Cruachan Pumped Storage

Clean power, capacity and system support

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Post 2027 hydro EBITDA target is plausible

Increasing electrification of the economy and a shift to an electricity system with considerably more renewables will require increasing levels of electricity storage for system operability and security. Pumped storage hydro has a key role to play and there is policy backing for new capacity.

Cruachan is a key asset in Drax’s flexible generation and energy solutions portfolio, delivering clean power, capacity and system support. Planned upgrades to units 3 and 4 are a building block in Drax’s plausible target to deliver post 2027 EBITDA of £150m from its hydro portfolio. Subject to an appropriate remuneration framework, Cruachan II will help meet evolving system needs, and represents a source of incremental income in the 2030s.

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Executive summary

- Increasing electrification of the economy and a shift to an electricity system with considerably more renewables will require increasing levels of electricity storage to aid energy security, deal with the intermittent nature of wind and solar, and provide a range of services to the Electricity System Operator (ESO) to keep the system in balance.
- Different electricity storage technologies offer varying degrees of duration, but pumped storage is the only mature long-duration electricity storage (LDES) technology currently deployed on the GB energy system. Policy support for the development of additional LDES is favourable.
- Drax's Cruachan plant, located in Argyll and Bute, is one of four pumped storage plants in GB, and was acquired by Drax in January 2019 as part of a portfolio of assets.
- Cruachan is a reversible 440MW four unit pumped storage power station which can reach full load in 30 seconds and maintain it for up to 15 hours.
- Strong free cash flow generation post-acquisition and the disposal of gas plant has delivered a five-year payback period on Drax's original investment in the portfolio, a successful acquisition for Drax.
- Cruachan's ability to provide clean power, capacity and system support delivers a diverse set of revenue streams over and above price arbitrage, with ancillary services, the Balancing Mechanism, and the Capacity Market all important.
- Drax is upgrading units 3 and 4 to add 40MW of capacity, improve efficiency and provide a wider operating range. The upgrade will cost £80m and is underpinned by a 15-year Capacity Market contract at £65/kW/yr (effective delivery year 27/28, CPI linked).
- Drax has secured planning consent for a 600MW expansion of the Cruachan Power Station and, subject to the right investment framework, Drax is targeting a c.£600m final investment decision in 2026, with commercial operations commencing in 2030.
- Cruachan II seeks to optimise the use of the existing Cruachan Power Station, reservoir and dam, through the construction of a new, separate but linked, underground power station and associated infrastructure.
- The broader policy framework is favourable. Cruachan II would be of incremental benefit to the GB electricity system and, subject to the right investment framework, Drax too.
- The location of wind resource is likely to see considerable renewable build north of the B6 boundary with a generation surplus driving a need for significant transmission build in the current decade and beyond. Irrespective of where REMA lands, both have relevance for Cruachan's revenue streams.
- Change also creates opportunity and Cruachan's provision of a wide range of services points to resilience as this plays out.
- Drax's hydro business encompasses Cruachan and the two hydro schemes at Galloway and Lanark, forming one of the three pillars of Drax's flexible generation and energy solutions portfolio.
- Of the £250m EBITDA target from FlexGen and Energy Solutions, Drax has suggested around £150m of this could come from the hydro assets. Pricing dynamics in recent years have been favourable for hydro assets, but secured Capacity Market revenues, an increasingly intermittent electricity system, and ESO predictions that balancing costs will remain elevated, suggest that this is a plausible target.

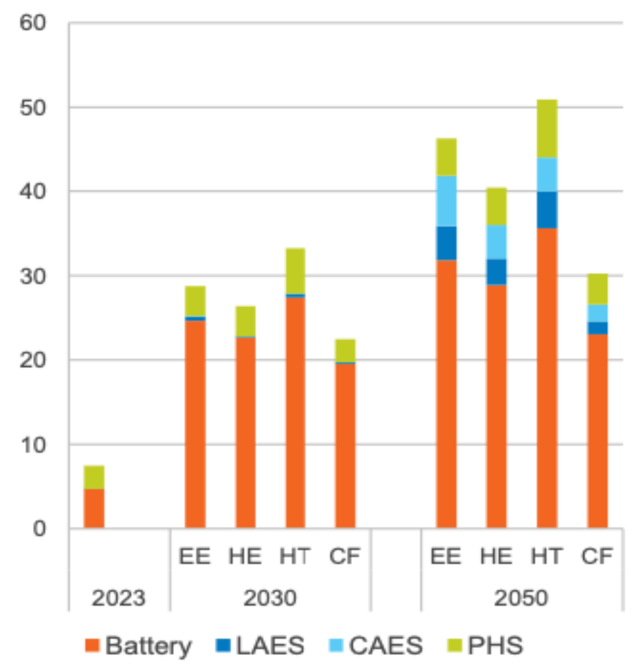
Increasing need for flexibility and storage

More LDES needed, pumped storage set to play a key part

Shift to intermittent renewables driving need for increase in electricity storage capacity…

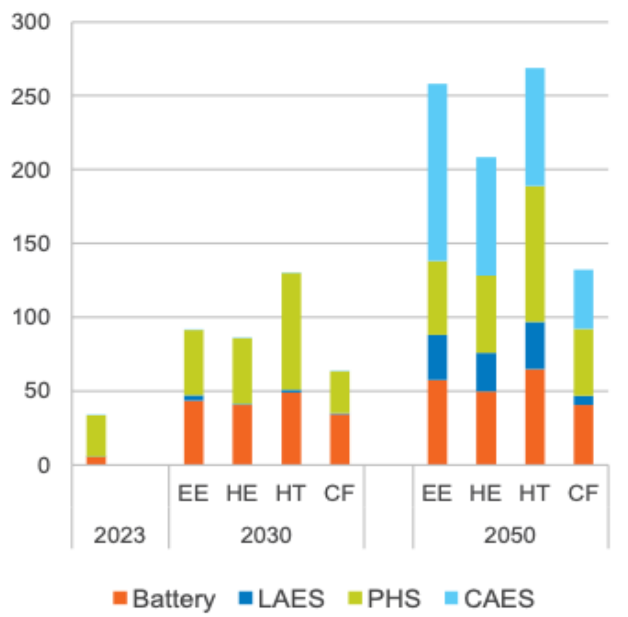
Increasing electrification of the economy and a shift to an electricity system with considerably more renewables will require increasing levels of electricity storage to aid energy security, deal with the intermittent nature of wind and solar, and provide a range of services to the ESO to keep the system in balance. Each of the three pathways set out in the ESO's Future Energy Scenarios (FES) 2024 ESO Pathways to Net Zero report suggest significant increases in both electricity storage capacity (GW) and volume (GWh).

Figure 1: Electricity storage capacity ex V2G (GW)



Source: National Grid ESO FES 2024 ESO Pathways to Net Zero

Figure 2: Electricity storage voluime ex V2G (GWh)



Source: National Grid ESO FES 2024 ESO Pathways to Net Zero

…range of technologies, pumped storage dominates long-duration storage

There is a diverse range of electricity storage technologies offering varying degrees of duration. Short-term storage has a duration of up to four hours, medium-term 4-12 hours, and long-duration over 12 hours. Batteries dominate the shorter end, with pumped storage the most prevalent technology currently on the GB system at the longer end.

Figure 3: Overview of selected energy storage technologies

Technology	Description	Response time	Discharge duration	Round-trip efficiency	Commercial readiness
Pumped Storage Hydro	Electricity is used to pump water from a lower to an upper reservoir where it can be stored. Electricity is generated by releasing water through the turbines.	Seconds	Medium, long	78-81%	Mature technology, deployed worldwide.
Lithium Batteries	Charge and discharge is effected by the movement of lithium ions between the anode and the cathode in an electrochemical reaction.	Milli-seconds	Short, medium (up to 6-8 hours)	90-95%	Mature technology, widely deployed.
Compressed Air Energy Storage (CAES)	Electricity is used to compress air and store it in caverns or above-ground vessels. Electricity is produced by releasing expanding air through the turbines.	3-10 minutes	Medium, long	42-56%	Limited deployment globally (China, Germany, US, with small plants in Canada and Italy).
Liquid Air Energy Storage (LAES)	Electricity is used to compress and cool air in liquid form. The liquid is regasified to drive turbines and produce electricity.	~2 minutes	Medium	55-65%	Highview Power to begin construction of UK's first commercial LAES plant.
Flow Batteries	A flow battery is a rechargeable battery in which electrolyte flows through electrochemical cells from electrolyte tanks. Conversion between electrical and stored chemical energy takes place in an electromechanical cell, consisting of two half cells separated by a porous/ion membrane.	Milli-seconds	Medium	65-80%	Deployed and increasingly commercialised.
Gravitational Energy Storage	During the charge cycle, electricity is used to raise large masses to a certain height. The potential energy in the raised masses can be recovered by lowering the masses in the discharge cycle, driving electric generators.	Seconds	Medium, long	75-80%+	Limited deployment, technology under development.

Source: Aquaicity analysis, National Grid ESO, Enel, Energy Vault, International Flow Battery Forum

Long-term energy storage is part of the clean energy mission set out in the Labour Party manifesto, while DESNZ's consultation, published in January, on designing a policy framework for LDES states that LDES "…*will be pivotal in delivering a smart and flexible energy system that can integrate high volumes of low carbon power, heat, and transport*."

2.8GW of pumped storage capacity currently on the GB electricity system…

Pumped storage hydro is the only mature LDES technology currently deployed on the GB electricity system with 2.8GW of capacity across four plants and a combined storage volume of 32GWh. Two of the plants are in Scotland, and two are in Wales.

Figure 4: Pumped storage hydro in GB

Plant	Ownership	Location	Opened	Output (MW)	Storage volume (GWh)
Cruachan	Drax	Scotland	1965	440	7.6
Dinorwig	First Hydro (Engie)	Wales	1984	1,728	10.4
Ffestiniog	First Hydro (Engie)	Wales	1963	360	7.6
Foyers	SSE	Scotland	1974	300	6.4

Source: Company reports, British Hydropower Association

…3.7GW in, or having secured, planning

There is also a material pipeline of projects, with 3.7GW (45GWh storage volume) listed on the Renewable Energy Planning Database (April 2024), with all bar one having secured planning consent.

Figure 5: Pumped storage hydro projects in GB

Plant	Operator (or applicant)	Location	Planning status	Output (MW)	Storage volume (GWh)
Coire Glas (Phase 1)	SSE	Scotland	Revised	600	30
Coire Glas	SSE	Scotland	Consented	1,500	30
Cruachan 3 and 4 upgrade	Drax	Scotland	Granted	40	N/A
Cruachan II	Drax	Scotland	Granted	600	1
Loch na Cathrach (Red John)	Statkraft	Scotland	Granted	450	2.9 (maybe up to 3.7)
Glenmuckloch	Buccleuch Estates	Scotland	Granted	400	1.6
Glyn Rhonwy (smaller version)	Snowdonia Pumped Hydro	Wales	Granted	49.5	N/A
Glyn Rhonwy (larger version)	Snowdonia Pumped Hydro	Wales	Granted	99.9	0.7
Loch Ness & Loch Kemp	Statera Energy	Scotland	Submitted	600	9

Source: Company reports, DESNZ Renewable Energy Planning Database, Scottish Renewables (Cruachan upgrade refers to incremental capacity)

Pumped storage is a topic du jour, and given its importance to the evolving GB energy landscape, a subject that warrants a deep dive. This report seeks to do this via a focus on Drax's Cruachan Plant given a recent visit to view the existing operations and discuss the plans that Drax has set out to upgrade and expand Cruachan.

Cruachan – The Hollow Mountain

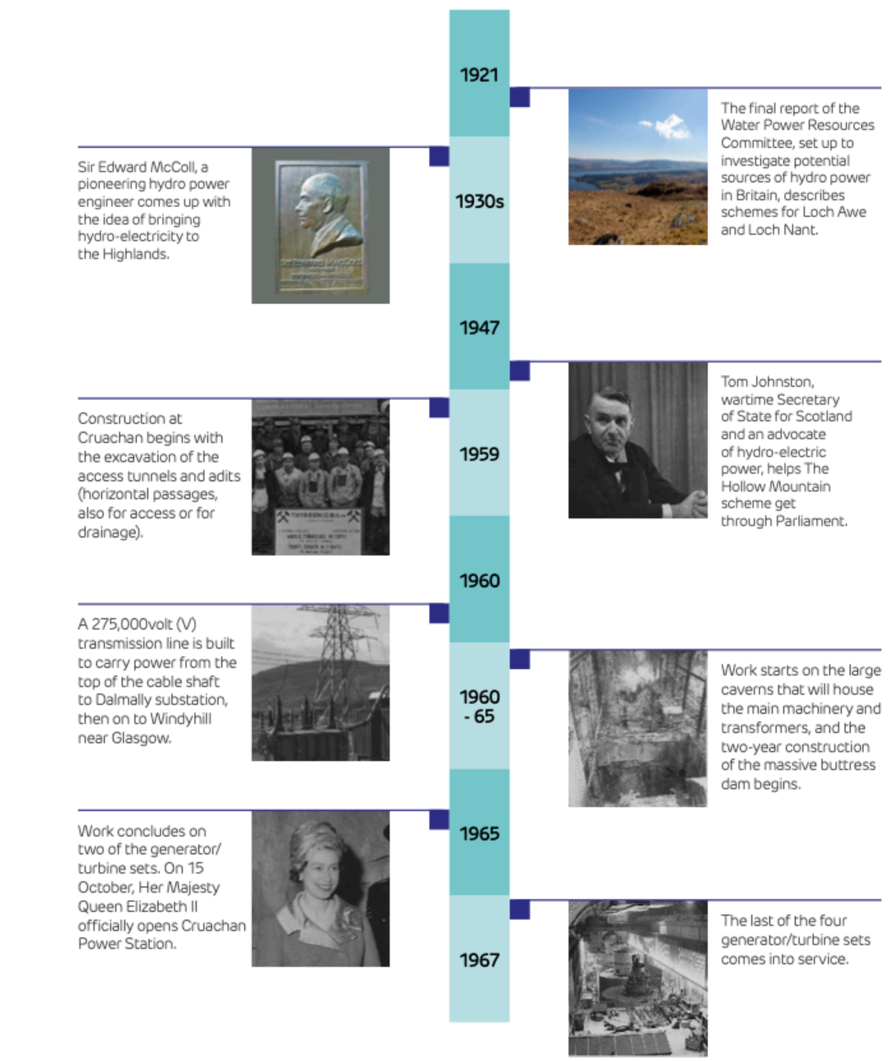
Cruachan – an overview

Cruachan's history can be traced back to the pre-war years

Opened in 1965, Cruachan was acquired by Drax in 2019

Cruachan Power Station is located in Argyll and Bute, Scotland, built inside the hollowed-out rock of a mountain, Ben Cruachan. Cruachan's history can be traced back to 1921 and the final report of the Water Power Resources Committee which described hydro power schemes for Loch Awe and Loch Nant, and subsequently the work of Sir Edward McColl to bring hydro-electricity to the Scottish Highlands. Tom Johnston, wartime Secretary of State for Scotland, helped the Hollow Mountain scheme through Parliament in 1947, with construction commencing in 1959, and linked to the development of the Hunterston A nuclear power station, as Cruachan could be used to store surplus nuclear power at night. Cruachan Power Station was officially opened in 1965, with the last of the four units coming into service in 1967. It was originally operated by the North of Scotland Hydro-Electricity Board before being transferred to the ScottishPower in financial year 1989/90, ahead of privatisation of the Scottish electricity industry in 1991. Scottish Power was acquired by Iberdrola in April 2007, with Drax acquiring a portfolio of assets, including Cruachan, from Iberdrola in a transaction that completed on 1st January 2019.

Figure 6: Cruachan timeline



Source: Drax

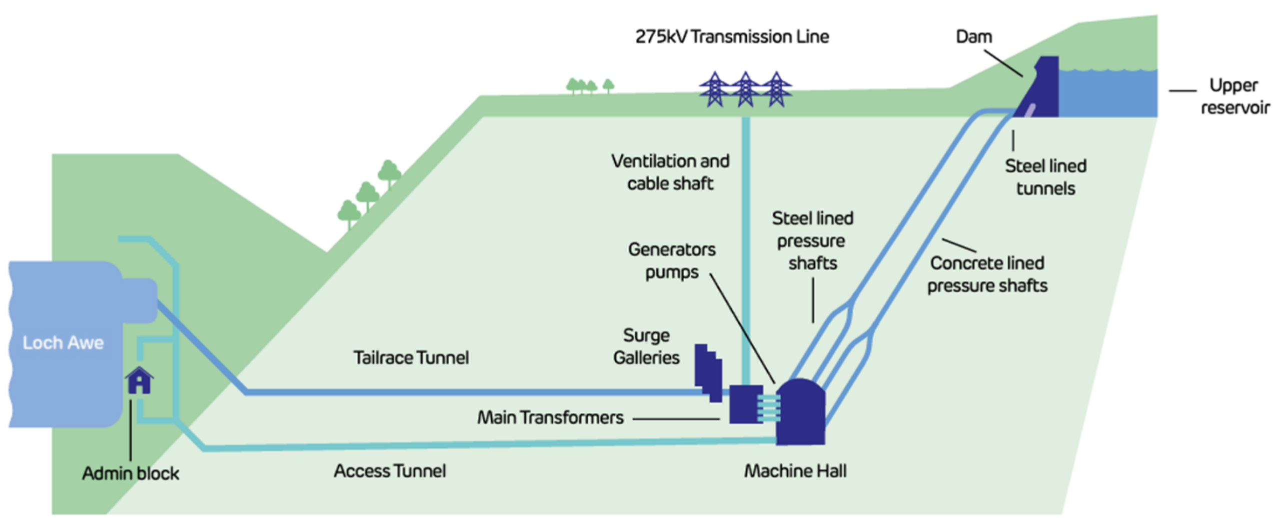
Cruachan is a scale provider of storage and system services

440MW capacity across four units, Cruachan can reach full load in 30 seconds, and maintain this level for up to 15 hours

Cruachan is a reversible 440MW four unit pumped storage power station which uses electricity from the grid at times of low electricity prices to pump water from Loch Awe to the storage reservoir, which also collects water from the surrounding hills. At times of peak demand, when electricity prices are generally higher, water can be released from the reservoir through the station's turbines to generate electricity. Cruachan can reach full load in 30 seconds and maintain it for up to 15 hours, making it a scale provider of long-duration electricity storage to the GB electricity system.

The upper reservoir with a 316m long, 46m high gravity buttress dam sits on the flanks on Ben Cruachan and houses two intakes to feed water to the power station, with a 90m long, 36m high machine hall housing four generator/motor sets (2x 120MW, 2x 100MW). Two are connected to a 270MVA transformer, the other two each connected to a 150MVA transformer, stepping up the generation voltage of 16kV to the transmission voltage of 275kV. When Cruachan is generating, water flows from the upper reservoir through two-concrete-lined shafts (penstocks) which split into two steel-lined pipes, these terminating in inlet valves which allow the water to flow into the turbine. After passing through the turbines, the water runs through a steel-lined tube pipe to a surge chamber, flowing to Loch Awe along a 975m long, 7m diameter tailrace tunnel. When in pumping mode, the flow of water is reversed.

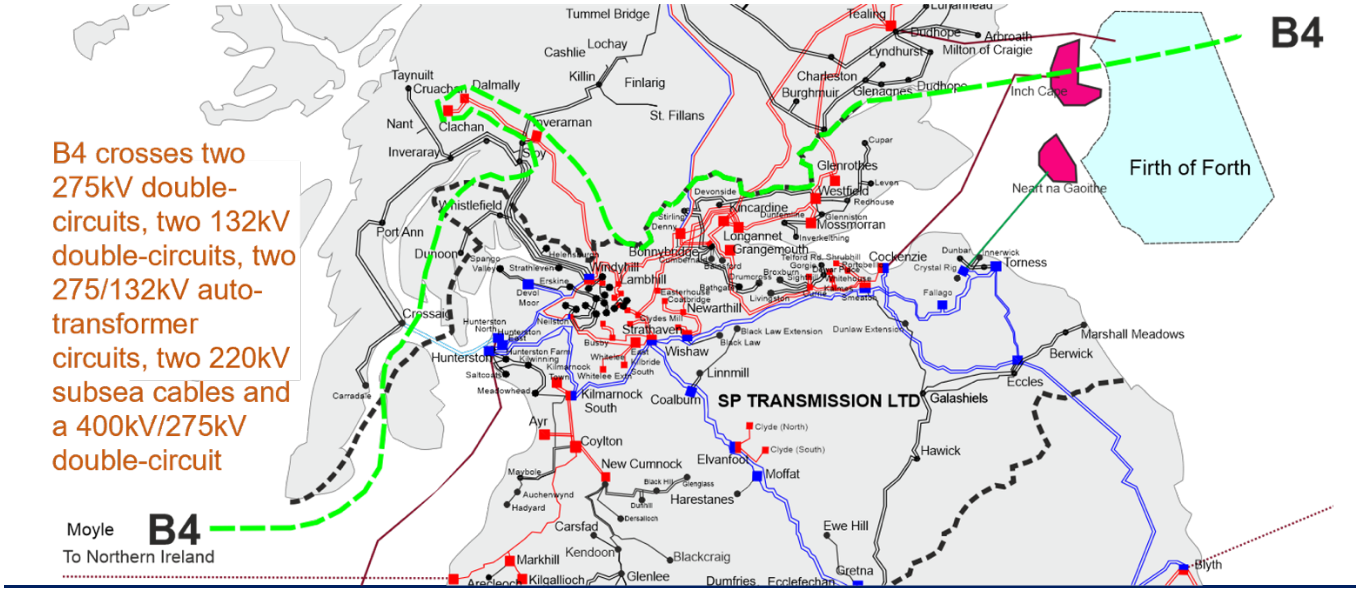
Figure 7: How Cruachan works (simplified diagram)



Source: Drax

Cruachan is connected to ScottishPower (SP) Transmission's network to the south of the B4 Boundary between SSEN Transmission (to the north) and SP Transmission (to the south).

Figure 8: Cruachan sits to the south of the B4 Boundary (SSEN Transmission to SP Transmission)



Source: National Grid ESO

Cruachan Power Station has four primary modes of operation:

- Generating: supplying electricity to the transmission system
- Pumping: taking electricity from the transmission system
- Spin gen: spinning without waterflow, to ready the system to generate electricity at short notice
- Spin pump: spinning without waterflow, to ready the system to pump at short notice

In addition to round-trip pump/generate cycles, Cruachan can provide a range of system support and balancing services

Cruachan can provide a range of system support and balancing services in addition to round-trip pump/generate cycles, with remuneration from both commodity and non-commodity revenues, as discussed later in this report.

Cruachan – the Drax years

Five-year payback on 2019 acquisition

Cruachan part of a 2.6GW portfolio acquired from Iberdrola for £692m in January 2019…

Drax acquired a 2.6GW portfolio of pumped storage, hydro, and gas-fired generation assets from Iberdrola in a transaction that completed on 1st January 2019. After remeasurements, the fair value of the transaction consideration was £692m.

Figure 9: ScottishPower Generation Group portfolio

Plant	Type	Location	Capacity (MW)
Cruachan	Pumped storage hydro	Argyll & Bute, Scotland	440
Galloway	Run-of-river hydro	Galloway, Scotland	109
Lanark	Run-of-river hydro	Lanark, Scotland	17
Damhead Creek	CCGT	Kent, England	805
Rye House	CCGT	Hertfordshire, England	715
Shoreham	CCGT	West Sussex, England	420
Blackburn Mill	CCGT	Blackburn, England	60
Daldowie	Biomass-from-waste	Daldowie, Scotland	n/a
Total			**2,566**

Source: Analysis of Drax company reports

…gas assets sold, EBITDA contribution from hydro has stepped up…

In the years preceding the acquisition the ScottishPower Generation Group reported EBITDA in range of £30-50m. EBITDA stepped up markedly in the first year of Drax's ownership with reported EBITDA in 2019 for Drax Generation Enterprise Limited (formerly ScottishPower Generation Limited) of £110m, lower operating and administrative expenses following the change of ownership being a contributory factor. This outturn was at the upper end of the £90-110m range forecast in the transaction acquisition circular. Adjusted EBITDA for the portfolio reported by Drax in its 2019 full year results presentation was slightly higher at £114m. The four CCGTs were subsequently sold to VPI for £186m in a transaction that completed on 31st January 2021.

Figure 10: Hydro/gas asset portfolio EBITDA (£m, 2015-2023)

	Iberdrola ownership				Drax ownership				
Plant	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Pumped storage/hydro	n/a	n/a	n/a	n/a	72	73	68	171	230
Gas	n/a	n/a	n/a	n/a	42	46	20	-	-
Adjusted EBITDA	**49**	**34**	**36**	**43**	**114**	**119**	**88**	**171**	**230**

Source: Acquisition circular (2015-17), Drax Generation Enterprise accounts (2018), Drax results presentations adjusted EBITDA (2019-2023, 2023 quoted post £23m EGL)

…with a five-year payback on Drax's original investment

With a further step change in pumped storage/hydro EBITDA in 2022 and 2023, largely due to higher power prices, cumulative EBITDA from the acquired portfolio over five years of Drax ownership has exceeded £700m, with 85% generated by the pumped storage/hydro assets. Free cash flow over the same period exceeded £500m with >90% from the pumped storage/hydro assets, leading to a five-year payback period on the original acquisition investment. It is reasonable to suggest that this has proved to be a successful acquisition for Drax.

Figure 11: Five-year payback on original investment

	Timeframe	£m
Acquisition	January 2019	(692)
Gas free cash flow	2019-2021	c.40
Divestment of gas assets	January 2021	186
Pumped storage/hydro free cash flow	2019-2023	c.470

Source: Analysis of Drax company reports

Cruachan's income streams include electricity sales, Capacity Market revenues, Balancing Mechanism and ancillary service revenues

How Cruachan makes money – demystifying the economics

Historically, the core margin generated by Cruachan Power Station was the difference between prices achieved through the generation of electricity and the cost of pumping to refill the reservoir at times of low demand, but an increasing proportion is now derived from system support services (incl. portfolio optimisation). Analysis of the financial statements of Drax Pumped Storage Limited, the owner of the Cruachan Power Station since 30th June 2021, shows the split of revenues into (i) electricity sales; (ii) balancing market revenues; and (iii) ancillary revenues and other income.

Figure 12: Drax Pumped Storage Limited (£m)

	2H 2021	2022	2023
Electricity sales	24.1	172.5	215.7
Balancing market revenues	16.0	25.0	18.8
Ancillary revenues and other income	12.7	25.7	30.6
Total revenue	**52.8**	**223.1**	**265.1**
Drax Pumped Storage EBITDA	**28.2**	**114.3**	**166.4**
Drax Hydro EBITDA (incl. EGL)	34	171	230
% Pumped Storage	**83%**	**67%**	**72%**

Source: Analysis of Drax company reports (FY22 balancing market revenues net of £6.1m payment to a Voluntary Energy Redress Fund)

- Electricity sales revenue is based on output delivered at rates specified under contract terms or amounts recharged to other Drax group companies. Optimisation gain/losses when the units are forward sold are recognised within revenue when Cruachan is exporting, and within cost of sales when it is importing. Sales can be both forward power, and more common for Cruachan, in-day/short-term power. Capacity Market revenues are included within electricity sales.
- Balancing market revenues relate to Cruachan's participation in the National Grid ESO operated Balancing Mechanism (BM) where generators 'offer' to increase generation, or 'bid' to reduce generation.
- Ancillary revenues cover services provided to National Grid ESO and primarily relate to services such as spin generation income, reserve income, frequency response income, black start income, constraint payments and reactive power income.

Pumped storage can provide clean power, capacity, and system support, a product suite that positions it favourably vs. other technologies, but understanding how Cruachan makes money, and its value, strategic and financial, requires an understanding of how the GB energy market works, and how Cruachan is positioned within it.

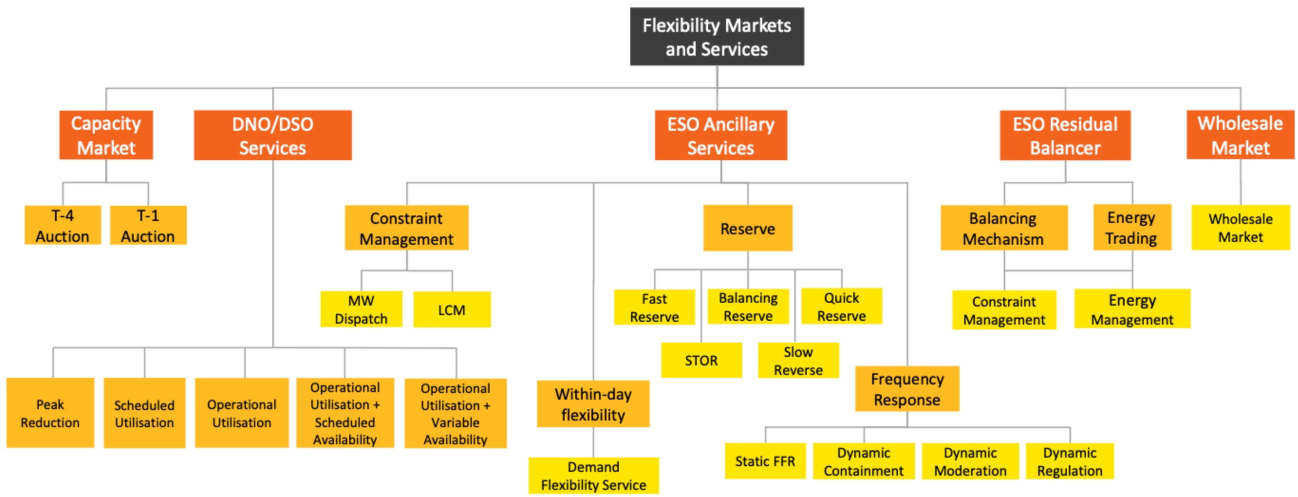
Figure 13: Pumped storage able to provide power, capacity and system support

		Pump storage	Hydro	Biomass	OCGTs	Nuclear	Wind	Solar
Power generation	**Power**	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Renewable generation	**Renewable power**	Yes	Yes	Yes	No	No	Yes	Yes
	Clean power	Yes	Yes	Yes	No	Yes	Yes	Yes
System Support	**Dispatchable**	Yes	Yes	Yes	Yes	No	Partial	Partial
	Inertia	Yes	Yes	Yes	Yes	Yes	No	No
	Reserve	Yes	Yes	Yes	Yes	No	Partial	No
	Reactive power	Yes	Yes	Yes	Yes	Yes	Partial	No
	Black start	Yes	Yes	Yes	Yes	Partial	No	No
Capacity		Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Drax

Figure 14 details current GB flexibility markets and services, capturing many of the revenue streams outlined above, although Cruachan can also generate revenues from other physical and non-physical financial markets additional to those depicted.

Figure 14: GB flexibility markets and services



Source: National Grid ESO Call for Input on ESO's Flexibility Market Strategy

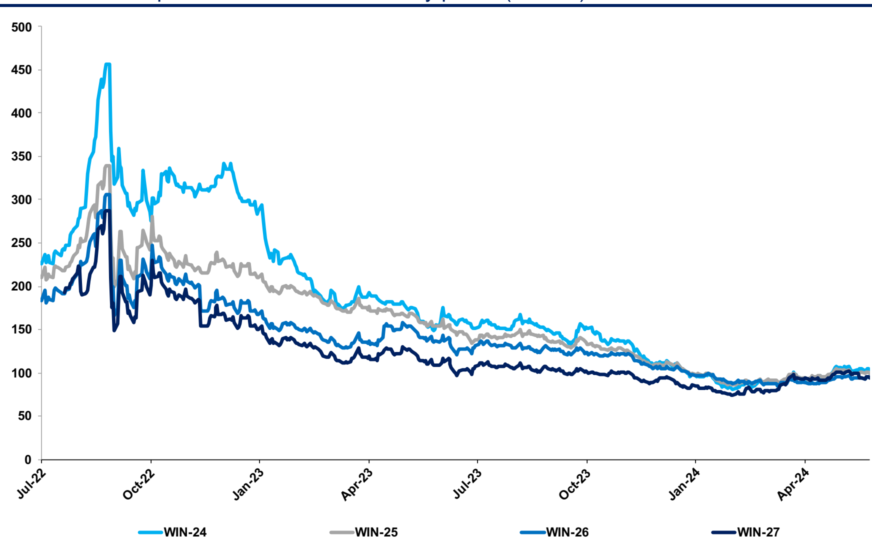
Wholesale market and optimisation revenues could moderate in future years, but Capacity Market revenue set to rise

Electricity sales (including wholesale and the Capacity Market)

Cruachan's electricity sales revenues are generated from the sale of power under contract or to other Drax group companies, optimisation gains, and revenues from the Capacity Market.

- **Wholesale market:** Cruachan is predominately traded in the near-term markets, although an amount of power was forward sold in FY23. Trading is executed with Drax Power Limited as the counterpart. Given the elevated levels of wholesale prices FY22 and FY23, it is reasonable to expect that wholesale market revenues in future years could outturn below FY23 levels.

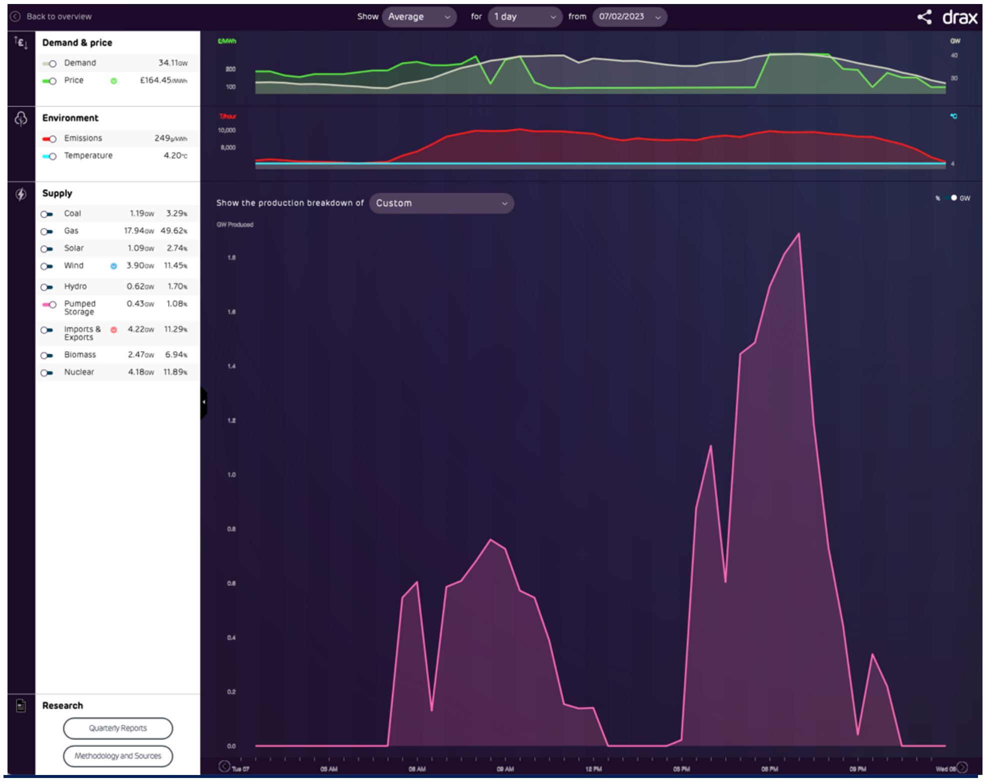
Figure 15: Forward peak winter season electricity prices (£/MWh)



Source: Drax (ICE data)

- **Optimisation:** There is a continuous optimisation programme, notably at day ahead. If Cruachan was forward hedged optimisation gains are recognised in revenues and optimisation losses in cost of sales. If a unit wasn't forward sold, export value is in revenue and import costs in cost of sales. Volatility is an important driver of optimisation opportunity, but the high price landscape of FY22 and FY23 was incrementally beneficial, and it is reasonable to expect that optimisation income in future years could be lower than in FY23. Figures 16 and 17 depict how pumped storage can be optimised to run at instances of peak pricing.

Figure 16: GB pumped storage operation (7/2/23)



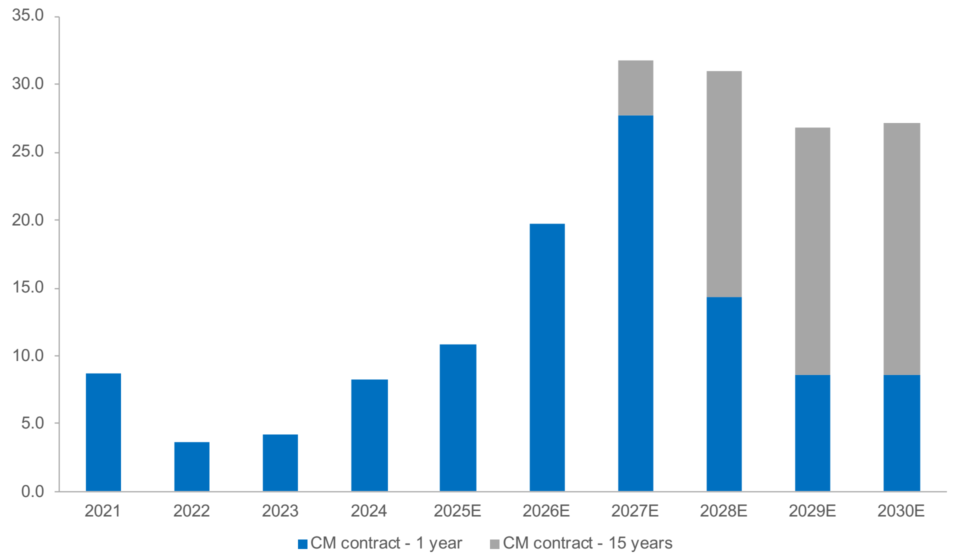
Source: Drax Electric Insights

Figure 17: GB pumped storage operation (7/3/23)

Source: Drax Electric Insights

- **Capacity Market**: The maximum clearing price in the T-3/T-4 auctions covering the seven delivery years (October-September) from 2018/19 to 2024/25 was £22.50/kW/yr. Consequently, Capacity Market revenues have historically been a small part of Cruachan's total revenue. The T-4 auction for delivery year 2025/26 cleared at £30.59/kW/yr, at £63/kW/yr for delivery year 2026/27, and at £65/kW/yr for delivery year 2027/28. Cruachan's four units secured contracts in each of these auctions, with units 3 and 4 securing 15-year refurbishment contracts in the most recent Capacity Market auction at £65/kW/yr. Assuming a clearing price of £35/kW/yr in future T-4 auctions, and that units 1 and 2 are able to secure contracts, the contribution to Cruachan's revenue from the Capacity Market is likely to be markedly higher in the second half of the decade.

Figure 18: Cruachan Capacity Market Revenues (£m, 2021-2030E)



Source: Aquaicity analysis of EMR auction results (Annual factor of 1.02 assumed where applicable to estimate CPIx and CPIbase for CCP calculation)

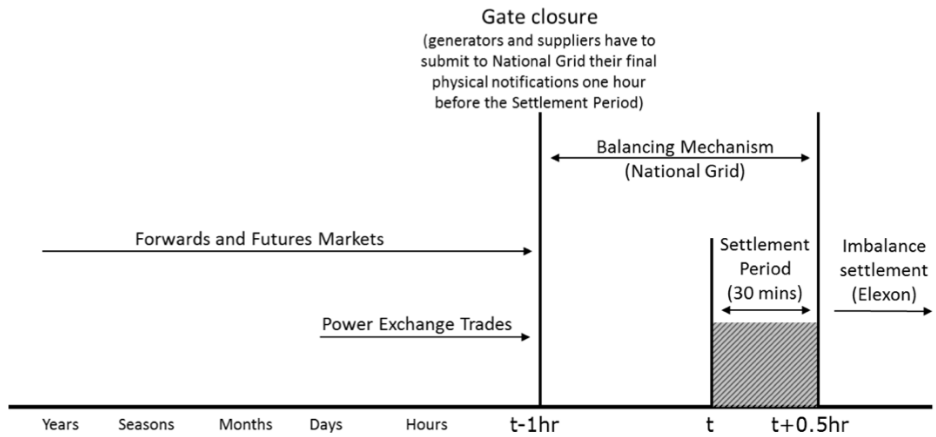
Balancing Mechanism

The BM is the primary tool used by the ESO to balance electricity supply and demand on the GB electricity system

Electricity is traded in half-hour blocks (settlement periods), with 48 periods every day. Suppliers and generators will endeavour to match their demand and generation, but mismatches will occur for a variety of reasons, leaving the system long or short, necessitating balancing by the ESO. The BM is the primary tool used by the ESO to balance electricity supply and demand on the GB electricity system.

The BM is the period between gate closure (the point at which generators and suppliers have to submit their final physical notifications), one hour before the commencement of a settlement period, and the end of that half-hour settlement period.

Figure 19: Balancing Mechanism timeline



Source: Ofgem

The BM is continuously open throughout the period 60 to 90 minutes ahead of real time. During this window market participants submit bids (a proposal to reduce generation or increase demand) or offers (a proposal to increase generation or reduce demand). The ESO will match supply and demand by accepting bids or offers (usually the most competitively priced), issuing Bid Offer Acceptances (BOAs), an instruction to the participant to change their output/demand, which participants have to accept.

Settlement calculations are performed for each Settlement Period where imbalances are calculated by comparing metered volumes against contracted volumes. Short generators/long suppliers must buy additional electricity, while long generators/short suppliers sell additional electricity. The price paid (£/MWh) to settle the imbalance is known as the System Price and is intended to reflect the costs incurred by the ESO to balance the system.

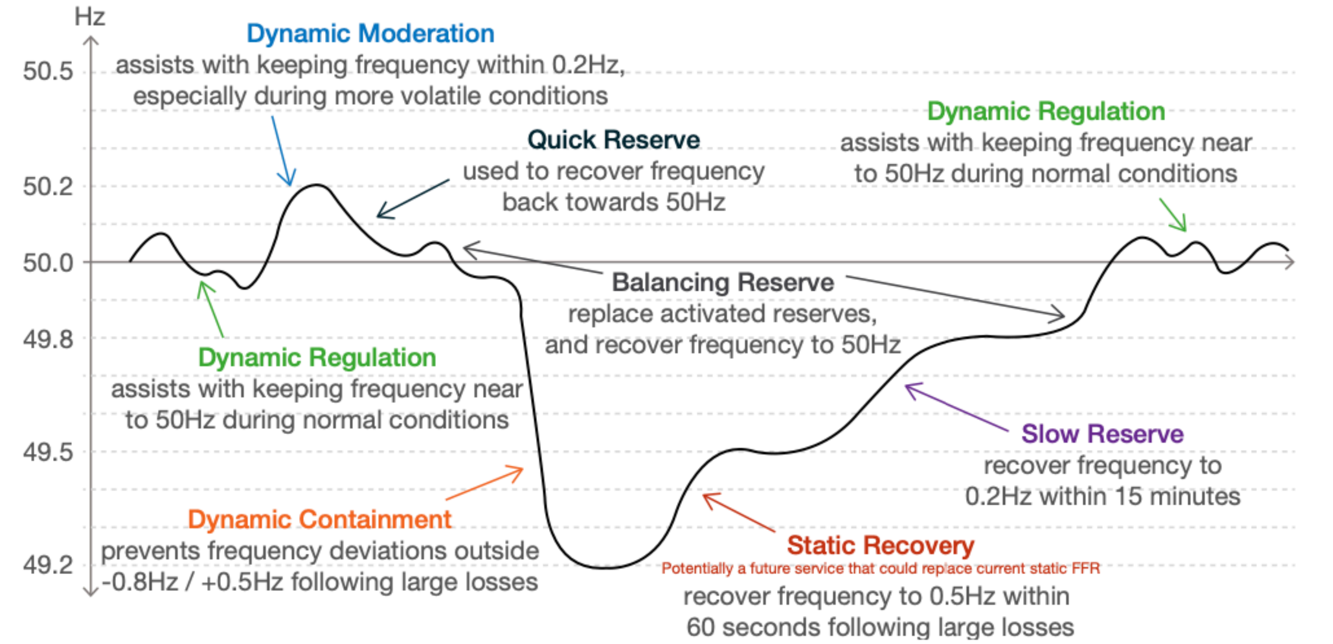
Cruachan is active in a number of BM revenue streams, notably offering the ESO an option to avoid wind curtailment

The BM is split between energy (balancing, reserve, and response) and constraints (restriction on the amount of power that can be moved in or out of a certain area), with the costs to alleviate Scottish constraints accounting for 42% of BM costs in FY22, and 34% in FY23. Cruachan is active in a number of BM revenue streams, but its ability to absorb and export power positions it attractively to offer the ESO an option to avoid wind curtailment.

Ancillary services

The ESO has a licence condition to keep the frequency of the electricity system within +/-1% of 50Hz, and it has a wide suite of ancillary services at its disposal to do so. Figure 20 depicts how these might be deployed in respect of frequency deviations, while Figures 21 to 23 explore the product suite in greater depth, referencing Cruachan's ability to participate.

Figure 20: Use of Balancing, Quick and Slow Reserve



Source: National Grid ESO Markets Roadmap (March 2024)

Figure 21: ESO ancillary services (i)

Service	What is it?	How is it procured?	Who can participate?	How is it remunerated?	Material for Cruachan – Aquaicity view
Frequency Response					
Mandatory Frequency Response (MFR)	MFR is an automatic change in power output in response to a frequency change. Primary response (within 10s, sustained for a further 20s); (ii) Secondary response (within 30s, sustained for a further 30 minutes); (iii) High frequency response (within 10s, sustained indefinitely).	No tender process, mandatory for large generators.	A power station may be obliged to provide MFR, this being set out in their connection agreement.	Pay-as-bid holding payments (generator submitted £/h) and response energy payment (£/MWh).	x
Static Firm Frequency Response (FFR)	Non-dynamic frequency response service provided within 30s and sustained until 20 minutes following the point at which the which the frequency trigger was reached.	Day-ahead auction.	Minimum entry threshold of 1MW.	Pay-as-clear (£/MW/hour). 4-hour contract. Payments are for availability only.	x
Dynamic Containment (DC)	Fast-acting, post-fault service to help contain frequency within statutory limits +/-0.5Hz from 50Hz target frequency.	Daily day ahead auction via the ESO's Enduring Auction Capability.	Open to both BM and non-BM registered assets, with 0.5s maximum time between change in frequency and delivery of response, 1s maximum time to full delivery, and capable of sustaining delivery for 15 minutes. Minimum response capacity of 1MW, maximum 100MW per response unit.	Pay-as-clear auction (£/MW/hour). 4-hour contract. Payments are for availability only.	x
Dynamic Moderation (DM)	Fast-acting, pre-fault service to help contain frequency within statutory limits +/- 0.2Hz from 50Hz target frequency. DM responds between +/-0.1Hz and +/- 0.2Hz.	Daily day ahead auction via the ESO's Enduring Auction Capability.	Open to both BM and non-BM registered assets, with 0.5s maximum time between change in frequency and delivery of response, 1s maximum time to full delivery, and capable of sustaining delivery for 30 minutes. Minimum response capacity of 1MW, maximum 50MW per response unit.	Pay-as-clear auction (£/MW/hour). 4-hour contract. Payments are for availability only.	x
Dynamic Regulation (DR)	Staple slower pre-fault service across the operational frequency range to help contain frequency within statutory limits +/- 0.2Hz from 50Hz target frequency.	Daily day ahead auction via the ESO's Enduring Auction Capability.	Open to both BM and non-BM registered assets, with 2s maximum time between change in frequency and delivery of response, 10s maximum time to full delivery, and capable of sustaining delivery for 60 minutes. Minimum response capacity of 1MW, maximum 50MW per response unit.	Pay-as-clear auction (£/MW/hour). 4-hour contract. Payments are for availability only.	x

Source: Aquaicity analysis using National Grid ESO/Ofgem documentation

Figure 22: ESO ancillary services (ii)

Service	What is it?	How is it procured?	Who can participate?	How is it remunerated?	Material for Cruachan – Aquaicity view
Reserve					
Fast Reserve	Rapid delivery of active power from increasing output or reducing consumption.	Within day through the Optional Fast Reserve service.	Open to both BM and non-BM providers, connected to transmission or distribution who can deliver active power within two minutes of instruction, can deliver a minimum of 25MW, with a delivery rate in excess of 25MW/minute, and be able to sustain for a minimum of 15 minutes.	Availability fee (£/hour) if called and a utilisation fee (£/MWh) if dispatched.	√ √ √
Balancing Reserve (BR)	Regulating Reserve corrects energy imbalances.	Proposed BR service procured daily via Enduring Auction Capability with 08:15 gate closure.	BM units which can provide a minimum contract capacity of 1MW, with 10 minute time to full delivery.	£/MW/hour (Availability and utilisation payments. Max {BM accepted offer/bid price for energy or ESO trade for energy}/MW per Settlement Period).	√
Slow Reserve	Proposed service to provide the ESO with access to firm, bi-directional energy to displace large losses on the system and recover frequency to ± 0.2Hz within 15 minutes. Operates post fault. Separated into Negative Slow Reserve (NSR) and Positive Slow Reserve (PSR).	Daily day ahead via auction at 14:00.	Open to BM and non-BM units with minimum capacity of 1MW able to maintain delivery at 100% for service window duration (8 hour overnight block 23:00-07:00, and 8x 2 hour blocks).	Firm service (availability and utilisation); optional service (utilisation). Availability pay-as-clear; optimisation pay-as-bid.	√
Quick Reserve	Proposed service to react to pre-fault disturbances to quickly restore the energy imbalance and return the frequency close to 50Hz. Separated into Negative Quick Reserve (NQR) and Positive Quick Reserve (PQR).	Daily day ahead via auction at 14:00. Maximum bid size of 300MW.	Open to BM and non-BM units with minimum capacity of 1MW, and least one activation at 100% of contracted capacity per Settlement Period.	Firm service (availability and utilisation); optional service (utilisation). Availability pay-as-clear; optimisation pay-as-bid.	√
Short Term Operating Reserve (STOR)	STOR provides additional active power from generation or demand reduction.	Daily pay-as-clear auction closing at 05:00 for delivery the following service day (05:00-05:00).	Open to BM and non-BM units connected to transmission or distribution and able to increase generation or reduce demand by at least 3MW. STOR units must be able to respond within a maximum of 20 minutes, sustain the response for a minimum of two hours, and have a recovery period of not more than 20 hours.	£/MW/hour pay-as-clear (utilisation and availability).	x

Source: Aquaicity analysis using National Grid ESO/Ofgem documentation

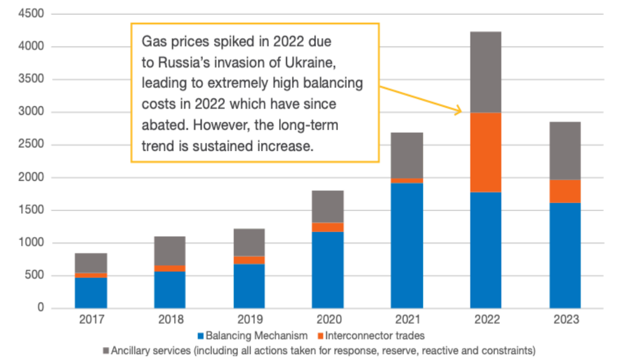
Figure 23: ESO ancillary services (iii)

Service	What is it?	How is it procured?	Who can participate?	How is it remunerated?	Material for Cruachan – Aquaicity view
Inertia					
Inertia	Kinetic energy stored in spinning parts of many generators.	Switching on thermal generators, Stability Pathfinder tender.	Large generators as generation by-product, synchronous compensators.	Contract and stability pathfinders.	√ √ √ (six-year synchronous compensation contract, exclusive use of one unit).
Restoration Services					
Restoration	Contingency arrangement to restore electricity supplies following a total or partial shutdown of the national electricity transmission system.	ESO tender process.	Generators or HVDC systems that have the capability to restart without external supplies.	Availability payment (£/settlement period).	√ √ √
Reactive Power Services					
Obligatory Reactive Power Service (ORPS)	Obligatory service to maintain voltage levels within a given range, generators/other asset owners instructed to absorb (decrease voltage) or generate reactive power (increase voltage).	Mandatory for large generators, no tender process.	All generators covered by the requirements of the Grid Code are required to have the capability to provide reactive power.	Utilisation (£/MVArh) paid via the default payment mechanism, updated monthly.	√
Enhanced Reactive Power Service (ERPS)	Non-obligatory service which complements the ORPS.	ESO tender, six monthly.	Generators which can provide reactive power over and above ORPS.	£/MVArh with capability and utilisation payment.	√
Constraint Management					
MW Dispatch	Route for Distributed Energy Resources (DER) to assist the ESO in managing regional transmission constraints.	DER providers register with the ESO which can issue instructions to the DNO to request that the DER provider curtails their asset output to zero.	Initially applies to DER connecting at 13 Grid Supply Points with NGED (South-West) and UKPN (South Coast).	Pay-as-bid for the volume of curtailed energy on a utilisation only basis.	x
Local Constraint Management (LCM)	The LCM was established to save overall costs at the B6 boundary as a generation turn down/turn up service when operationally safe and lower cost vs. the BM. Wide coverage of much of Scotland.	Tenders on the PicloFlex platform with day ahead and intraday instruction windows.	No minimum MW threshold, assets from 1kW eligible.	£/MWh for contracted tenders.	x
Within Day Flexibility					
Demand Flexibility Service (DFS)	DFS ran as a winter contingency service in winters 2022/23 and 2023/24. The ESO has proposed that it will move to a commercial year-round service.	In winter 2023/24 DFS was procured via test and live events.	Demand can participate via registered providers.	£/MWh bids for competitive test and live events.	x

Source: Aquaicity analysis using National Grid ESO/Ofgem documentation

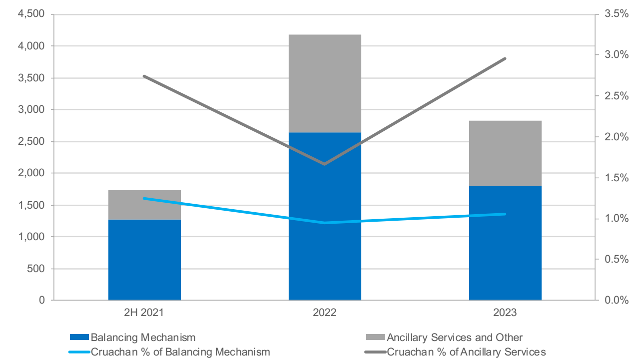
Across the 30-month period to December 2023, Cruachan averaged 1.0% of the ESO's Balancing Mechanism costs, 2.3% of the ESO's Ancillary Services costs, and 1.5% of the total.

Figure 24: Balancing costs (£m, 2017-2023)



Source: National Grid ESO Markets Roadmap (March 2024)

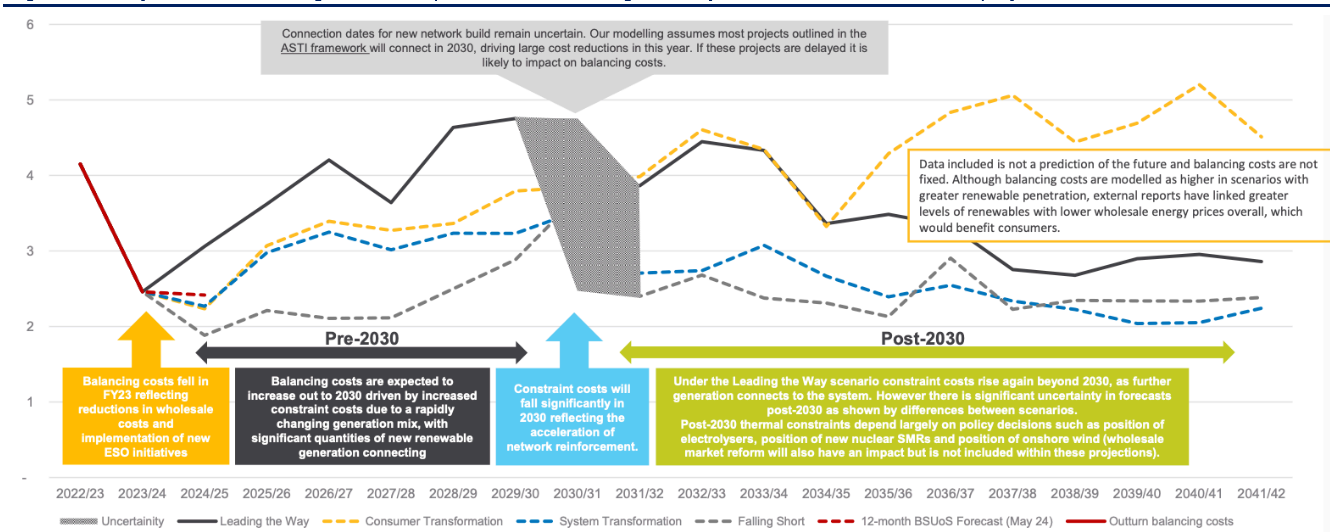
Figure 25: Balancing costs (£m, LHS), Cruachan % (RHS)



Source: Aquaicity analysis of Drax and National Grid ESO data

In May, the ESO set out projections for balancing costs through to 2030 and beyond using the four FES 2023 scenarios, with each pointing to elevated levels of balancing costs through to the end of the decade, and at a higher level than 2023/24 under three of the scenarios. (FES 2024 ESO Pathways to Net Zero was published on 15th July 2024 with three pathways and a counterfactual replacing the four scenarios of FES 2023. At the date of this report, we are not aware of an updated projection of balancing costs).

Figure 26: Projection of balancing costs extrapolated from Leading the Way residual thermal constraint projection

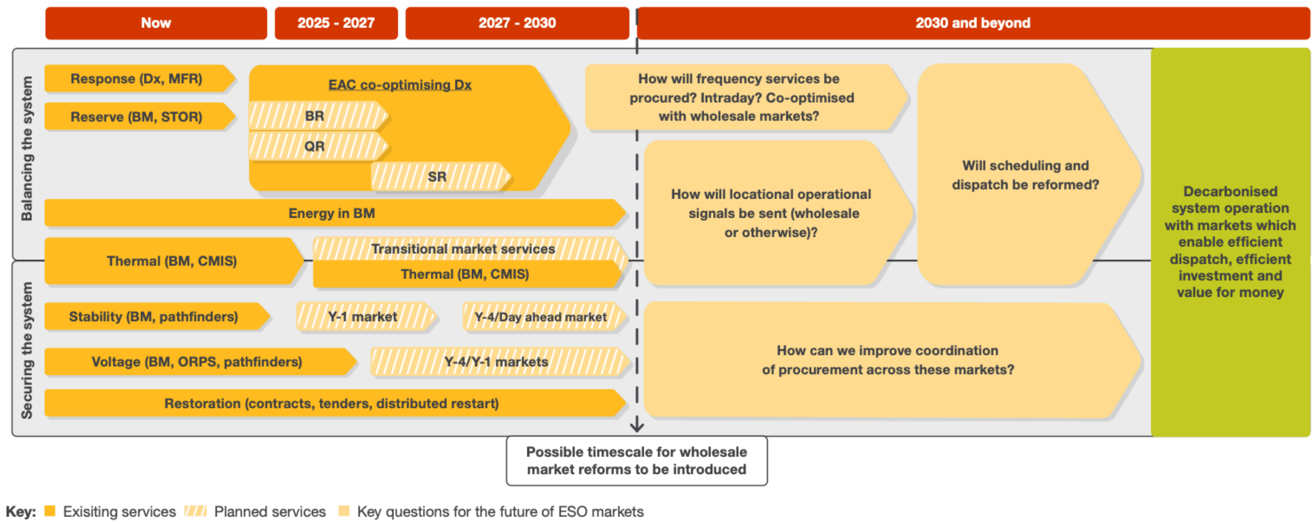


Source: National Grid ESO Balancing Costs: Annual Report and Future Projections (May 2024)

Possible upside risk to Cruachan's BM and ancillary services revenues through to 2030

This suggests that if Cruachan is able to maintain its share of the ESO's Balancing Mechanism and Ancillary Services costs, revenue from these two streams through to 2030 could nudge up from the levels seen in recent years. The post 2030 outlook is likely to be entwined with both the Reform of Electricity Market Arrangements (REMA), if it progresses, and the ESO's development of the suite of services it procures, potentially changing the mix, albeit against a backdrop of the ESO projecting sustained levels of balancing costs throughout the 2030s.

Figure 27: Forward-looking view of balancing service markets



Source: National Grid ESO Markets Roadmap (March 2024)

Cruachan is optimised to stack revenues across multiple products and services

Revenues can be stacked

The above revenue streams are not necessarily mutually exclusive and, in many instances, can be stacked to drive value for flexible assets. There are three types of revenue stacking: (i) Co-delivery: being paid multiple revenues using the same MW, in the same time period; (ii) Splitting: being paid multiple revenues from different MWs, from the same asset, in the same time period; and (iii) Jumping: being paid multiple revenues from the same asset, in different time periods.

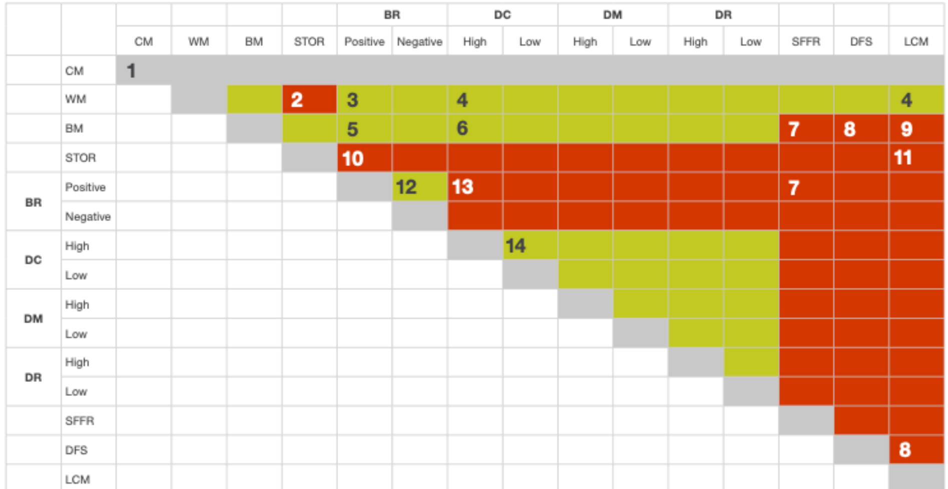
Figures 28 to 30 depict how revenues can be stacked, with Cruachan optimised and stacked across all permissible categories.

Figure 28: Revenue stacking: Co-delivery

						BR		DC		DM		DR				
		CM	WM	BM	STOR	Positive	Negative	High	Low	High	Low	High	Low	SFFR	DFS	LCM
	CM				1										2	1
	WM			3	4	3		5								
	BM				6										2	7
	STOR															8
BR	Positive															9
	Negative															
DC	High															8
	Low															
DM	High															
	Low															
DR	High															
	Low															
	SFFR															
	DFS															2
	LCM															

Source: National Grid ESO Markets Roadmap (March 2024: Green – stacking in the same delivery window allowed; Orange – stacking in the same delivery window not allowed)

Figure 29: Revenue stacking: Splitting



Source: National Grid ESO Markets Roadmap (March 2024: Green – stacking in the same delivery window allowed; Orange – stacking in the same delivery window not allowed)

Figure 30: Revenue stacking: Jumping

Source: National Grid ESO Markets Roadmap (March 2024: Green – stacking in the same delivery window allowed; Orange – stacking in the same delivery window not allowed)

Referencing the May 2024 balancing cost projection under the Consumer Transformation scenario, assuming Cruachan is able to maintain a revenue share in line with that of the 30-month period to December 2023, the uptick in Capacity Market revenues (secured through to September 2028) and optimisation opportunities in an electricity market with more renewables, suggests Cruachan can continue to deliver triple digit revenues post 2027.

Cruachan I upgrade increases capacity and flexibility

Opportunity identified to increase the output of units 3 and 4…

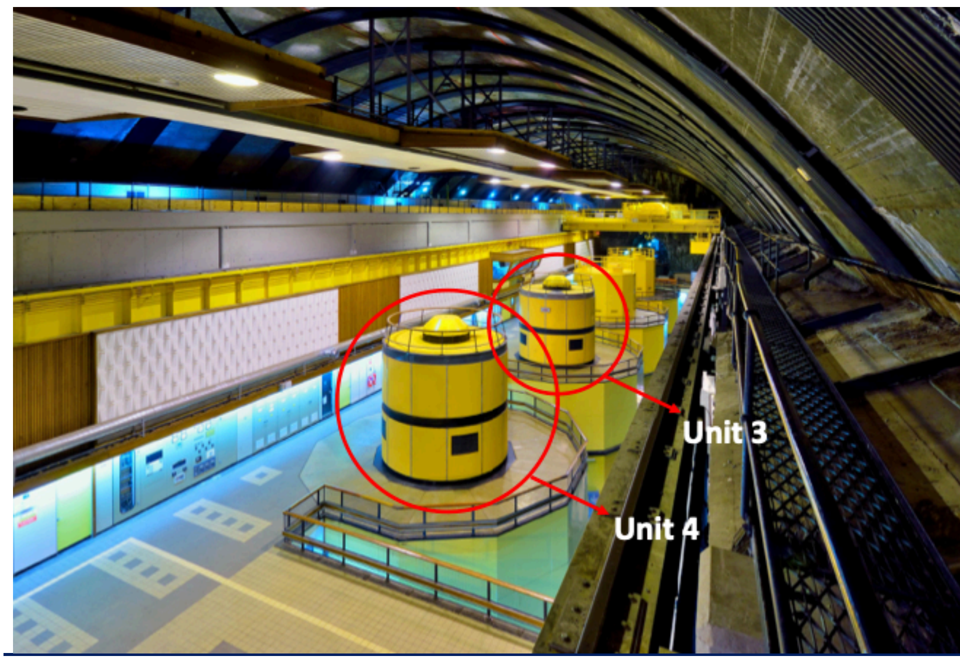
Cruachan units 3 and 4 (both 100MW) were originally commissioned in 1965 and have been in service since. While the generators have been replaced since original commissioning, the turbines are largely original components. Start/stop cycle operation of pumped storage limits the life of key components, and an assessment was undertaken to consider the future requirements for the plant.

The operating level of Cruachan is determined by the size of the dam, the steel inlet location, and the hydraulic characteristics of the turbines. With hydraulic modelling suggesting that the dam can be operated to a lower level with turbine replacement, and new turbine design enabling a 40-120MW operating range (vs. 70-100MW currently), the potential to increase power, improve efficiency, and widen the operating range was identified.

…development consent granted in December 2023…

The planning application for the Cruachan I upgrade project was submitted in February 2023, and development consent from the Scottish Government was received in December 2023. The upgrade includes the installation of new inlet valves, the complete replacement of the generator, turbine impellor and other turbine components, increasing the capacity of each unit to 120MW. The new turbines will fit within the existing physical infrastructure at Cruachan, minimising the environmental impact.

Figure 31: Cruachan Power Station Machine Hall



Source: Drax

…work to commence in 2025, completing in 2027…

ANDRITZ Hydro was appointed as the main contractor for the upgrade project in April. Drax envisages that site works will commence in 2025, completing around June 2027, with planning application documents suggesting peak work activity around October 2026. Units 3 and 4 will be offline for c.90 days in summer 2025, with unitised outages of c.6 months in 2026 and 2027 for units 3 and 4 respectively. Mid-year 2027 completion is consistent with the 15-year Capacity Market contract that Cruachan has secured for units 3 and 4, effective delivery year 2027/28.

…£80m investment underpinned by £221m of Capacity Market revenues

Drax has indicated that the upgrade will cost £80m, spread across 2024-2027, the investment underpinned by the 15-year Capacity Market contract at £65/kW/yr (2022/23 prices, CPI linked), a record high in the T-4 auctions. This is complemented by the benefits of increased capacity, improved efficiency, and a wider operating range.

Cruachan II – incremental benefit to system and Drax

Cruachan II project overview

Cruachan II is a c.£600m 600MW expansion, with Drax targeting FID in 2026 and commercial operations in 2030…

As highlighted earlier, Drax has secured planning consent for a 600MW expansion of the Cruachan Power Station. Consent under s36 was awarded by the Scottish Government in July 2023. Voith Hydro has been appointed to complete a Front-End Engineering and Design study for the mechanical and electrical components of the design, and subject to the right investment framework Drax is targeting a c.£600m final investment decision (FID) in 2026, with commercial operations commencing in 2030.

…power output would more than double and Cruachan's ability to deliver system services would markedly increase

Cruachan II seeks to optimise the use of the existing Cruachan Power Station, reservoir and dam, through the construction of a new, separate but linked, underground power station and associated infrastructure. Both power stations will use Loch Awe as the lower reservoir and Cruachan Reservoir as the upper reservoir. Although electrical storage capacity would only increase by c.13%, the power that can be delivered would more than double, while the addition of up to four turbines means Cruachan's ability to deliver a range of much needed system support services would markedly increase. The broader policy framework is favourable, and Cruachan II would be of incremental benefit to the GB electricity system, and subject to the right investment framework, Drax too.

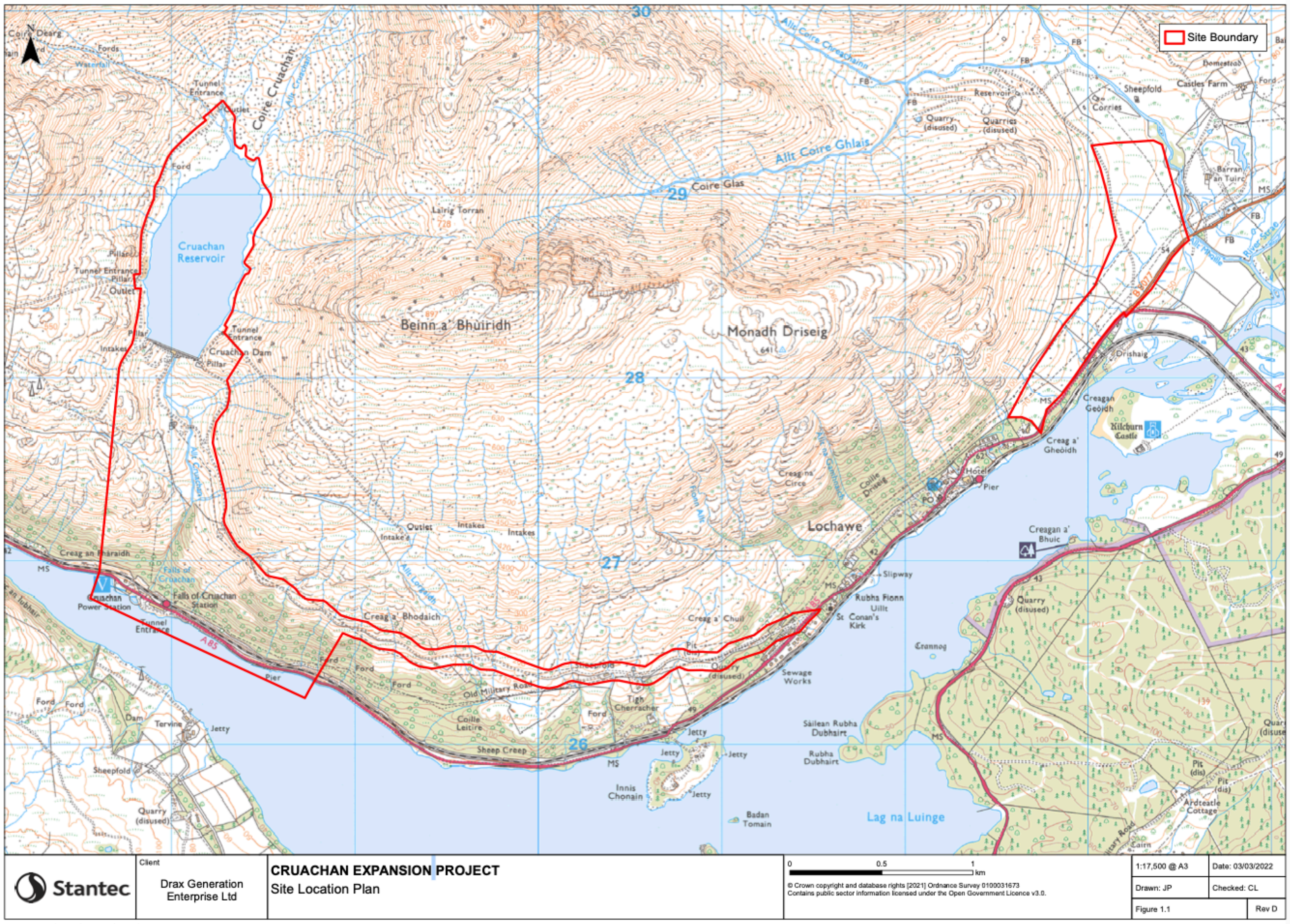
The main elements of the Cruachan II development are set out in Figure 32, complemented by a selection of images to show location (Figure 33), scheme layout (Figure 34), the power station schematic (Figure 35), the upper intake (Figure 36), the upper intake post restoration (Figure 37), and the lower works layout (Figure 38).

Figure 32: Main elements of Cruachan II

Design element	Proposal
Upper control works	A new intake structure would be located within and adjacent to the Cruachan Reservoir to direct water into a new tunnel and underground waterway system.
Underground waterway system	A series of underground shafts and tunnels carrying water between the upper reservoir and lower reservoir, directed through the underground powerhouse cavern.
Powerhouse cavern	A series of underground caverns containing turbines and generators which will use water to produce electricity.
Substation	The existing substation compound is required to be extended in order to provide a suitable connection to the existing overhead circuits that connects to Dalmally substation, located some 7km to the east.
Ventilation shaft	A ventilation shaft will be required to circulate fresh air through the underground access tunnel and cavern power station complex.
Tailrace tunnel	A concrete-lined low-pressure tunnel will conduct water between the turbines and Loch Awe, the lower reservoir.
Lower control works	Comprising screened inlet/outlet structure, positioned in Loch Awe at the end of the tailrace tunnel below the water level. These structures would channel water in and out of Loch Awe.
Quayside	Constructed on the northern shore of Loch Awe to facilitate the construction of the underground access tunnels, waterway system and powerhouse cavern, and the temporary storage of spoil prior to its off-site removal.
Canopy structure	The quayside would also house a canopy structure, covering the stockpiles of spoil. The canopy structure would be enclosed on three sides by brick/concrete walls and have a corrugated roof. The primary purpose of this structure would be to prevent silt from stockpiles mobilised by wind/rainfall from entering Loch Awe and the surrounding landscape.
Administration building	Above ground administration and workshop buildings located on the quayside, required for day to day operational and maintenance tasks.
Storage buildings	Above ground buildings located on the quayside, required for regular plant maintenance.
Access tunnels	A main access tunnel, 1,450m in length, would be constructed to provide access to the underground power plant, close to the shore of Loch Awe. This will cross connect to the existing Cruachan I to allow personnel to easily move between the plants and provide a further means of access/egress.
Service roads	Existing service roads will be used as far as possible to facilitate the long-term operation of the generating station. Some upgrades of these roads may be required to facilitate access by heavy machinery and the removal of spoil.

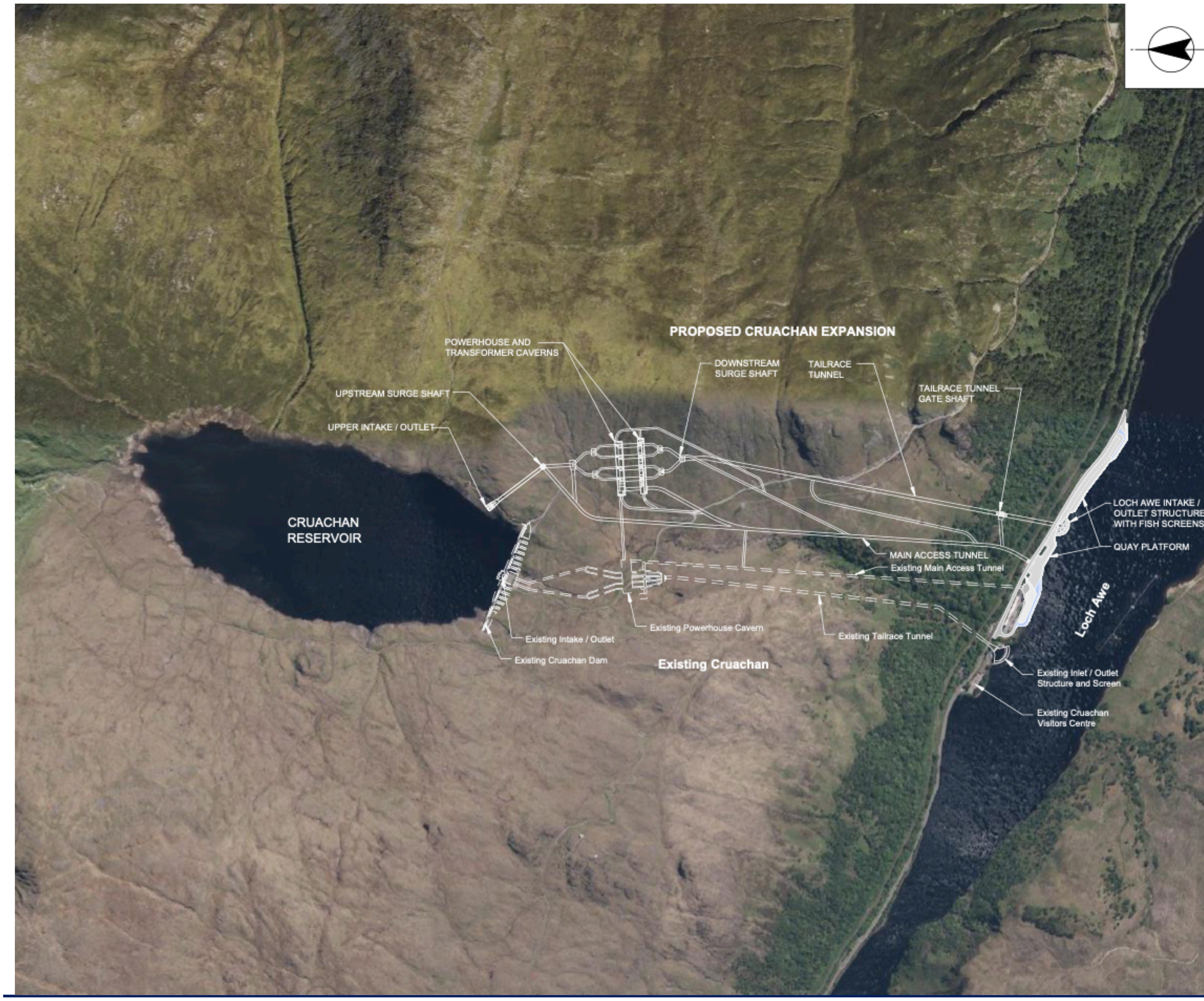
Source: Cruachan expansion project, planning statement

Figure 33: Cruachan II location plan



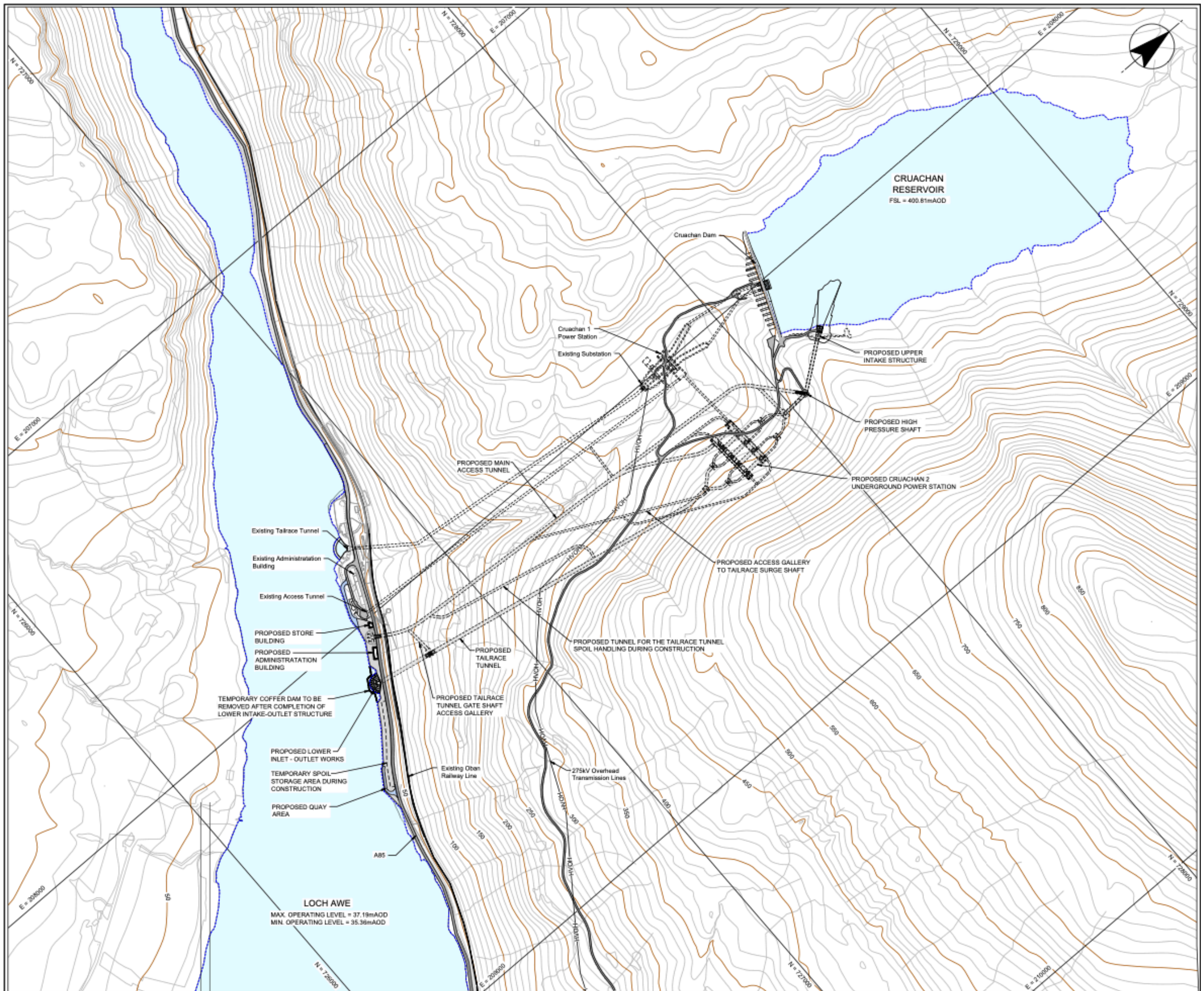
Source: Cruachan expansion project, s36 application drawings

Figure 34: Cruachan II scheme layout



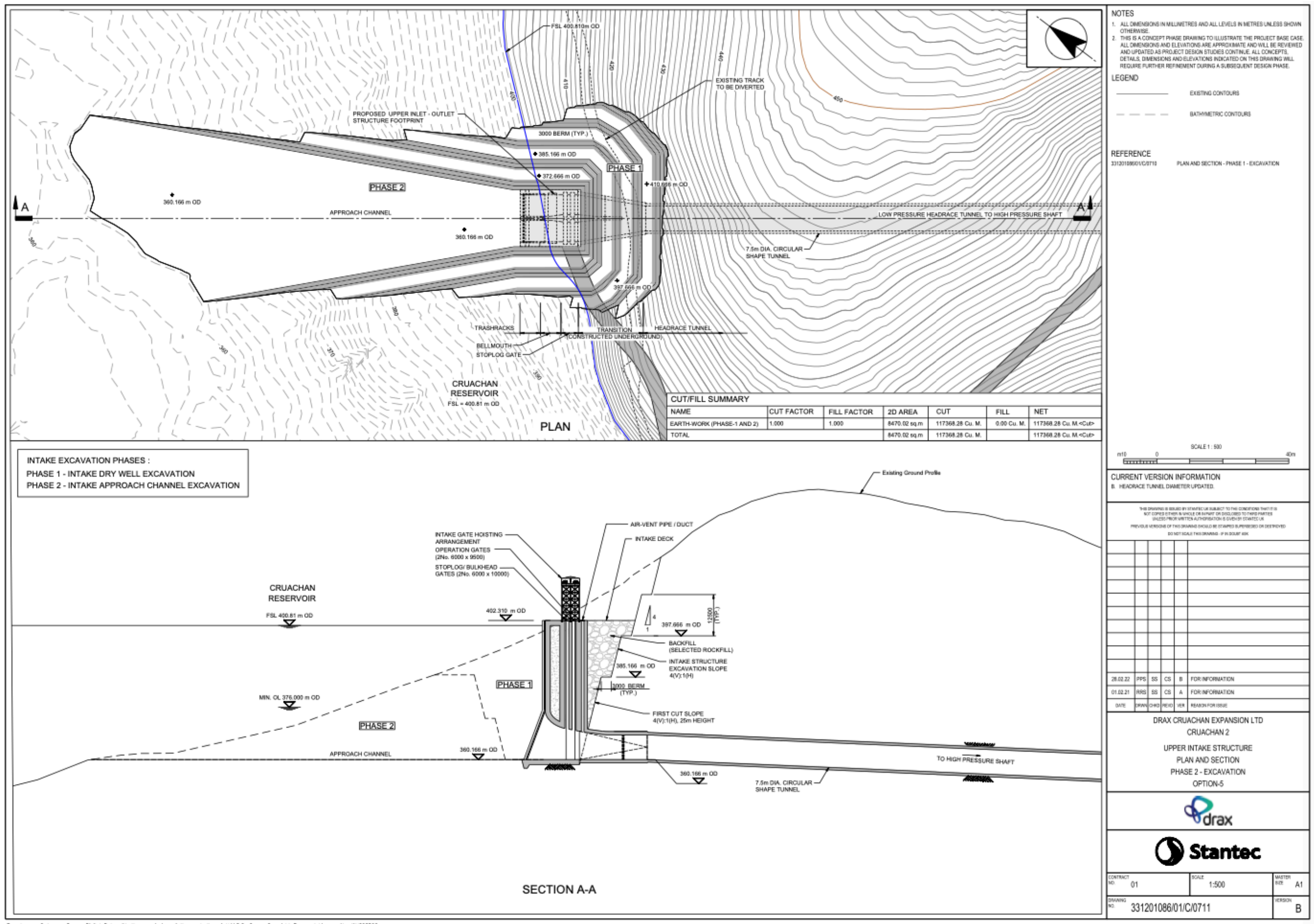
Source: Cruachan expansion project, s36 application drawings

Figure 35: Cruachan II schematic



Source: Cruachan expansion project, planning statement

Figure 36: Cruachan II upper intake (Cruachan Reservoir)

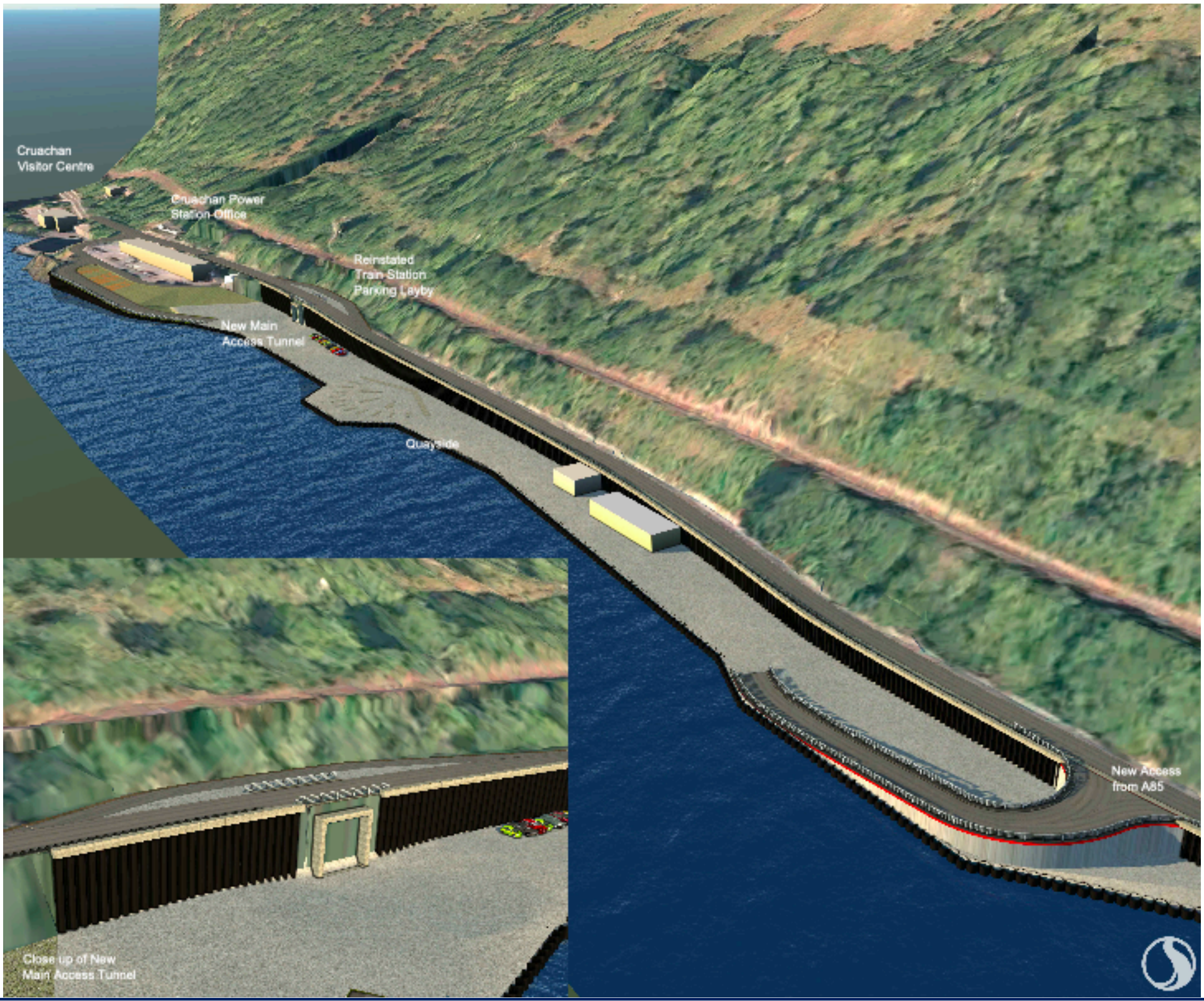


Source: Cruachan expansion project, s36 application drawings

Figure 37: Cruachan II upper intake visualisation (Cruachan Reservoir)

Source: Cruachan expansion project, s36 application drawings

Figure 38: Cruachan II lower works layout (Loch Awe)



Source: Cruachan expansion project, s36 application drawings

Engineering challenge, notably on the civils side, but projects needing dam construction face greater challenges

Undoubtedly Cruachan II will be an engineering challenge, more so on the civil engineering side, which represents c.70% of the c.£600m investment. With infrastructure constraints, drill and blast is the recommended tunneling method, with the lake tap method used to create the intakes, both of which present challenges, notably around geology and the possible need for concrete reinforcement of the tunnel. Rock and rubble (c.1.5mt) will need to be removed by road with a significant number of truck movements, while some parts of the rotating mass of the gensets cannot be subdivided. There is a risk that the target of commercial operation in 2030 could slip, and it is also possible that Cruachan II becomes operational in stages.

Compared to other pumped storage projects, there is no need construct a dam, something that brings considerable engineering and environmental challenges, and a lengthier construction phase. SSE estimates a construction time of 5-6 years for Coire Glas. However, use of the existing dam at Cruachan limits the increase in storage volume.

Cap and floor framework likely, but design details needed

DESNZ consultation sets out intention to develop cap and floor mechanism for LDES…

Drax has previously indicated that it is evaluating investment models for Cruachan II with a final investment decision dependent on the right investment framework. A DESNZ consultation, published in January, on designing a policy framework for long duration electricity storage (LDES) acknowledges the pivotal role of LDES in a smart and flexible energy system with a high volume of low carbon power, but recognises the need for policy support to enable investment. The consultation sets out an intention to develop a cap and floor mechanism similar to that for interconnectors as the most appropriate policy to enable investment in LDES, with Figure 39 outlining proposals for a number of key design elements. The consultation closed on 5th March, with the government yet to respond.

Figure 39: Long duration electricity stoarge consulation – selected design proposals for cap and floor regime

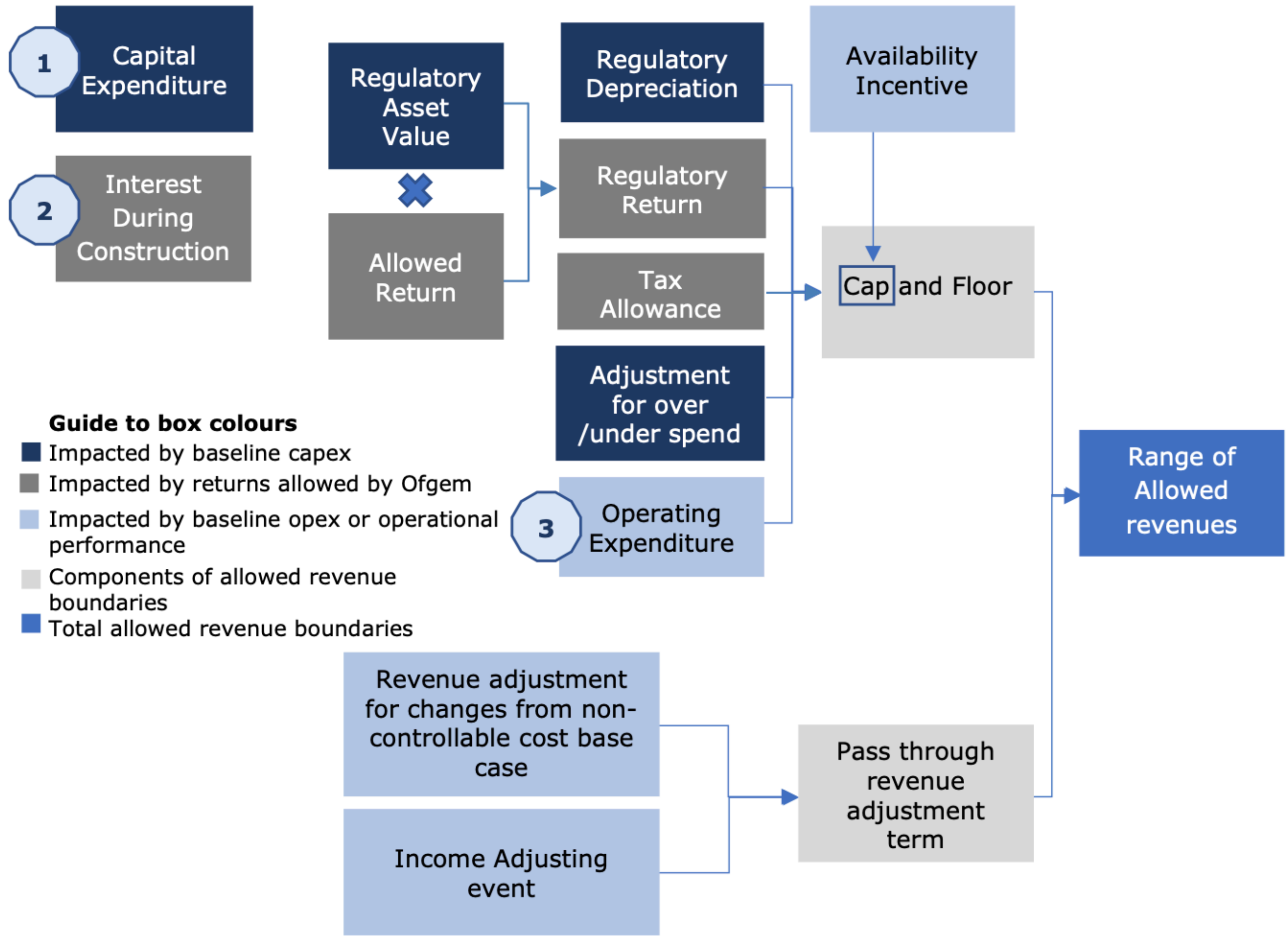
Design element	Proposal
Duration and efficiency	Projects should be able to demonstrate a minimum duration of six hours at a specified power capacity. No minimum efficiency proposal put forward, but stakeholder views invited.
Technologies	Two streams: Stream 1 (established technologies), Stream 2 (novel technologies). Pumped storage hydro in Stream 1.
System benefits	LDES projects seeking a cap and floor agreement should be able to demonstrate a strong benefits case to the wider system for the project's lifetime, such benefits including ancillary services, location-based benefits, system costs, consumer benefits, local economy benefits, constraint management, and energy security.
Setting cap and floor levels	Floor level should be set such that a project can recover its debt-related costs, with the cap at a level that incentivises asset operation, allows a fair return on equity investment, and protects consumers from excessive cost. Gross margin to be used to set both the cap and floor level.
Addressing operational risks	Floor distortion risk could be mitigated by setting the floor at the cost of debt, introducing a longer period to review gross margin revenues, and setting availability or performance requirements. Cap distortion risk could be mitigated by introducing a longer period to review gross margin revenues, setting soft-caps to return gross margin on a sliding scale, and setting availability or performance requirements. Measures under consideration to minimise gaming risk distortion include a transparency requirement, banning vertically integrated offtake and supply agreements within an umbrella company, and developing a deemed revenue index.
Administrative allocation	Administrative process considered best suited to delivering a cap and floor mechanism as it should support a range of LDES projects that bring the most system benefits.
Contract length	Project lifetime identified by the developer, with the administering authority having a role in approving the exact lifetime. Project lifetime is the lifetime prior to refurbishment and is likely of shorter duration than the asset's technical lifetime.
Revenue opportunities	LDES assets in receipt of cap and floor support should be able to access and operate in the available electricity system markets.
Pre-qualification criteria	Financial position of the project, its connection location and grid agreement, land/lease ownership, planning permission, environmental permits, and whether the project has an electricity generation licence.
Additional factors	Review periods needed to assess if the gross margin achieved by the developer has breached either the cap or floor thresholds, with multi-year periods suggested. Force majeure and exceptional events should be taken into account and adjusted for. A proving period to incentivise delivery is under consideration, as well as a proposal to set target commission dates. If targets are missed by more than 12 months, the duration of the delay period will be deducted from the support period.
Delivery routes	Two possible routes: (i) conditions in generation licences issued by Ofgem; (ii) via CfD-style contracts. Option 1 would likely be funded via TNUoS charges, with option 2 would likely be funded via a supplier obligation levy.

Source: Analysis of DESNZ long duration electricity consultation

…further engagement on design in 2024, administrative allocation process helpful to Drax in securing incremental margin

Detailed design of the cap and floor model needs to be completed and DESNZ has indicated that it will seek further engagement during the course of this year. Given common upper and lower reservoirs it is reasonable to expect Drax to seek a design that looks at incremental gross margin to avoid negative impact on Cruachan I. The administrative allocation process should be helpful in this respect. By way of example, Figure 40 sets out at a high level the cap and floor regime for interconnectors, with the cost of debt/equity return applied to 100% of the RAV to determine allowed returns at the floor/cap respectively.

Figure 40: How cap and floor levels are set for interconnectors



Source: Ofgem Interconnector Cap and Floor Regime Handbook

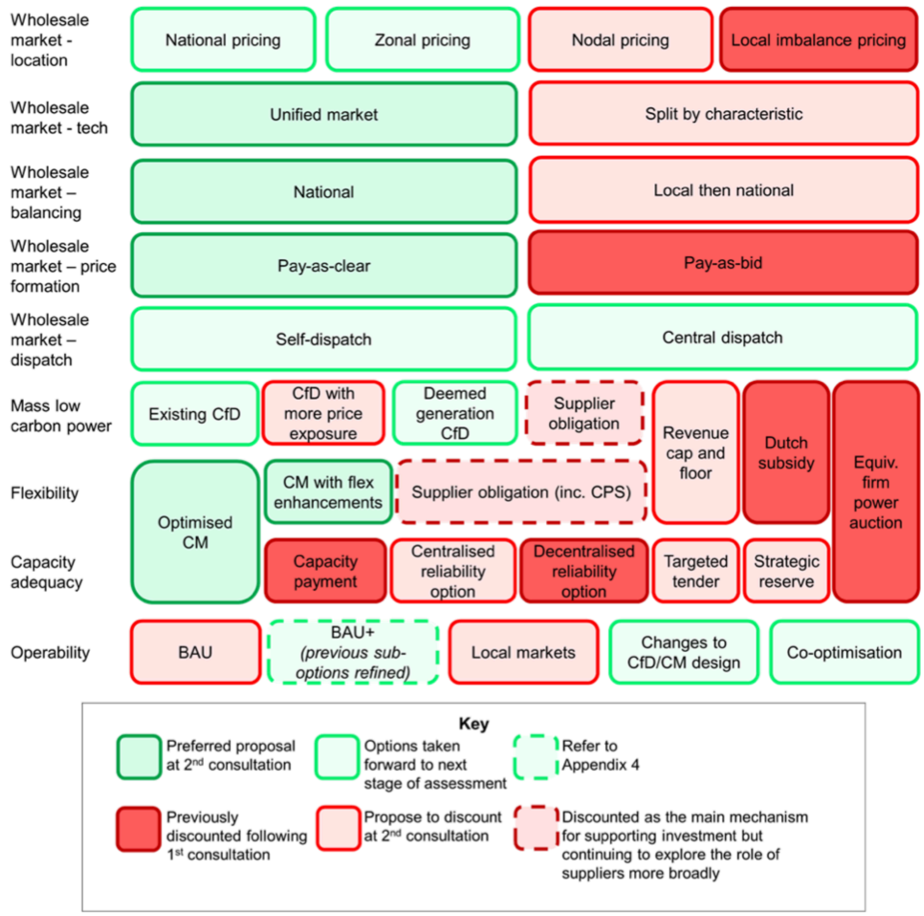
Change coming, diversity gives Cruachan resilience

REMA could impact GB electricity value chain participants and electricity consumers, but there are valid arguments for a pathway of pace over perfection…

There is broad acceptance that changes are needed to the current electricity market framework to deliver a clean, secure and low-cost electricity system, and the REMA consultation process sets out a number of proposals and policy options. Depending on which, if any, are ultimately taken forward, they could impact GB electricity value chain participants and electricity consumers.

The second REMA consultation narrowed the range of options, but there was an election induced hiatus, and the new government is yet to communicate granular detail on energy policy. However, given the manifesto commitment to decarbonise the power sector by 2030, can the government accommodate a potentially long consultation process, and a subsequent lengthy design and implementation phase? There are some polarised stakeholder views, particularly around the national vs. zonal pricing debate, but the magnitude of investment needed across the electricity value chain underscores the need for investor confidence, and there are valid arguments for pursuing a pathway of pace over perfection.

Figure 41: REMA options (second consultation)



Source: DESNZ (Review of Electricity Market Arrangements: Second Consultation)

If REMA survives, irrespective of where it ultimately lands, the location of wind resource is likely to see considerable renewable build north of the B6 boundary (between SP Transmission (to the north) and National Grid Electricity Transmission (to the south)) with a generation surplus (Figure 42) driving a need for significant transmission build in the current decade (Figure 43) and beyond (Figure 44). Both have relevance for Cruachan's revenue streams.

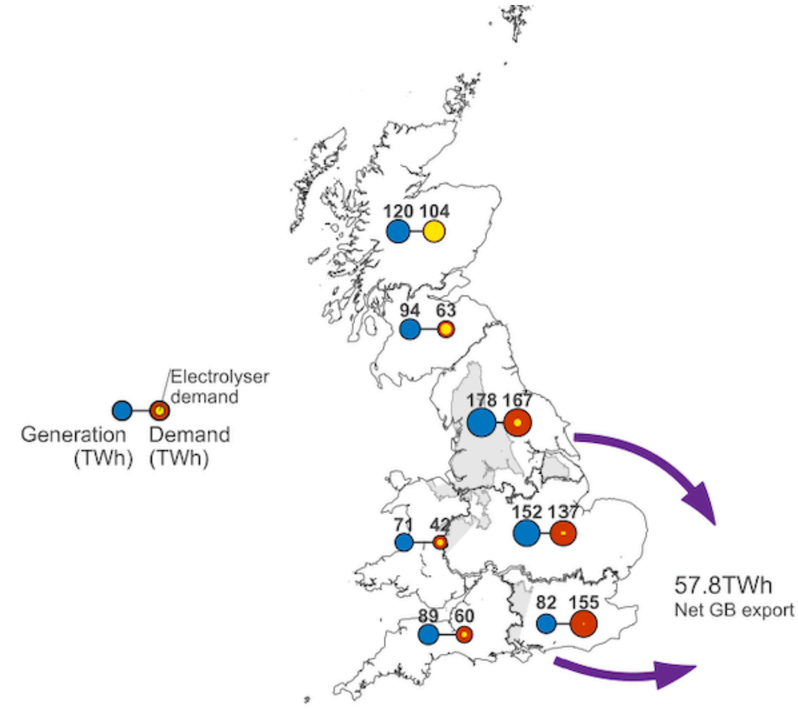
- **Arbitrage opportunities**: adding more renewables to the system is likely to increase the number of low/zero/negative price periods and these could be longer in duration, favouring long-duration storage. More renewables are likely to suppress wholesale prices, although commodity prices are likely to remain a key driver of peak pricing. Cruachan benefitted from high power prices in 2022 and 2023, but a key driver of Cruachan's profitability is the ability to pump when prices are low and generate when prices are high. Arbitrage opportunities should continue, albeit with likely lower spreads.

- **Thermal constraint revenues:** Network build should ease some of the constraints at the B6 boundary, but the ESO predicts that balancing costs could remain elevated through to 2040 (Figure 26).

…change also creates opportunity, and Cruachan's wide range of services points to resilience as change plays out

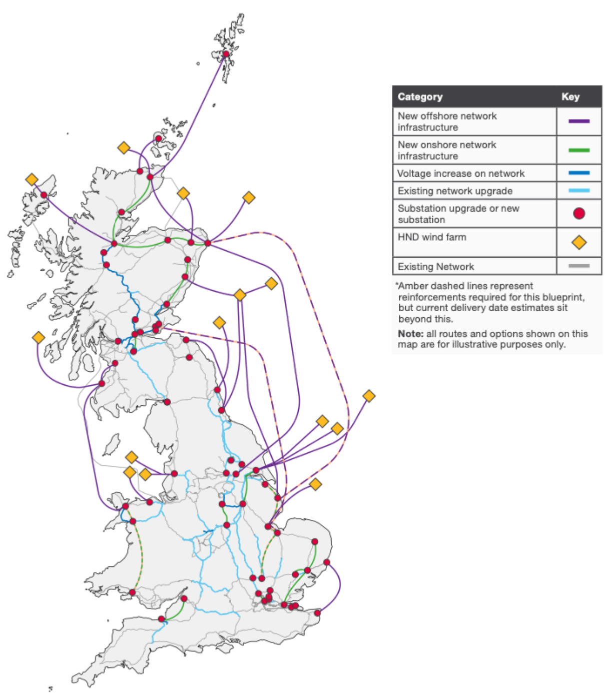
There will be change, change that could impact some revenue streams, but also create opportunity. Cruachan's provision of a wide range of services points to resilience as change plays out.

Figure 42: Locations of electricity generation output and demand in Holistic Transition



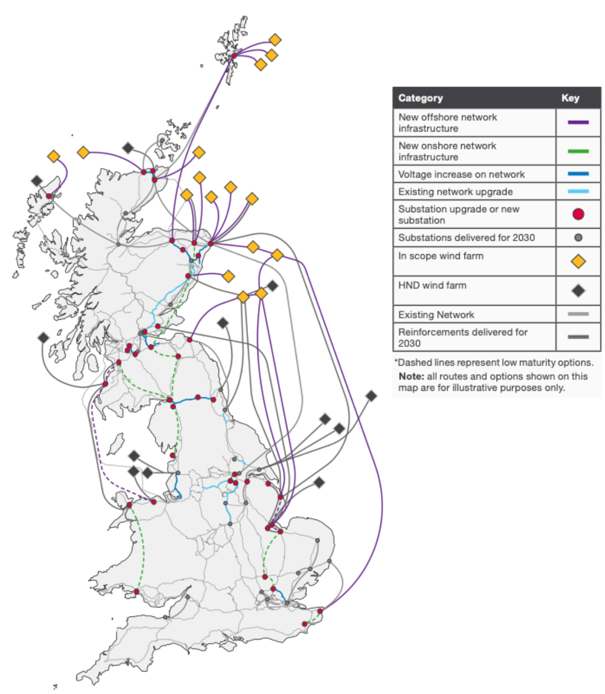
Source: National Grid ESO FES 2024 ESO Pathways to Net Zero

Figure 43: Network infrastructure to be delivered by 2030



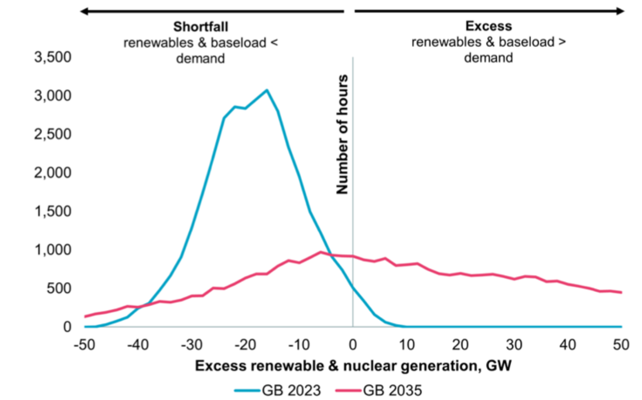
Source: National Grid ESO Beyond 2030

Figure 44: Network infrastructure to be delivered beyond 2030



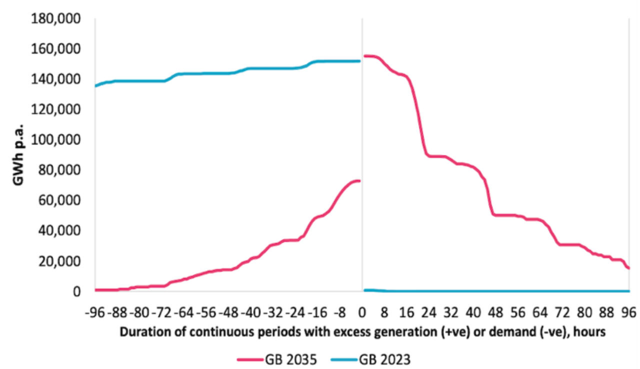
Source: National Grid ESO Beyond 2030

Figure 45: Excess renewables and baseload generation for the DESNZ Higher Demand scenario



Source: DESNZ Research Paper Number 2023/47 – Scenario Deployment Analysis for Long-Duration Electricity Storage

Figure 46: Energy in continuous periods of excess or shortfall of renewable and nuclear generation



Source: DESNZ Research Paper Number 2023/47 – Scenario Deployment Analysis for Long-Duration Electricity Storage

Flexgen & energy solutions, hydro contribution key

Drax's hydro business also includes two hydro schemes…

The Galloway and Lanark hydro schemes are an important part of Drax's generation portfolio…

Pumped storage and Cruachan is the primary focus of this report, but Drax's Galloway and Lanark hydro schemes are also an important part of Drax's portfolio of generation assets, delivering clean power, providing system services, and a material contribution to EBITDA in recent years.

Galloway and Lanark are run-of-river schemes located in southwest Scotland with a combined capacity of 126MW. Both were acquired by Drax in January 2019 as part of the ScottishPower Generation transaction.

Figure 47: Galloway and Lanark hydro schemes

Scheme	Type	Location	Scheme description	Capacity (MW)	RO accreditation
Galloway	Run-of-river hydro	Ken/Dee river system, Galloway and South Ayrshire	Six power stations (Drumjohn (2.2MW), Kendoon (24MW), Carsfad (12MW), Earlstoun (14MW), Glenlee (24MW) and Tongland (33MW)), 12 turbines, 8 dams, 16km of tunnels and pipelines. Average load factor of 25%, with average annual output of c.250GWh.	109	28MW (Drumjohn, Carsfad, Earlstoun)
Lanark	Run-of-river hydro	River Clyde, Lanark	Bonnington (11MW) and Stonebyres (6MW), with annual output of c.50GWh.	17	17MW (Bonnington, Stonebyres)

Source: Drax company reports

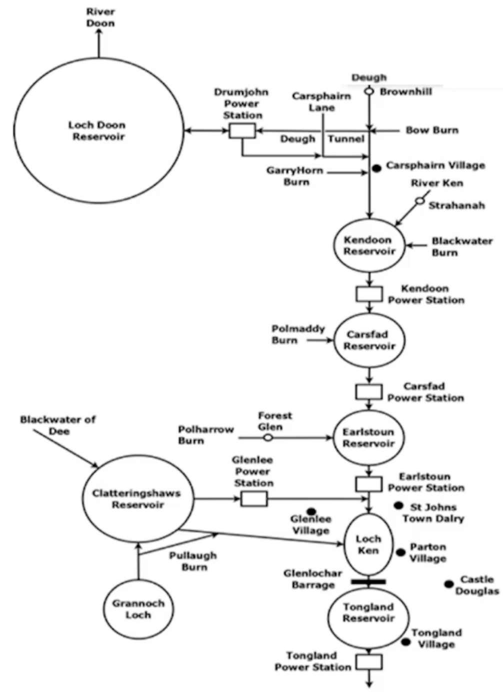
Lanark operates a run-of-river facility powered by three waterfalls with water flow diverted into Lanark's two power station by weirs. Lanark's operating profile is dictated by the availability of water. Both of the Lanark power stations are RO accredited, receiving one ROC/MWh through to March 2027, and participating in the Capacity Market from October 2027.

The Galloway system is different, as Galloway also operates a reservoir and dam system providing power storage capabilities and opportunities for peaking and system support services. Galloway typically generates power when there are peaks in electricity demand when water is released from the reservoirs and used to spin turbines and generate electricity. Average annual output from the Galloway system is in the region of 250GWh. 28MW (Drumjohn, Carsfad, Earlstoun) of Galloway is RO accredited, receiving one ROC/MWh through to March 2027, with the other power stations (Kendoon, Glenlee, Tongland) participating in the Capacity Market. All the Galloway power stations are participating in the Capacity Market from October 2027.

Figure 48: Galloway scheme

Source: Drax company reports

Figure 49: Galloway scheme schematic



Source: Drax company reports

…with the running profile dependent on market prices, rainfall, storage capability and river conditions

Drax's strategy for trading its hydro power plants is to forward sell a proportion of the electricity output based on the expected forecast of rainfall through the year, with these sales re-profiled in the short-term markets to match expected generation. The running profile of both Galloway and Lanark will depend on market prices, rainfall, storage capability and river conditions. Cruachan is generally not sold forward, although Drax took advantage of favourable prices to forward sell power from Cruachan for delivery in FY23.

Analysis of Drax's results and Drax River Hydro's financial statements suggests (to the extent that Drax has provided disclosure) that Drax typically hedges c.0.3TWh of expected output from the run-of-river assets by the start of the financial year, and at average prices above those for the Drax portfolio in the round. This tallies with the running profile of Galloway and Lanark.

Figure 50: Drax River Hydro Limited (£m)

	2H 2021	2022	2023
Electricity sales	11.2	55.8	77.1
ROC sales	-	8.2	8.7
Balancing market revenues	4.7	4.3	0.9
Embedded benefits and other income	0.9	2.1	2.1
Total revenue	**16.8**	**70.5**	**88.8**
Drax River Hydro EBITDA	**1.7**	**51.9**	**57.4**
Drax Hydro EBITDA (inc. EGL)	34	171	230
% River Hydro	**5%**	**30%**	**25%**
Assumed output (TWh)	0.15	0.3	0.3
Implied unit electricity price (£/MWh)	70.7	183.9	254.5
Hedged price per prior period (FY) results	51.7	90.9	158.1

Source: Analysis of Drax company reports (Hedged pricing ROC portfolio, ex. 2022 which is hydro, CM revenue recorded in electricity sales, implied unit price adjusted for CM)

… £150m EBITDA post 2027 appears plausible

Drax is targeting £150m hydro EBITDA post 2027…

Taken together, Cruachan, Galloway and Lanark constitute Drax's hydro business, one of the three pillars of Drax's flexible generation and energy solutions portfolio, rounded out by energy solutions and the three OCGTs currently under construction. At the FY23 results presentation Drax set out a post 2027 recurring adjusted EBITDA target contribution of £250m+ from this portfolio, with c.£150m suggested to be from the hydro assets. This target is below the level of hydro EBITDA in the past two financial years, but above that of the periods that preceded it.

This report makes no attempt to provide financial forecasts for the hydro business, but in the context of the revenue streams available to Drax's hydro assets, appraising the plausibility of Drax's £150m post 2027 EBITDA target has merit. Figure 51 presents a scenario analysis that looks at possible changes to the revenue streams and cost base of the hydro business between 2023 and 2028. Drax's post 2027 target does not include a contribution from Cruachan II and Cruachan II is not included in the possible bridge.

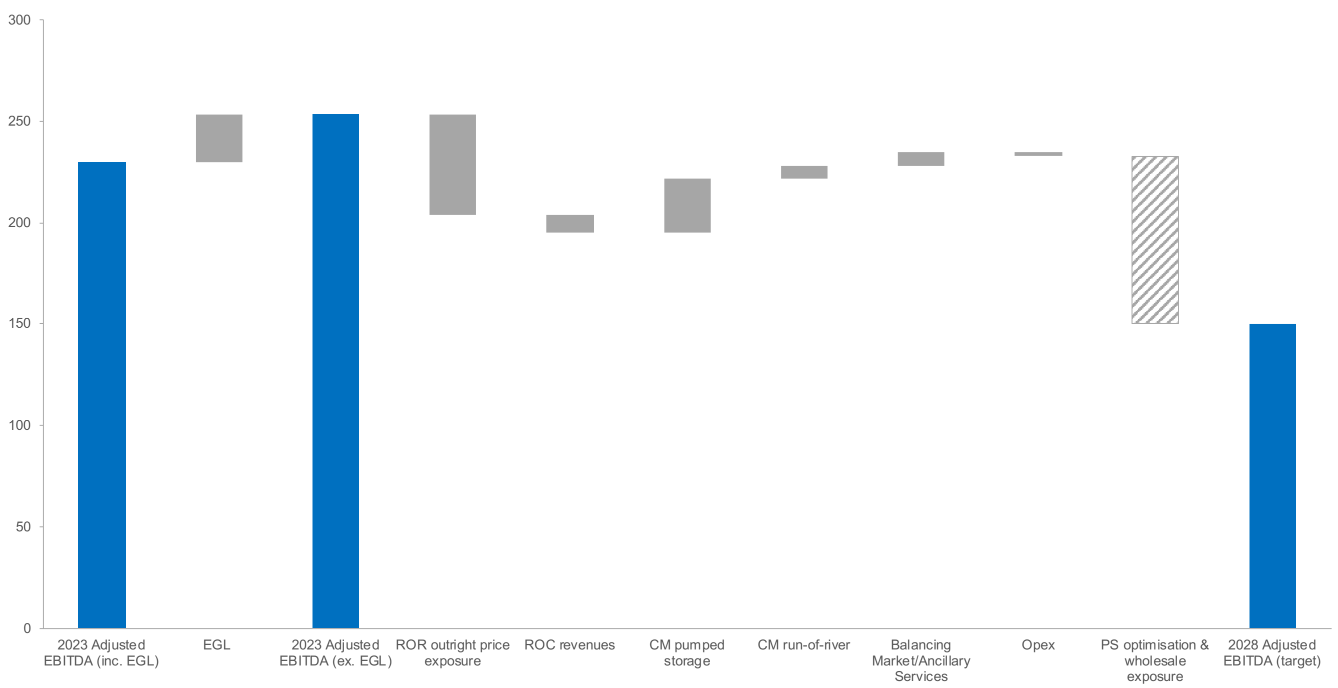
Key assumptions:

- Assumed 0.3TWh Drax River Hydro output and assumed hydro price of £90/MWh (consistent with winter-27 peak prices as of June 2024) vs. estimated achieved price in FY2023 of £257/MWh.
- Balancing Mechanism/Ancillary Services market share at 1.6% of £3.5bn assumed total costs.
- Capacity Market price of £35/kW/yr for delivery year 28/29, with all hydro assets securing contracts.
- No EGL in 1Q28 (EGL sunset date of 31st March 2028).
- Opex increases of 2% per annum, no step up from upgrade of units 3 and 4.

…a level that appears plausible

This suggests that Cruachan could accommodate a contraction in optimisation/wholesale price income of up to £83m and deliver the post 2027 target level of hydro EBITDA. Equivalent to c.67% of the 2023 optimisation/wholesale spread, this is a scenario which appears plausible.

Figure 51: Hydro EBITDA possible bridge to 2028 target



Source: Aquaicity analysis, Drax company reports

Basis of Preparation

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