gpm (11.4m^3/min)

Standby diesel
1500 kW at 0.8 P.F

275kV cables
6x 275kV single core, 3.2cm^2 oil-filled cables up vertical shaft

The future

In May 2022, Drax applied for consent to build and operate a new underground generation facility inside Ben Cruachan to the east of the existing power station. In July 2023, Scottish Ministers approved the scheme, which we call 'Cruachan 2'.

Once it's built, 'Cruachan 2' will more than double the power station's existing capacity - taking total output to more than 1GW. This will help to deliver UK energy security and enable thousands more homes and businesses to use renewable power.

'Cruachan 2' would be the first newly-constructed pumped storage hydro plant in the UK for more than 40 years. It's estimated that this major infrastructure project will support around 900 jobs across the supply chain – with around 150 on site.

This will contribute over £400M to the UK economy during an estimated six years of construction.

The Drax plan for Cruachan is another sign that we do things differently from other power companies.

While supporting the increased use of wind and solar across the UK energy system, we're also aware that these intermittent sources aren't always available. So at Drax Power Station in North Yorkshire, we use sustainable biomass to generate a more reliable form of renewable electricity.

Combining our output from Drax Power Station with our storage capabilities at Cruachan and other hydro generation assets means that we're always ready to provide electricity when it's needed. This security of supply is integral to keeping the lights on across the UK, even when the wind's not blowing and the sun isn't shining.

About Drax

At Drax, our strategy is to be a global leader in sustainable biomass pellets and carbon removals, and to be a leader in dispatchable renewable generation in the UK. Our ambition is to be a carbon negative company by 2030, and our purpose is to enable a zero carbon, lower cost energy future.

Drax is the second largest sustainable biomass producer globally, and the UK's largest source of renewable power by output. At Drax Power Station, we're progressing options for bioenergy with carbon capture and storage (BECCS), while also exploring options for international, new-build BECCS.

Cruachan Visitor Centre
Dalmally
Argyll
Scotland
PA33 1AN

visitcruachan.co.uk
drax.com

facebook.com/CruachanHollowMountain

Visit.Cruachan@drax.com

01866 962630

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