MOTT MACDONALD

New purpose for a former precious resource

Project
Kidston pumped-storage hydro project

Location
Queensland, Australia

Client
Genex Power and McConnell Dowell-John Holland joint venture (MDJH-JV)

Expertise
Hydropower, solar energy, optimisation, detailed design

Dependable, flexible, fast-responding generating capacity

When the sun shines and the wind blows, solar photovoltaics and wind turbines provide clean electricity. But after the sun goes down or when the wind fails to blow, what then?

Batteries are one option for storing renewable energy. Converting electrical power into hydrogen for storage is another, though doing so at scale is still some way off.

Pumped-storage hydropower is by far the largest-capacity form of grid energy storage currently available. It's a tried and trusted process, dating back more than 100 years. It works by using surplus generation when demand for electricity is low to pump water from a lower to an upper reservoir, with the water flowing back when demand rises to turn turbines and generate electricity. It's effectively a giant 'water battery'. The International Hydropower Association estimates that the more than 130 pumped-storage hydropower plants around the world can store up to 9TWh of electricity.

There is now a resurgence of interest in pumped-storage hydropower as it provides dependable, flexible, fast-responding generating capacity to help stabilise our low-carbon grids.

Kidston, in northern Queensland, was once home to Australia's largest open cut gold mine. It closed in 2001. Now, we're helping to transform the site into a renewable energy hub – with a combination of solar, wind and pumped-storage hydropower. The pumped-storage facility is under construction and when it is completed in 2024 water will move up and down between the two former mine pits, recharging and discharging via two reversible-pump turbines.

It is Australia's first privately-owned pumped-storage project in 40 years and the first anywhere to repurpose an abandoned gold mine.

When fully operational, the pumped-storage operation will generate 250MW of power – enough electricity to power 143,000 homes for up to eight hours. The project will create about 500 direct jobs, stabilise the local grid and unlock the renewable energy potential of North Queensland, delivering more jobs and economic opportunities. It will also help the state meet its 50% renewable energy target by 2030.

> Genex is repurposing an otherwise useless old mine site into a renewable energy hub. This is not only a fantastic environmental story, but also establishes a large-scale energy storage facility, which will support the development of renewable energy projects in north Queensland.

Arran McGhie
Chief operations officer at Genex Power

The business case for pumped-storage hydro

Delivering the energy transition from fossil fuel-fired generation

The business case for pumped-storage hydro is strong. The global growth of intermittent renewable sources requires cost-effective storage to balance and stabilise the grid. Pumped-storage hydro is the best proven bulk energy storage technology available and is the lowest cost energy storage over long durations – up to eight hours of on-demand stored energy will be available at Kidston.

Lifespan is at least 80 years, which is five times that of most of today's batteries. The scale and relatively long lifespan of pumped-storage hydro means its production and storage in terms of cost/kW are lower than other technologies.

Making pumped-storage hydro part of the energy system also avoids capital expenditure on additional generation because it can respond to potentially large electrical load changes within seconds as demand for electricity rises.

The advantage of pump storage is that its role can vary depending on what the offtaker or party buying the electricity requires.

The original principle behind pumped-storage was 'energy arbitrage' or storing electricity during cheaper, off-peak periods to use during peak times, when tariff rates are at their highest. Pumped storage in a renewable energy system has a different focus: regulating voltage and dealing with the intermittency of renewable sources (such as solar and wind), to enable the diversification of the domestic energy portfolio to fully harness clean energy.

For the Kidston project, Genex will receive a fixed-monthly fee from the offtaker, EnergyAustralia (EA), which has full dispatch rights to the facility for up to 30 years. Kidston provides EA with 'insurance' should its wind and solar operations not deliver the guaranteed generation it has sold to the market.

Over the past few decades, new hydropower projects have mostly been in emerging and developing economies. But pumped storage, with its flexibility and large-scale, quick release storage potential, should generate renewed interest in hydropower in mature economies as they accelerate their transition to a clean energy system. More projects in more regions will reduce costs, unlock financial mechanisms, and help establish environmental and social sustainability best practice.

The earliest large-scale pumped storage plants date from the 1960s and 1970s, and we were involved in many of these. This includes the construction of Dinorwig Power Station in Wales. Known as Electric Mountain, the plant opened in 1984 and is still regarded as one of the world's most imaginative engineering and environmental hydro projects. It is comprised of 16km of underground tunnels, deep below Elidir Fawr mountain, and uses off-peak electricity to power six generating units to transport water from the lower reservoir to Marchlyn Mawr, a lake high in Snowdonia National Park. Dinorwig has a storage capacity of more than 9GWh. We continue to be involved in the operation of Dinorwig, and many of our experts who worked on the station and other pumped storage projects are now helping to deliver the Kidston project.

> Regulating voltage and dealing with the intermittency of renewable sources will be the new focus for pumped storage around the world and assist the accelerated retirement of conventional thermal baseload plant.

Brian Minhinick
Kidston project director for Mott MacDonald

Turning a former gold mine

Gold was first discovered at Kidston in the 1880s and prospectors descended on the area in 1907 as part of the Oaks Rush, the last big alluvial gold rush in North Queensland. In 2001, the surviving open cut mine closed, leaving two craters, each 300m deep.

These huge legacy mine pits are crucial to Kidston's future as a renewable energy hub and were what attracted the attention of a new breed of environmentally conscious prospectors. The pits, called Wises and Eldridge, are up to 225m apart and will act as the upper and lower reservoirs for the 250MW pumped-storage hydropower plant.

into a renewable energy hub

North Queensland is one of the highest solar irradiance zones in Australia, perfect for generating solar power, and the Kidston renewable energy hub will make the most of this free resource.

The 50MW Kidston solar project (KS1) is located on 300ha of rehabilitated land the former mine used to store tailings – the rock left after extracting the gold – and started generating power at the end of 2017. It provides up to 26,000 Australian homes with electricity and offsets about 120,000t of CO_2 a year.

A further 270MW solar array is planned in addition to KS1 and the pumped-storage facility. Kidston will potentially also be home to a 200MW windfarm, effectively turning the former gold mine into the complete renewable energy hub for the future.

Up to eight hours of power

The pumped-storage hydro project at Kidston will generate up to eight hours of on-demand electricity to stabilise the Queensland network by supplementing fluctuations in generation from other renewable sources.

The Kidston powerhouse will contain two 125MW reversible pump turbine units, with pumping from the lower to upper lasting up to seven-and-a-half hours. Almost 160m³/s of water will run downhill from the upper reservoir, turning the turbines to generate 250MW of electricity or 2000MWh of dispatchable power.

The mine was already connected to the electricity grid and this transmission line is now used for the solar plant. For the pumped-storage plant, a new, higher capacity 185km transmission line from Kidston to Mount Fox will be constructed as part of a separate government-backed project. This new line will enable further renewable generation projects to be connected to the grid. There is also an existing water pipeline from Copperfield Dam to Kidston, as well as offtake rights for 4500M litres per year, so even though it's a closed-loop system the reservoirs can be replenished if necessary.

Round trip efficiency – the percentage of electricity put into storage that is later retrieved – is 77%, which is at the higher end for pumped storage.

Mott MacDonald's project director Brian Minhinick says Kidston's relatively high efficiency is due to the fairly short waterway length to the water head – another advantage of using the old mine.

Repurposing a redundant industrial site has challenges and in this case pollution from the former mining process was the biggest. The tailings – the materials left over after gold was extracted, and which contain heavy metals – had polluted the groundwater that had collected in the pits. A risk assessment was required to determine the potential risk to the environment and the pumped-storage equipment. Genex had undertaken the necessary studies and found that, with new water entering the system, pollution would be sufficiently diluted to not pose a danger.

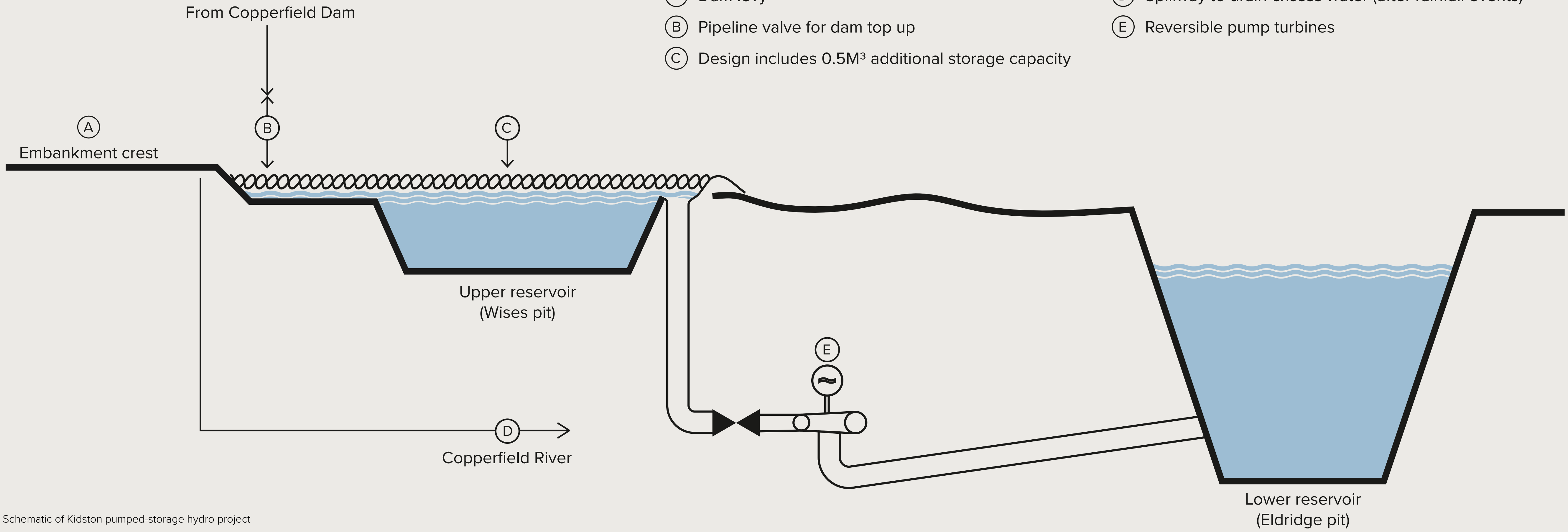
> Kidston was the complete site in other ways. It was already connected to the grid via a transmission line. As an added bonus, there was a pipeline to the nearby Copperfield Dam, so the reservoirs can be refilled in case of evaporation.

Simon Kidston
Executive director at Genex Power

A giant water battery

Water is pumped up to Wises reservoir during periods of low demand for electricity. When demand rises or solar/wind production falls, water runs back down to the Eldridge reservoir, passing through two, reversible turbines to create electricity to power Queensland.

Ⓐ Dam levy
Ⓑ Pipeline valve for dam top up
Ⓒ Design includes $0.5M^3$ additional storage capacity
Ⓓ Spillway to drain excess water (after rainfall events)
Ⓔ Reversible pump turbines



Schematic of Kidston pumped-storage hydro project

250MW

installed capacity – two 125MW units

110 seconds

standstill to full generation

160m³/s

discharge capacity

8 hours

generation time

165-225m

head (height) difference from lower to higher reservoir

Capital cost savings at Kidston

As with any large infrastructure project, the capital costs of pumped-storage hydro are relatively high, but innovative solutions and digital delivery can significantly reduce project costs. We were engaged to review an earlier design for the Kidston facility and our optimisation study and proposed changes to the original concept were crucial to the financial viability of the project.

The earlier design included the construction of an enclosed earth embankment – known as a turkey's nest – on higher ground to maximise the scheme capacity. This would have been expensive. By slightly reducing the capacity of the scheme to better meet the needs of Kidston's energy offtake partner, EnergyAustralia, we made using the existing Wises pit a viable option. As well as reducing capital costs, and excavation and dam works, our optimisation study considered the use of variable speed pump-generator turbines to provide more operational flexibility.

The analysis also found that we could reduce costs and risk and improve the project schedule by replacing one large waterway with two small ones. Two smaller waterways enabled us to simplify construction using the raised boring method of construction – a way to excavate a shaft by back reaming the pilot hole using drill rigs – and remove the need for the underground bifurcation for the two turbines units, reducing construction cost and time.

The design for the powerhouse structure is a combination of structural steel, precast and in-situ concrete. We selected this arrangement to reduce the workload at site and expedite progress.

Our optimisation study was carried out over a short, six-week period. To save time, we developed 3D digital models to enable the client to easily visualise our proposed changes to the design. These digital tools enabled our team – experts from Australia and across the globe – and Genex to explore many different solutions to deliver the optimal layout.

6 months

reduction in construction time

AUS$21M+

capital cost savings

Detailed design

Many hydro projects fail due to cost and limited performance. With our partners GHD, we helped to balance cost, performance and safety on the Kidston project by simplifying a number of features. For example, our water management plan removed the need for stoplogs at the intake. Stoplogs are installed to isolate equipment during maintenance, but their removal enabled us to also dispense with the need for an access tower or bridge – challenging conventional hydro thinking.

Further cost savings were achieved by allocating risk more effectively, so the party best placed to mitigate a specific risk was given responsibility for doing so, helping to reduce engineering, procurement and construction costs by sharing some risk efficiently with the owner. Our detailed risk register enables Genex to better assess and allocate risk, and will be critical to successful project delivery.

In addition to producing 3D visualisations and enabling collaboration among our multiple teams around the world, the digital processes and models we have employed on Kidston have delivered other benefits. Our BIM (building information modelling) models integrate the supplier models developed by the engineering, procurement and construction contractor (McConnell Dowell and John Holland joint venture), including the turbine and plant suppliers, and provide a 'single source of truth' that all team members across all disciplines as well as stakeholders, including the owner, can access at any time. This maintains data consistency and ensures the design is fully co-ordinated for all components across the project and makes it easier to amend as more information becomes available. Clash detection is automated and there is an inbuilt check and approval process – both helping to save time. The models will be an important asset for the future operation and maintenance of the facility.

Our detailed design with GHD is being delivered using the latest BIM suite of software and methodologies. This enables real-time review of the design as it develops and encompasses both the geotechnical and geological model (Leapfrog) as well as the scheme arrangements (Revit and Civil 3D). GHD used 3D geotechnical mapping tools to rapidly transfer the results of its underground investigations into a form where the impact on pumped-storage hydro structures could be effectively evaluated.

Removing the need to dewater the lower reservoir and reduce dam construction and underground construction works will help reduce construction time by six months. The changes also provide the contractor with the freedom to undertake more work in parallel if needed.

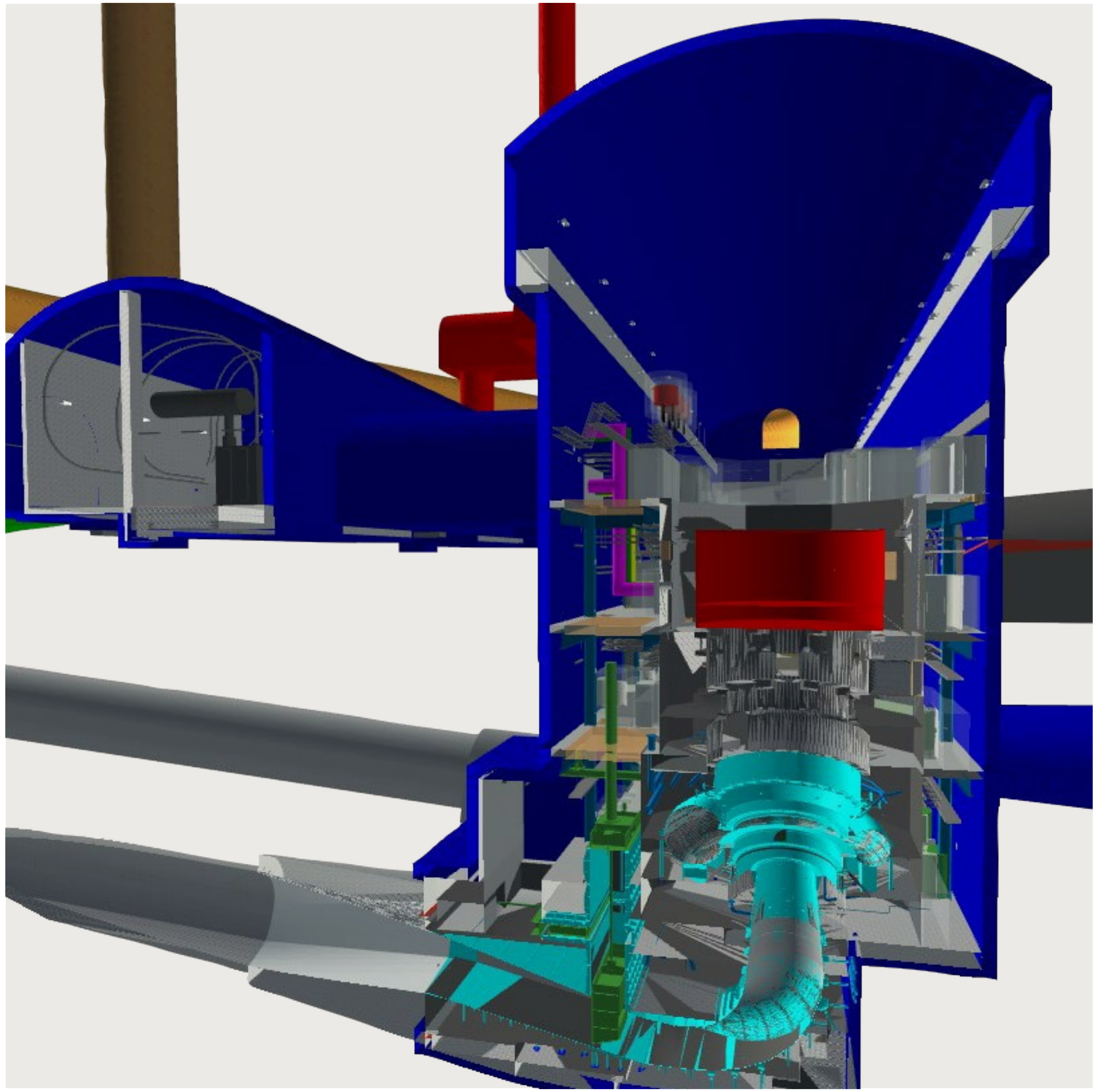
In all, our design saves more than AUS$21M.

> "Our optimisation study fundamentally transformed the design concept into an economic solution. We showed that a smaller capacity scheme – 250MW rather than 450MW – would require significantly less capital and reduce construction time, enabling the project to move forward.

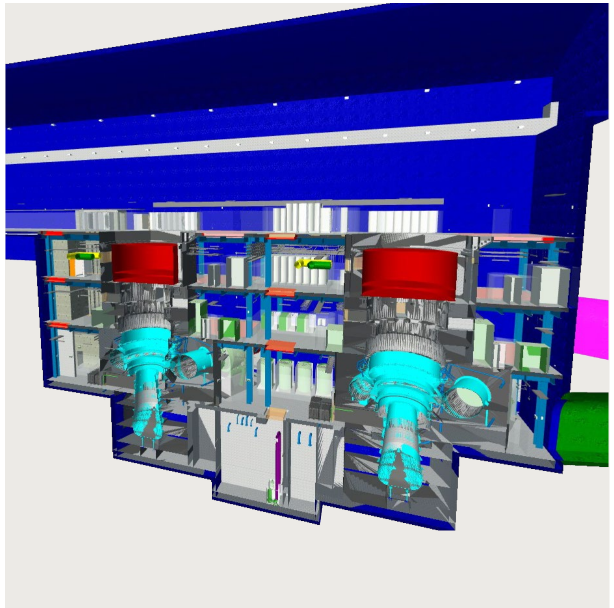
Neil MacDonald
Kidston project manager for Mott MacDonald

Model design

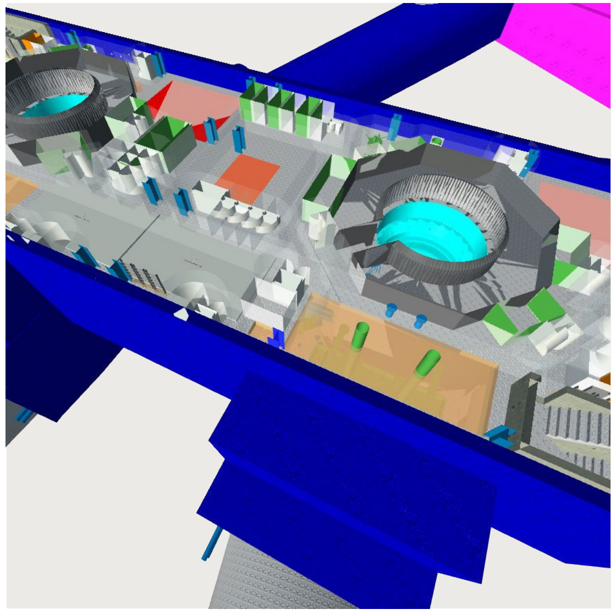
Cross section through the powerhouse and transformer caverns at unit 1



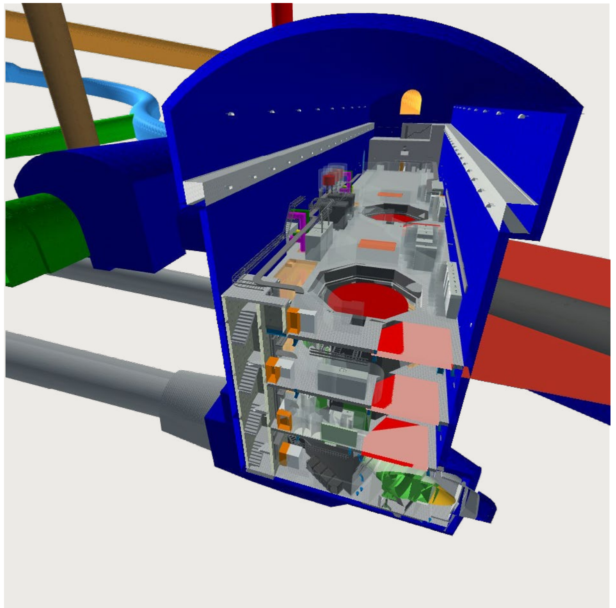
Long section of the powerhouse cavern showing cut through of both units



Plan view of the powerhouse cavern at generator floor level



Cross section through the powerhouse at machine hall wall of cavern



What goes on beneath the surface

Significant underground infrastructure is required for this project, and this includes designing the powerhouse cavern, waterway shafts and tunnels to transfer water between the reservoirs.

Our global team is responsible for the overall scheme layout as well as designing the infrastructure from the intake canal, water conveyance shafts and tunnels and associated ancillary structures. Experts from seven countries are regularly inputting to the design development in support of our team in Australia.

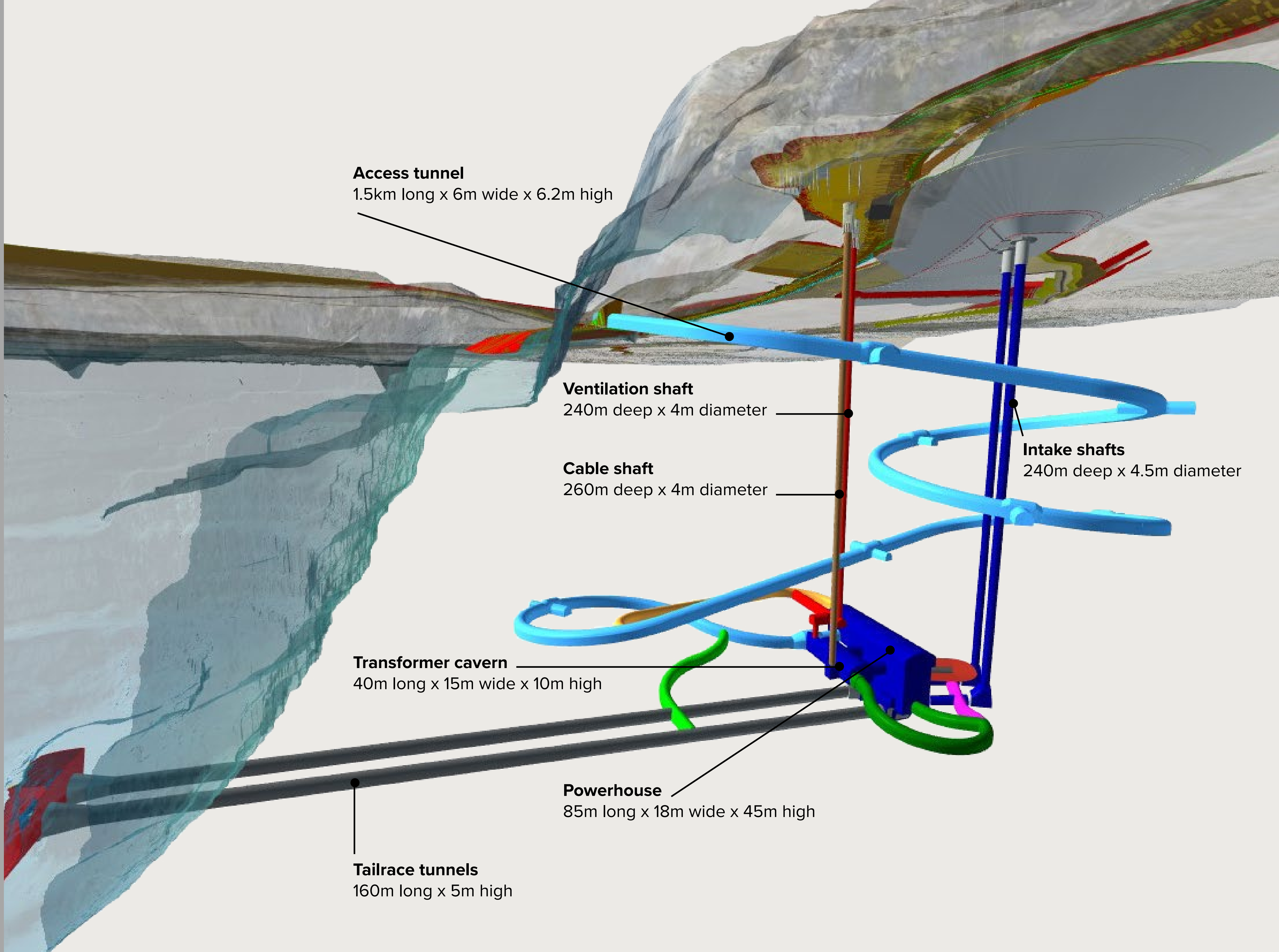
Tunnelling is within a hydrothermal breccia pipe system – cylindrical bodies of brecciated or sedimentary rock composed of broken fragments of minerals and rocks cemented together – with the headrace pressure shaft and powerhouse complex located within the Einasleigh metamorphics, a biotite gneiss rock.

The anticipated rock quality for the project is considered very good, though there are some known faults in the area. Leapfrog software was used to locate the main structures and to miss the predicted faults. Data from further geotechnical investigations was added to the Leapfrog model to enhance the geological model. This model is being updated with the actual conditions as tunnelling progresses to verify the model and identify any potential changes.

Drill and blast tunnelling method is being used to excavate most of underground spaces, including the tunnel crown and powerhouse cavern opening, and involves drilling blast holes and loading them with explosives, then removing the blasted rock after detonation. The main access tunnel will have a concrete slab for the roadway and shotcrete lining.

Groundwater is relatively high, but modelling predicts minimal flows into the excavated underground spaces. The hydraulic tunnels near the caverns, where water pressure is highest, will be lined with steel, while concrete will line the other conveyance tunnels. Temporary support prior to the concrete lining will be achieved using rock-bolts and shotcrete adjusted to suit the rock quality. With the quality of the rock the tunnels are designed as undrained.

Underground facts and figures



> As Queensland charges towards its renewable energy target, storage projects like Kidston will enable the continued investment in otherwise intermittent renewables.

Mick de Brenni
Queensland's minister for energy, renewables and hydrogen
(quoted in North Queensland Register, 21 May 2021)

AUS$343M

net public benefit

Opening opportunities with connected thinking.

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