Enabling new pumped storage hydropower

A guidance note for key decision makers to de-risk pumped storage investments

iha international hydropower association

Contents

Abstract

This guidance note provides recommendations to reduce risk and improve certainty for pumped storage hydropower project development and delivery. If the pumped storage hydropower market is to increase significantly over the next two decades, as it must to support the energy transition, then these issues need to be addressed to secure finance and expand the supply chain.

Disclaimer

Time for action: The pressing need for a guidance note to de-risk pumped storage hydropower investments

Without accelerated development of pumped storage hydropower (PSH) the transition to renewables will falter, and fail. The COP28 commitments to triple renewable capacity by 2030 to at least 11,000GW is laudable, and achievable, but if it is all variable generation without complementary storage, we will have no hope of meeting even 2°C goals.

The shift of energy generation to wind and solar is the fastest energy transition in our history. Last year 80% of additional net global generation capacity was solar and wind growing at compound rates of 22% and 11% annually.

This shift from dispatchable fossil fuel energy sources, to variable renewable sources means we need to be able to store the solar and wind energy when we have excess supply and then use it when we do not.

The failure to adequately focus on this need for long duration electricity storage is the ignored crisis within the energy crisis. PSH has the unique capacity to resolve this challenge at huge scale, well beyond the reach of even the largest batteries. Pumped hydro systems can also provide inertia and grid stability without reliance on fossil fuels.

The need for pumped hydro dawned on me in 2016 when we had a massive blackout in South Australia, a state very dependent on wind generation. It was clear that in the transition from coal to wind and solar power, we had not adequately planned for storage – to fill the hole left by coal.

PSH is the largest form of renewable energy storage, with nearly 200GW installed capacity providing more than 90% of all stored energy across the world. In 2021, the International Forum on pumped storage hydropower brought together governments, industry, financial institutions, academia and NGOs to develop recommendations on how PSH can best support the energy transition[1]. Now, more countries than ever are including pumped storage targets in their net zero plans.

Electricity markets have been effective at incentivising generation, but are not tailored to incentivise the construction of long duration storage that represents the assured reliability of supply a modern society needs. Without either direct government investment (as was the case with Snowy 2.0) or appropriate policy frameworks, PSH as a highly cost-effective, low impact technology will not be deployed at the scale needed to support an efficient and reliable energy transition.

The industry also needs to get its act together. PSH, like many forms of large infrastructure, must be developed in a sustainable and environmentally responsible manner, e.g. as outlined in the Hydropower Sustainability Standard. This includes addressing concerns about the potential investment risks of PSH projects, as well as ensuring the public understands the nature of PSH which is very different from conventional hydropower. PSH uses relatively small amounts of land and water, its environmental impact is modest, but few appreciate this. Investors need long term certainty for their investment given the high initial capital costs of building large infrastructure projects. Without the right risk mitigation measures in place, this will delay much needed energy storage development.

The recommendations within this guidance note set a course for delivering the energy storage solution the world needs. Policymakers and the industry need to act on these recommendations now to be in with a chance of meeting net zero goals by 2050.

I welcome this effort to provide a succinct guidance note on how to provide a succinct guidance note on how to best de-risk investment for pumped storage projects. By utilising the guidance note, a new market entrant will be better able to understand the risks and create a mitigation strategy to address them. The time for action was yesterday, let us use the tools of industry to ensure that any energy storage is done in a sustainable manner.

Malcolm Turnbull,
IHA President

[1] For more information on the International Forum on Pumped Storage Hydropower: https://pumped-storage-forum.hydropower.org/

Working group

Unlocking a vitally important sector

While the need for energy storage is growing globally, many projects are not reaching investment decision and may be at risk for cost and schedule over-run. The working group brought together a wide group of stakeholders to discuss the issues and identify actionable recommendations to unlock this vitally important sector.

The growing need for energy storage is becoming abundantly clear: by 2050 forecasts predict that global electricity demand will triple and will increasingly be met by renewable generation. To support the rapid growth of variable renewable energy (VRE), it is fundamental to increase energy storage.

However, the particular need for 'long duration' energy storage (LDES) is less understood. Despite it being accepted as a requirement for decarbonised energy systems, its development has been largely overlooked in policy and market development. Short duration storage, primarily chemical batteries, is effective for managing fluctuations in supply over seconds/minutes, and, with improving technology, up to ~4 hours. This was sufficient in the early stages of energy transition. However, as the percentage of generation which comes from renewables increases, weather-driven variation in wind and solar generation means there is an increasing gap between the lack of power being produced when we need it, and excess power being produced when we don't. Electricity systems will require much larger capacity and longer duration storage and there is a growing realisation that short duration storage is therefore inadequate to provide this type of energy security. It is impossible to achieve an efficient, reliable, net zero power grid without combining renewables with large-scale, long duration energy storage[2]. LDES effectively enables variable renewable energy to be a dispatchable source, not just a variable one. LDES will need to dramatically increase to support an efficient, reliable, net zero power grid (IEA, 2023).

This is where pumped storage hydropower (PSH) comes in. Outside of the hydropower industry, there is little awareness or understanding of what PSH is or why it is so important. This is despite PSH, sometimes known as **'Rechargeable Water Batteries'**, being the most proven, efficient, low carbon grid scale storage technology, provides significant flexibility to grid operators and a range of grid stabilising ancillary services. PSH is also abundant, accounting for over 90%[3] of long duration global energy storage capacity, with over 400 projects in operation built primarily in the 1960s to 1980s, supporting energy systems and providing clean energy jobs.

Despite the need for long duration storage, PSH projects are facing significant challenges:

1. A lack of projects progressing to construction – PSH projects take multiple years and significant levels of investment to gain permit approval and develop to Final Investment Decision (FID). If we are to meet commitments for security of supply, lower electricity costs, and ensure the sustainability of the energy sector, we need to see more progress. If we do not get more projects into construction, the required storage will not be available when grids need it.
2. Cost and schedule overruns during construction – PSH projects are major, complex infrastructure projects with considerable inherent risk. While projects can be and are delivered successfully, research demonstrates that some projects can suffer from significant cost and schedule overruns (Plummer Braeckman, 2020). If this trend continues there will be an impact on the reputation of the industry, affecting government, investor, and supply chain confidence.

[2] A recent study looked at resource drought events (times when solar and wind were severely limited), to indicate how much long duration energy storage would be required based on current VRE mixes, noting that with increased reliance in future grids on VRE, even greater amounts of long duration energy storage will be required in future (Somani, et al., 2024).

[3] IEA World Energy Outlook 2023 indicates that Battery Energy Storage is at 45 GW globally, with most battery energy storage being limited to 4-hours maximum duration. A PSH represents 8+ hours of energy storage, and has over 180 GW installed nominal capacity, it represents 75% of all installed electrical storage capacity and the vast majority of long duration energy storage.

The sector is too important to fail, and we need to do better and address these challenges. The World Bank has said it is actively considering providing resources for long-term energy system planning, including PSH, to better deal with climate resilience water-related shocks and energy storage related shocks (World Bank Group, 2021). We see leading market commentators advocating for change, e.g., calling for rapid deployment of energy storage to support VRE (IRENA, 2024), that "projected growth in grid-scale storage capacity is not currently on track with the Net Zero Scenario and requires greater efforts" and that "Governments should consider pumped-storage hydropower [and other storage technologies] as an integral part of their long-term strategic energy plans" (IEA, 2024).

We felt it was the right time to seek to address the challenges and support the market. The objective to 'de-risk pumped storage' from an overall project perspective, required input from a broad range of experienced sector participants from across the world. Industry members came together to form a working group to tackle the key areas of risk management for developing PSH. Under the chairmanship of Bechtel and the Secretariat of the International Hydropower Association, the group has met regularly to discuss the issues that stakeholders need to consider and to produce this guidance note.

I thank the IHA for pulling together such an impressive group of organisations and individuals. The Members were selected based on their knowledge from across different elements of pumped storage and the wider hydropower community. The working group included owners, operators, developers, equipment manufacturers, engineers, contractors, and consultancies, as well as academia, investors, financiers, legal and financial service providers.

The approach we took was to (1) discuss the multiple risks and issues that are faced by all players in the sector, (2) categorise these into thematic areas, (3) identify the thematic areas which are causing the greatest barriers to success; and (4) provide consensus recommendations on how the major risks and issues should be addressed. We agreed early in the process that it was important that we reach a collective view on how we can 'de-risk the project', not simply de-risk from any one participant's point of view.

We considered who should use the guidance note and how it should be used. The goal was not to develop a detailed toolkit for the development of PSH projects. Rather, we wanted to provide guidance for key decisionmakers, i.e., policymakers, investors, off-takers, owners/developers, and the supply chain, so that they understand the unique risks and barriers to PSH development and are able to make early, informed decisions which will shape the market at this important time. Owners/developers in particular have a fundamental role to play as primary drivers of determining how projects are set up.

This guidance note seeks to explore how the PSH market can make improvements to the development process to ensure reliability and confidence in delivering projects. It is the outcome of excellent analysis, healthy debate, and open sharing of industry best practice. We were encouraged by the alignment of views, and consensus around what is important and how the market should proceed. We recognise that the recommendations in this note may mean making choices which are different to how projects may have been developed in other sectors. We encourage key decision makers to adopt the recommendations and enable industry to deliver sustainable, affordable, reliable power for all.

Working group Chairman,
Chris McMonagle, Bechtel

Organisation and Content

The guidance note begins with an introduction to PSH and the key risks to consider, along with a typical timeline for a project. The second half of the document considers the risks across three thematic areas and provides mitigation recommendations. It is not possible to address all the risks that a specific project faces, but the working group sought to focus on those issues which it felt were the most important and unique to PSH, and that, if addressed, would have the greatest positive impact on the industry. The three thematic areas presenting the greatest barriers to success are:

- **Markets and Revenue** – In liberalised electricity markets, PSH projects will likely be predominantly private-sector developed. However, most market designs in liberalised markets preclude or do not consider the role of large capacity, long duration energy storage technologies like pumped hydropower, and therefore private developers are not incentivised to invest in these assets. This is despite PSH being a strategic benefit to electricity grids. For PSH to be brought forward by private investors there must be a clear partnership between them and Government, which requires a clear enabling framework. Developers and lenders need confidence in revenue streams long into the future, and clarity on how potential cost-overruns will be addressed. Governments need to bring forward policies which enables private investment in large energy storage assets, as part of their strategies for securing electricity supply, lowering costs, and ensuring the sustainability of the energy sector; **this is fundamental to getting projects off the ground**.
- **Project Development** – PSH projects are among the largest and most complex in the infrastructure sector. The opportunity to influence cost and risk factors is at the highest during the early stages of planning a project. Challenges later in the process are often the result of insufficient up-front planning and understanding of the interface challenges and constructability. Mitigation of environmental aspects by considering sustainability and other SDG goals should also be considered early in the process. Owners must invest in a robust project development period with a focus on de-risking and achieving cost and schedule confidence. The more complex a project, the earlier the complete delivery team should be in place (including owner, designer, contractor, original equipment manufacturer (OEM), etc), allowing them to focus on de-risking the project; **this is fundamental to optimising the design and de-risking delivery**.
- **Risk Allocation** – The allocation of risk, through the procurement and contracting strategy, is critical. Owners must collaborate early with suppliers to agree the sharing of risks. If projects are not structured correctly, the supply chain will not be there to deliver. It must be recognised that due to the risk profile, PSH projects do not fit a full risk-transfer fixed-price EPC (Engineer Procure Construct) execution model with limited change rights. Risks can be managed by the party best able to oversee them but must be shared and borne by the organisations best able to bear them. Critical considerations for owners include delivery model selection, effective procurement, fair allocation of risk, and clear contracts which promote collaborative development of cost and schedule; **this is fundamental to attracting a reliable supply chain and having confidence in managing cost and schedule**.

Questions to consider

When reading the guidance note, there are questions for each thematic area. The questions are intended to guide the reader in their awareness and understanding of the issues surrounding PSH; and some (but not all) of these are touched on in the guidance note. Each PSH project is different, so there are limits to the coverage of risks that one guidance note can address. Being aware of the complexity of such projects and the fact that there might not be answers to problems at the outset is a key first step in mitigating / managing PSH project risk.

Pumped storage hydropower: the rechargeable water battery

PSH works on a simple principle: At times of excess supply and low demand, power is used to pump water from a lower reservoir to an upper reservoir - 'charging the battery'. Then at periods of low supply and high demand, the water is released to drive turbines and generate electricity – 'discharging the battery'. This cycle continues as required to balance the intermittency of renewable power generation, effectively converting it from being a variable power source to a dispatchable power source.

The power output (GW) is determined by the number and size of turbines installed. The duration the power can be provided for (hours) is determined by the size of the reservoirs and is quoted for continuous provision of peak capacity. Projects typically range from a few megawatts to 3 GW and durations from 6 hours to 24+ hours.

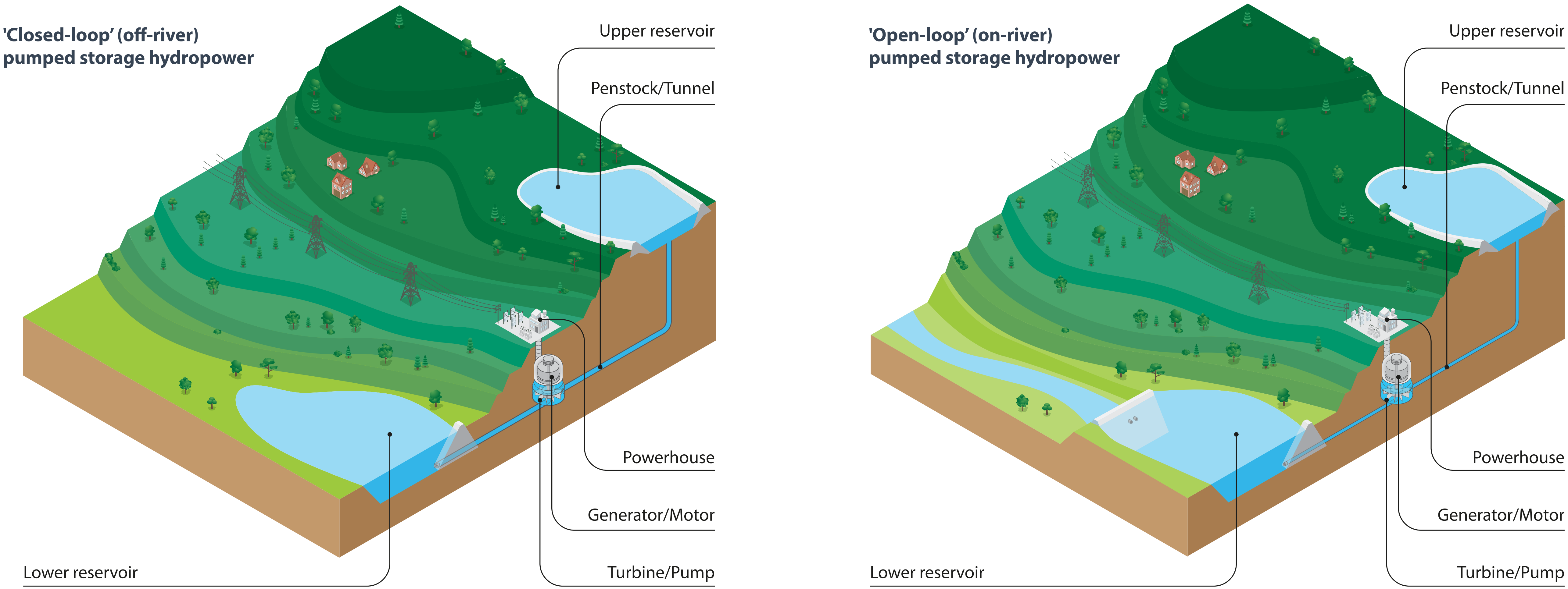
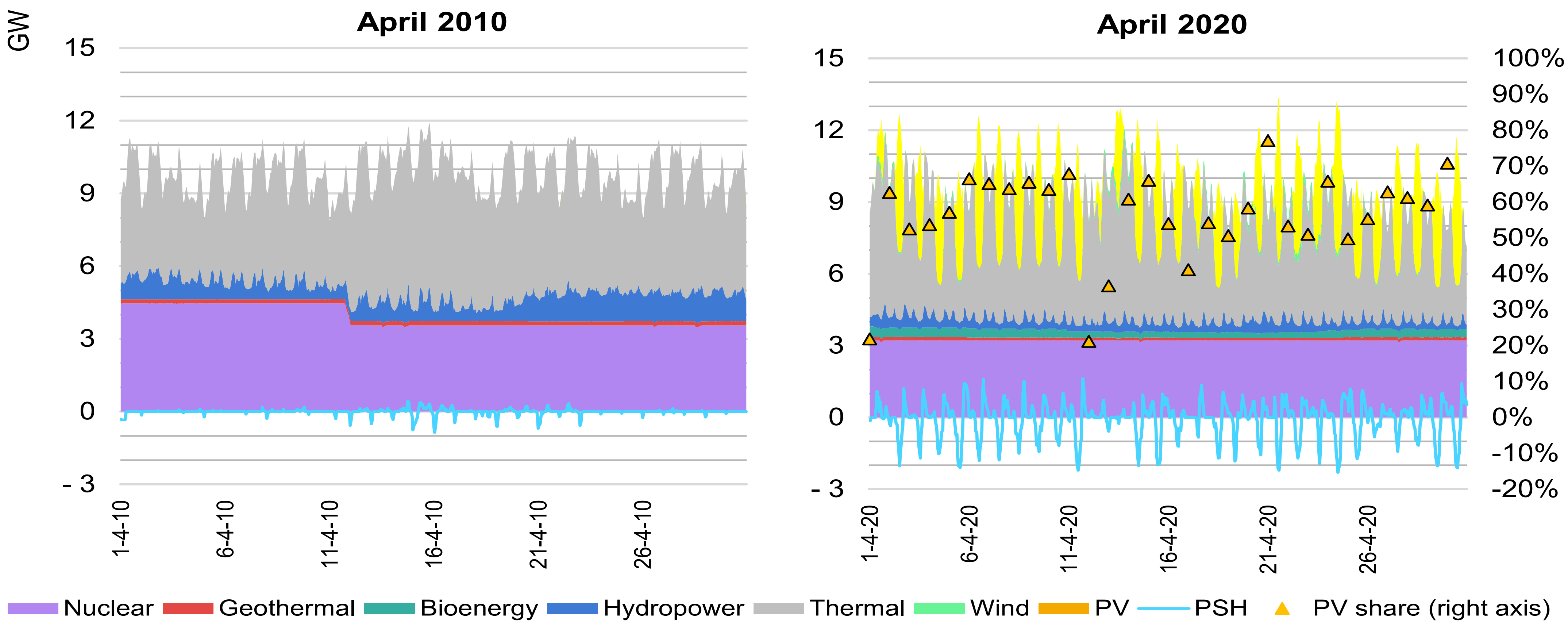


Figure 1: The two types of PSH are: 'open-loop' (on-river) which has either an upper or lower reservoir that is connected to a naturally flowing water source, and 'closed-loop' (off-river) which circulates water between an upper and lower reservoir without significant natural inflow.

But it does much more than just discharge electricity, PSH participates in numerous grid services such as:

- **Inertia:** Large hydropower units rotating in sync with the power system frequency provide passive resistance, reducing the speed at which the grid frequency changes after an unexpected major disturbance.
- **Frequency Response/Regulation:** This involves the automatic or manual adjustment of the power injected into the grid to limit and compensate for fluctuations in grid frequency due to mismatches between generation and consumption. PSH and other hydropower technologies can deliver the full range of frequency services typically required by power systems. This capability is crucial for stabilizing the intermittent and variable generation from wind and solar PV without wasting valuable resources. Additionally, in many new projects, PSH development is now integrated with large wind and solar PV farms, stabilizing electricity generation before it enters the power system.
- **Emergency Backup:** Turbines in a PSH plant can activate within seconds, providing a rapid and sustained response for several continuous hours to major grid incidents, such as the loss of generation capacity due to plant failures.
- **Absorbing Oversupply:** By pumping during off-peak times and generating during peak times (arbitrage), PSH converts low-value energy into high-value energy. This service helps stabilize electricity prices and prevents the curtailment of wind and solar PV.
- **Weekly, Monthly, and Seasonal Storage:** Water can be stored in the upper reservoir for several days, months, or even entire seasons, shifting surplus power generation to periods of higher demand and less favourable renewable generation. This capability makes PSH a strategic technology for enhancing regional energy security.
- **Blackstart:** PSH can restart a power plant during a grid blackout, from a completely non-energized state, without any external power feed.

Figure 2: Evolution of PSH in flexibility and storage services between 2010 and 2020 in Kyushu Island, Japan. The figures demonstrates the increased need for rapid ramping rates, ancillary services, and general flexibility needed to support VRE deployment (IEA, 2021).



- **Voltage and Reactive Power Regulation:** PSH can control the nominal set values for voltage levels and reactive power, essential for the proper functioning of the distribution network.

A huge benefit of PSH is that it can provide many of these services rapidly, e.g. from standby / spinning reserve to manage sudden drops in generation or increases in demand. And PSH can also absorb oversupply of VRE to avoid unnecessary curtailment (or what happens when the sun shines and the wind blows more than is demanded).

There is also an increasing need for dispatchable ramping of energy storage daily, as solar outputs decline and demand grows in the evening. This is part of wider trend due to increases in electricity demand due to high electrification rates, rapid increases in VRE deployment, and reduction in traditional thermal generation. These trends combined will for system flexibility to avoid the "crisis within the crisis".

Other forms of energy storage are available in the market (e.g. chemical batteries, like lithium-ion) and the needs of any electricity system will require a blend of storage solutions. The storage, flexibility, speed of response, and ancillary services that PSH provides facilitate the integration of renewables. With more wind and solar power being deployed on the grid, storage becomes even more important as a means of avoiding wasted generation. IRENA has stated for its net zero scenario that we will need to have at least 420 GW installed PSH by 2050, more than doubling the existing installed capacity (IRENA, 2023). As we rely more on variable renewable energy, we must plan for wind and solar drought events, ensuring LDES needs are considered at the national level.

PSH is one of the most proven long duration storage technologies[4], operating at scale since the 1930s. Assets were originally built by nationalised grid operators to provide grid storage and flexibility, in complement to inflexible assets such as nuclear. It accounts for more than 90% of global long duration energy and is one of the best solutions as it can provide>6-24+hrs with >80% round-trip-efficiency (Viswanathan, Mongird, Franks, & Baxter, 2022) (Pumped storage hydropower capabilities and costs, 2021).

While upfront capital expenditure for PSH is high, the overall cost of energy storage is one of the lowest compared to other energy storage technologies especially if developed with large capacities and long duration energy storage. In part this is because PSH has a 60+ year lifetime, so the high capex is amortised over a long period. PSH is therefore both the cheapest and most mature low-carbon long duration energy storage and flexibility technology[5].

PSH is often discussed alongside conventional hydropower (which is a purely generating asset, not an energy storage asset). Like conventional hydropower, it has extremely low operating costs and long operating lifespans. Beyond this, there are some key areas that are different. Especially for off-river PSH, it has on average has lower environmental impacts than conventional hydropower. Design and geographical requirements are not the same, as PSH requires an upper and lower reservoir with large civil infrastructure, and significant subsurface works which are typically much more extensive than conventional hydropower.

[4] PSH has a high technology readiness level (TRL) of 9 indicating its maturity in comparison to newer types of and grid energy storage (IEA)

[5] Numerous studies have been done on energy storage costs, including the 2022 Grid Energy Storage Technology Cost and Performance Assessment which indicated that PSH becomes significantly cheaper, if not the cheapest option, for larger capacities and longer durations based on 2021 data and analysed to 2030 figures. The operating costs for 1,000 MW of 24-hour storage are significantly lower than chemical or flow batteries, and cheaper than the CAPEX required for 24 or 100hr for CAES, and also significantly better round-trip-efficiency (RTE)(%). (Viswanathan, Mongird, Franks, & Baxter, 2022).

Risks to consider when developing pumped storage hydropower

PSH projects are major, complex infrastructure developments with the characteristics common to this category, i.e. long planning periods and multiple interfaces between project components[6]. Delivery can be high risk, with multiple opportunities for low-probability, high-impact events to occur. Without the right risk mitigation measures in place, the possibility that projects will over-run in cost and time could deter policymakers, and mean they turn away from energy storage. Similarly, projects may not reach the critical stage of final investment decision if such uncertainty deters private investors.

Due to the relatively small number of projects delivered in the last 30 years, they may be developed by teams without deep domain knowledge which, as a result, may lead to significant optimism bias on project costs and schedules, and inappropriate risk awareness and allocation. However, with appropriate investment in the development process, bringing the right tools and skills to bear, the risks can be reduced.

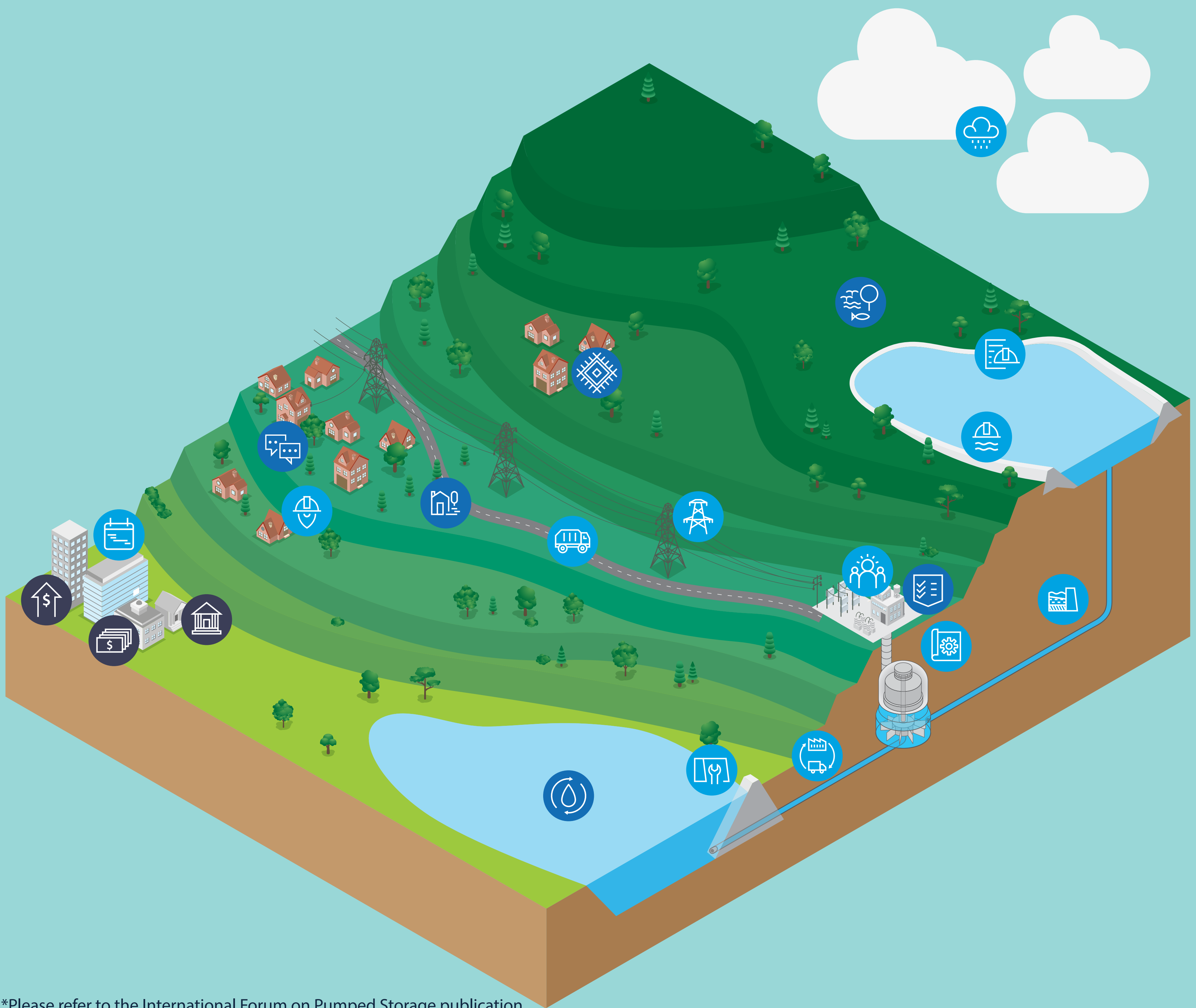
There are multiple risks that need to be considered. Figure 3 indicates some of the key risks which were considered by the working group. It is important that Owners and Developers understand all of these risks during the development of their project.

Market / Financial

The working group considered the development of projects in a liberalised electricity market environment, which will have different considerations than those PSH projects that are considered by centralised government developments. Critical to the market and financial risks that need to be considered in the business case in a liberalised market is PSH's role in the energy transition. In many electricity markets, PSH already plays a key role in energy security and will play an increasingly important role in future. It is therefore essential that electricity market regulators consider the long duration and flexibility needs of their system as the generation mix changes, and then design appropriate market mechanisms to procure long duration energy storage and flexibility. Existing markets have not fully rewarded PSH assets for the numerous benefits they provide. Market mechanisms to incentivise long duration energy storage must be in place to enable revenue certainty, helping projects to reach financial close. Depending on how the market is set-up, bespoke government or regulatory interventions may be required, e.g., revenue stabilisation measures like using long-term capacity contracts focused on securing the provision of flexibility (XFLEX Hydro 2024).

[6] For a breakdown in risk faced by hydropower projects in general, please see additional materials on large hydropower risks, including in Technical Documents Log and Academic research (Plummer Braeckman, Markkanen, & Seega, 2022) (Markkanen & Plummer Braeckman, 2019).

Figure 3: Risks to consider when developing PSH.



Environmental and Social*

- Permit approvals (ESIA etc)
- Land acquisition & resettlement
- Water availability and quality
- Biodiversity & ecology
- Cultural heritage
- Community support

Technical

- Ground risk
- Labour availability
- PSH Experienced Delivery leadership
- Site Access and Impacts
- Dam Safety
- Aligning plant performance with market requirements
- Programme
- Civil & OEM interface / integration
- In-water construction
- Weather
- Plan for operability
- Materials and supply chain scarcity

Financial / Market

- Cost escalation
- Revenue certainty
- Political support - policy implementation

*Please refer to the International Forum on Pumped Storage publication [Working Paper on Sustainability of Pumped Storage Hydropower]

In addition to electricity markets that enable the business case of PSH, governmental support is key to ensure the flow of capital. These support measures can include recognising and valuing flexibility, removing regulatory barriers, streamlining licensing, as well as in-kind support such as providing physical infrastructure like access roads. When projects are in development stages, as defined in the Path of a project chapter, changes in government or its policies, unrest, or a general lack of government support for the technology can heighten uncertainty in financing, threatening its availability or raising costs.

There are financial risks associated with inflation/cost escalation over a long-term project which can be mitigated through hedging against price increases or transferring risk through contracts, bonds, and/or insurance measures.

Environmental and Social (E&S)

Planning and permitting requirements, which vary depending on the location of the project, can directly impact numerous areas. Political/governmental support is important to ensure confidence in the permitting process for Environmental and Social considerations, for example the Government of Poland's "Bill on the preparation and implementation of investments in the field of pumped-storage power plants and accompanying investments" which now regulates all necessary aspects related to the preparation and implementation of investments in PSH and associated projects (Government of Poland 2023).

Due to the locations that PSH projects are typically sited in, issues such as land acquisition, cultural heritage, and water availability should be considered, as well as ensuring support from the local community. PSH projects can be sited in areas away from rivers that may have cultural significance, thus limiting the potential social impacts like resettlement, noting that as with any infrastructure project community support is critical to ensuring project success. With large head variation and potentially a smaller footprint than conventional hydropower, PSH projects, especially closed-loop, can also limit the potential environmental impacts on water quality and availability, biodiversity, fish habitats, etc (Working Paper on Sustainability of pumped storage hydropower, 2021).

The Hydropower Sustainability Standard (HSS) can help assess and ultimately certify the sustainability performance of PSH projects. The HSS is a comprehensive and globally applicable assessment framework that covers 12 sustainability topics, including resettlement, biodiversity, climate change and hydrology (HSA , 2021). The HSS and supporting tools have already been used on PSH projects such as the Kaunertal Expansion Project in Austria and can continue to guide E&S considerations during the development of PSH projects.

While PSH supports the transition to a low-carbon grid, projects themselves must be sustainably developed. The only acceptable pumped storage is sustainable pumped storage.

Technical

PSH projects comprise multiple different components, including dams, reservoirs, underground works, tunnels, vertical shafts, major mechanical and electrical equipment, transformers, transmission and distribution. There are specific technical risks associated with each component, though these are generally well understood by industry, e.g. dam safety[7].

PSH have multiple distinct parts that need to operate together, e.g. a project's civil and electromechanical equipment requirements will be based on the specific services required by the electricity network, and this will have a direct impact on the hydraulic design to pass large volumes of water in pumping or generating. In addition, supporting facilities and grid connection will need to be integrated and considered simultaneously with demand centres. These multiple distinct parts create complex interfaces which are managed through appropriate contracting.

Also, the considerable geotechnical (underground) risk, due to the required location of the dams, powerhouse, and associated tunnels, needs to be assessed and managed. Investing in understanding the geology is vital to develop deliverable designs and realistic cost and schedule plans.

[7] Dam safety is a crucial component of PSH and hydropower to ensure long-term sustainability and multi-purpose benefits of projects. The structural integrity of dams for PSH are keystones of dam safety and a critical component for increasing social acceptance of PSH projects (ICOLD, 2019) (Lino, Canale, Giraud, & Geisseler, 2023).

It is important to have experienced and capable partners when beginning a PSH project. Designers, owners, contractors and those with specific operational experience who are familiar with PSH risks. Where a project may require additional oversight to support limited experience, they could consider having an oversight board to provide review and quality assurance.

Beyond this, other major risks include:

- Aligning plant performance with market requirements,
- Construction craft labour availability and productivity, and
- Insufficient quantification of risks leading to optimism bias on cost and schedule, and underestimating contingency requirements.

Path of a project

The PSH Timeline (Figure 4) provides a simplified timeline for a project, from early site identification through to handing over operations. Each project is unique so the timelines will naturally vary depending on factors such as permitting requirements, project complexity, financing etc. The timeline shows three key activity areas, which are related to project development, allocation of risk, and markets and finance. Stages are described in different ways in different parts of the world, but typically fall under the categories of project identification, feasibility, design development, and project delivery, after which the project enters into operations.

- **Project Identification:** Refers to the period spent identifying potential site(s) for the elements of a PSH development, including the upper and lower reservoirs, powerhouse, and transmission connection. It is also important to consider ESG issues during the project identification stage[8]. The Owner's appetite for risk needs to be considered at this stage.
- **Feasibility:** Contains the pre-feasibility stage which determines whether a project is financially viable and what technical options should be considered. It will also include the permitting needs and a general market assessment. The feasibility study builds on the pre-feasibility analysis and includes a techno-economic evaluation of the preferred option, desktop geotechnical investigations, and beginning of the environmental and social licenses processes. At this stage, a procurement strategy should be considered.
- **Design Development:** During this phase the financing and contracting arrangements will be finalised, procurement of the OEM and Civil Works should take place as well as the detailed design undertaken. A detailed design will include all specifications for quantities and materials. Before this stage is completed, feedback on the designs and cost of delivery will inform the final investment decision.
- **Project Delivery:** This includes construction of the reservoirs, tunnelling, and powerhouse transmission substations, which can take several years. Upon completion of the civil works the equipment installation will be performed, followed by testing, commissioning, handover and appropriate operation and maintenance training before the official commissioning.

[8] A new tool HYDROSELECT, being developed by the Hydropower Sustainability Alliance, can help ensure that new PSH projects being developed identify any ESG-related red flags or potential fatal flaws associated with project siting early on. The HSS covers the three main life project cycle stages (Preparation, Implementation and Operation) and can help support PSH project developers to address ESG challenges and de-risk their projects across each life cycle stage.

As part of the pre-development stage, it is important to have a realistic schedule that includes the permitting and construction phases. The time it takes for projects to get from announcement to commissioning depends on many factors and especially on the permitting and licensing requirements for each respective jurisdiction. Many projects fail to get planning or permits; therefore, it is critical that projects consider E&S measures.

De-risking (or risk management) needs to start at project identification. Stage 1, Project Identification, can take several years, although spend during this time is low compared to overall project CAPEX, it is undertaken entirely at the developer's risk. Therefore, the owner's appetite for risk needs to be considered at the project identification stage.

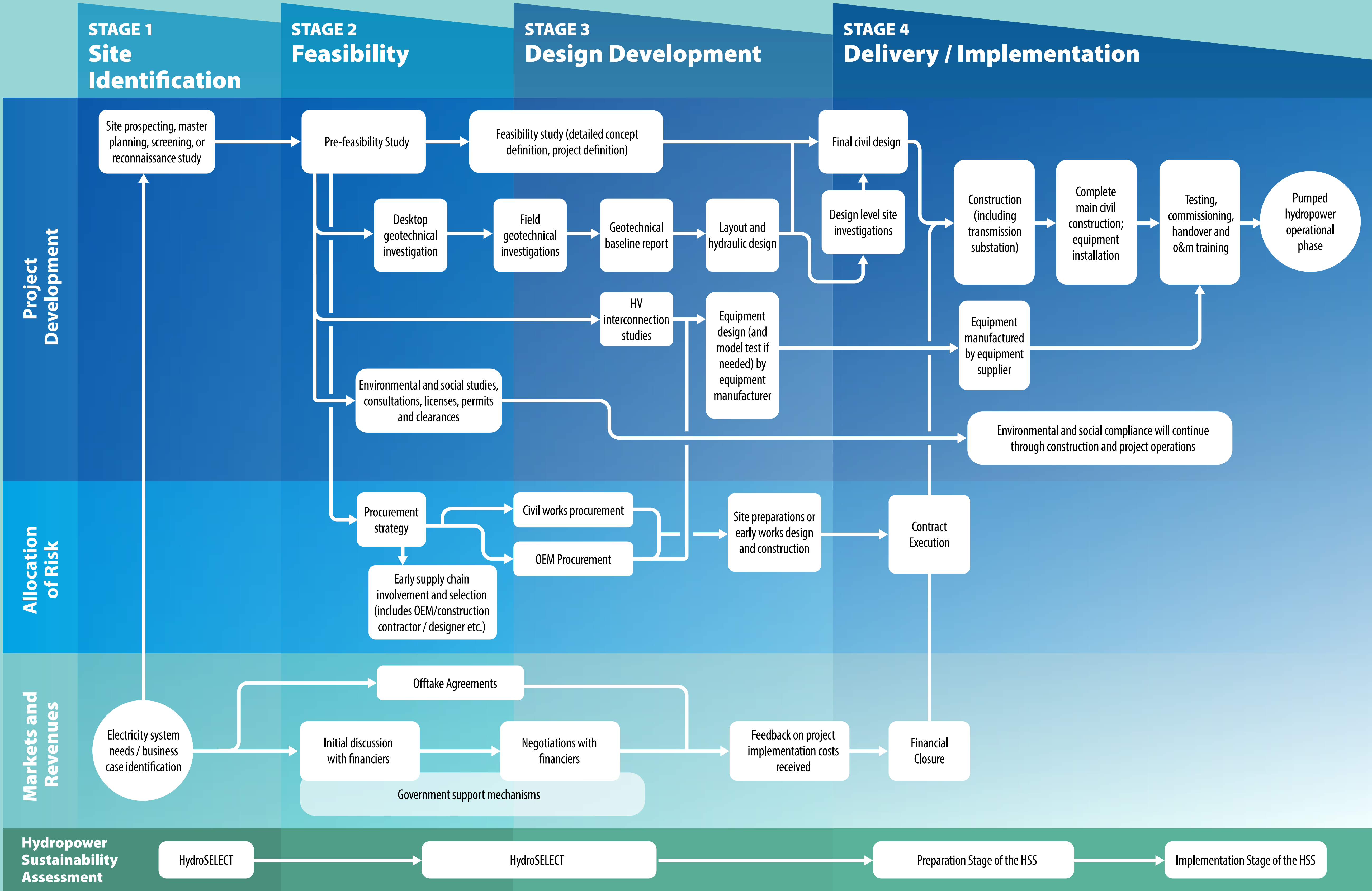
Typically, Stages 2 and 3, Feasibility and Design Development, can take 3-5 years, with Stage 4, Project Delivery, typically taking 4-8 years. It is during the Feasibility and Design Development, Stages 2 and 3, that significant investment is required. Pre-development costs may be in the range of 3-8% of the expected total project cost. Significant spend comes from building Owner teams, procuring supply chain to develop the designs and plan for construction, and undertaking geotechnical investigations. Some tools exist to help developers to consider costs relevant to their project. Note that every project is unique and therefore the costs of a project will vary site by site, as these will be directly related to location, project specific supply chain, and resourcing costs[9].

There is a trade-off between 1) understanding and minimising risk, and 2) achieving stages on the timeline. For example, developers may wish to minimise spend at early stages of the project. However, this can lead to misunderstandings or insufficient data to quantify risks, whilst moving ahead with the indicative design. Spending in the development stages can lead to savings later on but, as this investment is at risk, developers may be deterred from spending money. If risks can be reduced through appropriate measures, e.g., a partnership with government or private investors, then everyone wins.

It is important for developers to consider the risk mitigation required and how this may impact the timeline, and this will be considered further in subsequent sections.

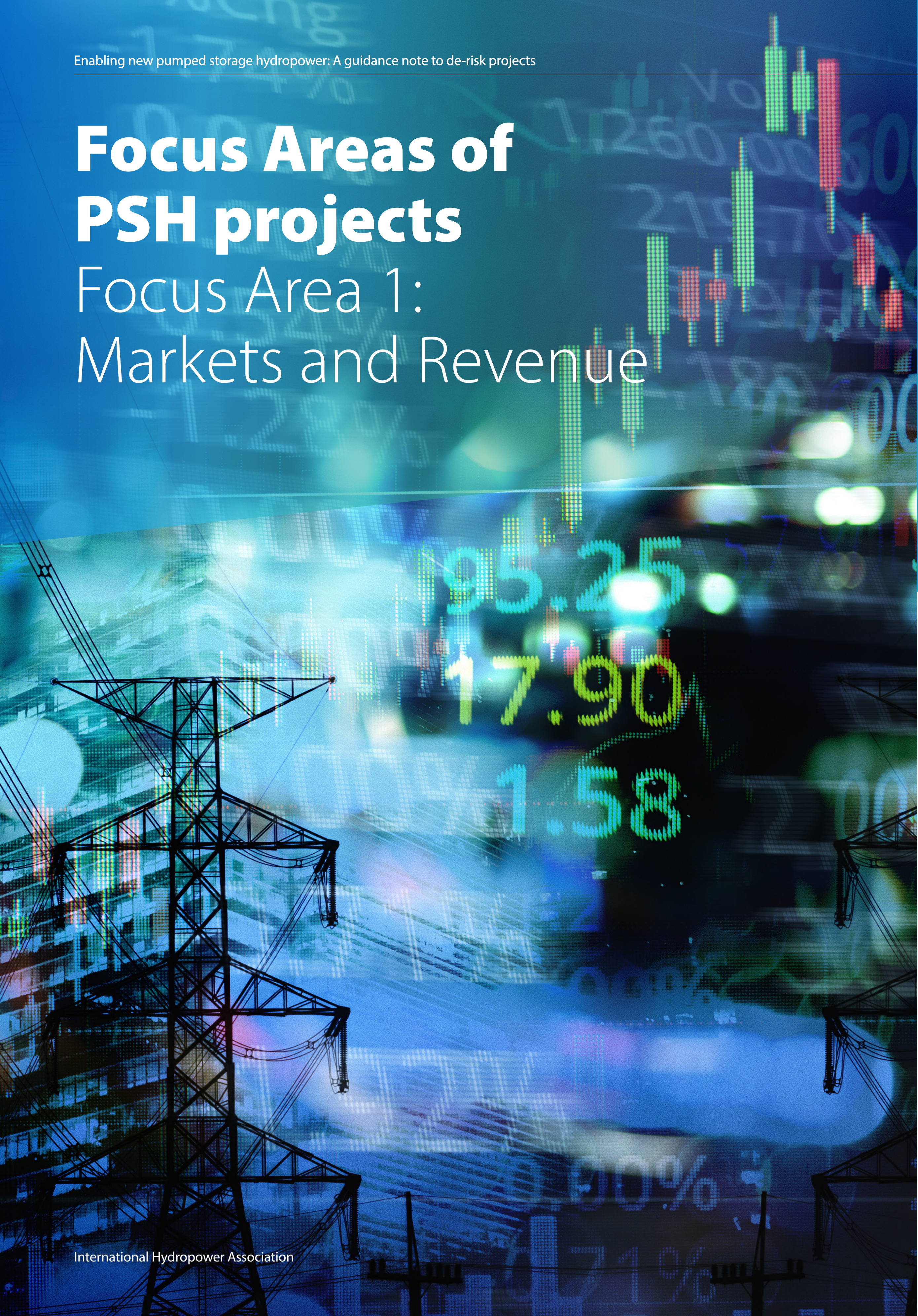
[9] Some governments and their affiliated research institutions have set out high-level costings for pumped storage projects, including the Norwegian Government and US Department of Energy's National Renewable Energy Laboratory PSH Cost Model.

Figure 4: Path of a PSH Project



Focus Areas of PSH projects

Focus Area 1: Markets and Revenue



Key considerations:

- **Storage capacity and grid services should be considered based on a dedicated storage masterplan to quantify the future needs of the national power system in line with their energy and climate plans.**
- **Policymakers should engage with the market to design tailored support mechanisms for PSH, ensuring clarity on policy timelines and setting energy storage targets.**
- **Policymakers and project developers when performing economic comparisons between different storage technologies should follow a consistent and technology neutral approach and consider the full-lifecycle benefits of assets.**

In the first wave of PSH projects (1960s-1980s), developers were typically governments, government owned businesses, or vertically integrated utilities, who were able to optimise the whole system costs and benefits. The utilities also had greater control in using the asset, as pumping was typically supplied by surplus off-peak energy generated by the utility's thermal or nuclear power assets, and often delivered over the same company's transmission system. These companies recognised the economic benefit of running these assets at high load factor and using storage to avoid investment in peaking plant, taking a commercial risk that benefited the grids of yesterday and today.

While there are many new PSH projects being developed by the public sector, PSH now operates in predominantly liberalised markets. This means that, in many cases, if PSH projects cannot attract private investors/capital, they will not be developed. In liberalised electricity markets, while the private sector is ready and able to deliver, to do so at the required scale globally we need to primarily consider the scenario of PSH which is **private sector developed but public-sector enabled**. The drivers in markets where public ownership is predominant should be conceptually simpler, focused on central planning and funding, whereas in liberalised markets there needs to be suitable incentive or subsidy mechanism.

The reasons for this are multiple. In common with other large low-carbon infrastructure, much of the lifetime cost of PSH is incurred during construction, with high development and capital costs, permitting delays, and real or perceived risks which occur during development and construction. A typical PSH will take eight years or more from identification to commercial operation date (COD). Therefore, the revenues for projects that start project identification today will start in the 2030s. However, financing for a new project must be based on today's markets and historic auction prices.

In most markets only a small range of ancillary services are remunerated, with a number of the vital grid services that PSH can, and does, provide not being fully remunerated. Where there are plans for remuneration, the parameters have not been fully determined, and even where there are some parameters, the market prices and valuations will change over time. For example, in many markets inertia is currently plentiful, with high levels of combustion generation, e.g. combined cycle gas turbines (CCGT) on the system. While a requirement of some grid interconnection, inertia services currently receive no remuneration at all. However, with the progressive retirement of gas and coal plants, the level of synchronous inertia available on the grid at any given time of the day may become insufficient, causing issues in the frequency control and increasing system instability (EPRI 2019). This reduces grid resilience to unexpected events and increases the risk of blackout and load shedding. Synchronous inertia is therefore one of the key services provided by PSH which in the future could have high value for the power system.

These projects are needed more than ever to support the fluctuations in the power system but have suffered as a result of electricity markets or economic models that encourage technologies with lower capital costs and short pay-back periods. This view is shortsighted and can start as far back as initial resource planning, where models may use average levelised cost values for renewable generation, which do not reflect that the value of renewables will vary with time. Increasingly the 'capture price' of renewables will be close to zero or even negative, reflecting when generation is greater than demand and there is a need for energy storage. These resource models do not capture the value that multi-day, weekly, monthly, or even longer duration storage brings and the immense operational value that it provides. Without a degree of long-term revenue certainty or appropriate incentives, investors are unwilling to invest, even if the technology is highly cost effective and sustainable. Some governments have begun considering possible mechanisms to address this uncertainty, e.g. the UK Government has held two consultations with stakeholders to determine the best option for long duration energy storage development, with a cap and floor their preferred option which could provide a minimum level of revenue certainty while avoiding the consumer overpaying (UK Government, 2024).

The working group recognised, in line with the IFPSH, there is a real risk that without appropriate policy frameworks, PSH will not be deployed at the scale needed to support an efficient and reliable energy transition. No two electricity markets are identical – different mixes of energy resources, regulatory frameworks, market structures and historical characteristics mean that there is no 'one size fits all' approach to securing the place of much needed long duration storage technologies like PSH[10]. While this note cannot seek to address the intricacies of each market, there are high-level recommendations which can be made, which are applicable in all contexts[11]. These include:

- *In designing market products, policymakers must ensure that those products provide enough long-term revenue visibility to stimulate investment in the most efficient low carbon technologies. There are many options to do so, including ensuring appropriate contract lengths, allowing for 'bundled' grid services products and introducing income floor mechanisms.*
- *Providers of ancillary services such as frequency control, inertial response and voltage control should be remunerated for those services as well as providing transmission congestion solutions.*
- *Where PSH can participate in ancillary services markets, those market rules should be stress-tested to ensure they are not inadvertently excluding the most efficient technologies, and low carbon solutions should be prioritised.*
- *Transmission and distribution system operators should be allowed and encouraged to procure long-term contracts for PSH services for which they are responsible, and where that would be the most efficient way of managing grids.*
- *In turn, in liberalised markets transmission and distribution system operators should not be allowed to build PSH or any other type of storage facilities that may affect the competitive procurement of PSH services.*

[10] International Forum on Pumped Storage Hydropower – Capabilities and Costs paper includes a comprehensive overview of PSH's place as a mature, cost-effective, and efficient provider of large capacity long duration energy storage.

[11] Pump it up: Recommendations for urgent investment in pumped storage hydropower to back the clean energy transition, 2021

It is the job of policymakers and regulators to consider the "value" of long duration energy storage to their system. However, the 'value' and justification of the PSH project will come from the Transmission System Operators (TSOs) valuing the service on the system. Therefore, it is critical for policymakers and grid operators to consider their storage and flexibility needs now, i.e., through a dedicated storage masterplan and determining gaps in electricity market arrangements and grid operation rules that need to be addressed, so that pumped storage schemes, which might take longer to develop, are supported.

Liberalised electricity markets do not work to develop large capacity LDES without additional interventions because they prioritise short-term economic thinking over long-term system benefits. This has led to a failure in many markets to adequately incentivise PSH development. As more and more variable renewable energy is deployed, LDES technologies, especially PSH, will be critical to electricity systems (Somani, et al., 2024). The numerous benefits that PSH provides to the electricity system, including black start, firm flexibility, fast frequency response, etc. need to be adequately remunerated and valued within the market as they have not been to date. Furthermore, market changes, technology developments and the energy transition are moving fast, and consequently new energy or decarbonisation strategies may accidentally restrict PSH. This could lead to significant issues in supplying necessary grid services.

Governments should prioritise providing policy incentives, (e.g., capacity market auctions, availability payments and grants for infrastructure development, to ensure that the investment in PSH occurs before it is too late. This should also address market policy to ensure that PSH is rewarded for its role in decarbonising the grid and increasing resilience. By providing visibility and certainty of long-term payments, this will help projects and developers access suitable sources of project financing.

In addition to supporting through policy or market interventions, where strictly necessary, governments can underwrite the debt structuring in PSH especially in projects that are foreseen in the national interest. Debt is available in the market, although it requires revenue certainty, protection against significant cost overruns, and should be structured with a longer debt tenor.

PSH as a tool for climate mitigation and adaption is eligible for climate financing solutions (such as sustainability or green bonds) by many national governments and private companies. To support this further, the Climate Bonds Initiative together with the hydropower industry created hydropower specific criteria which include requirements for pumped storage assets in order to be certified as CBI compliant (CBI, 2021). To apply for CBI Hydropower certification, requires the use of the HSS certification. Projects that achieve HSS certification can not only demonstrate their sustainability credentials but also increase their attractiveness to donors as a low risk and green investment. The HSS is aligned with the safeguards of large banks like the World Bank and IFC and in addition to CBI has been recognized by RE100 for renewable electricity provision and by I-REC as a labelling authority for REC issuance. It has enabled Hydro-Québec in Canada to sell HSS Premium RECs from their certified project Eastmain in domestic carbon markets.

If governments recognise that long duration storage is fundamentally required to meet commitments for security of supply, lower electricity costs, and ensure the sustainability of the energy sector, they need to expedite supportive policy implementation. This starts with defining the need for PSH and then moves to implementing enabling policies tailored to encourage private investment in PSH. Importantly, governments need to provide clarity on the timelines for policy implementation. Some jurisdictions are doing this well, but in others the clarity around market mechanisms and timing is still lacking[12].

In its conversations, the working group noted that while industry cannot directly control the electricity markets or revenue instruments, these have very direct implications for whether projects proceed or not; therefore, the working group sought to indicate those measures they could directly enable, and those for which governmental or regulatory intervention would be required to encourage PSH projects through electricity markets and revenue considerations.

[12] As electricity grids change, PSH's role will need to be better understood and valued by those in key decision-making roles. For a full suite of the tools available to policymakers, the IHA is developing a Toolbox of pumped storage hydropower policy measures to support governments and regulators with examples of policies that have been successfully implemented to support PSH development. In addition to the Toolbox for PSH policy measures, the IHA is reviewing policy and market barriers and enablers to hydropower in general for a whitepaper.

Markets and Revenues

Consider the market and business case upfront and develop an initial economic analysis.

- What does the grid need and how would a PSH asset address that need?
  - Once the project is ready to operate, what will the project be offering to "the market" and who are "the buyers"? Do those markets / buyers currently exist (or, if not, will they exist when the project is operational)?
- Have you identified market mechanisms that provide revenue? Are they fixed / quantifiable or 'merchant'? Are there any regulatory risks involved with these revenue mechanisms?
- What's required by financiers / lenders? Do you know what is required to reach your final investment decision?

Risks and Recommendations for Markets and Revenue:

RISKS	RECOMMENDATIONS
Lack of clarity on government support mechanisms stalls investment and risks achievement of net zero. PSH requires high development and capital cost over long periods. Projects need to come online to support the roll out of renewables. Grid stability is at risk through lack of action. Long-term visibility and certainty are required. Furthermore, when decisionmakers consider the energy storage needs of their system, there is a risk that the economics of storage is considered only for short-term, i.e., to repay the CAPEX, and does not look at the cost over the whole lifetime or factor in replacements of assets in 10-20 years, as may be the case for other technologies.	**Governments should analyse the amount of energy storage they will need to support their renewable energy capacity in future.** Large capacity long duration energy storage through PSH is a fundamentally important part of future grid stability and energy security. This is a strategic grid asset. **Governments need to own the problem and work closely with industry to build confidence, considering supportive policy or market mechanisms where possible.** Those looking to develop pumped storage hydropower should **work closely with regulators, transmission system operators and government to model and support the case for the long duration energy storage needs of the grid**, showcasing how modern plant performance of PSH can provide the flexibility and energy storage needed to support the energy transition. **When performing economic comparisons between different storage technologies, policymakers and project developers should follow a consistent and technology neutral approach, considering the full-lifecycle benefits of assets** that will be in place for 50-100 plus years.
Support mechanisms are not tailored for PSH PSH has a longer development time and asset life than other types of energy storage. Most existing revenue mechanisms don't recognise these differences in development or operational life, or reward the numerous grid services that PSH can provide. To combat this, it requires better understanding across stakeholders and governments of their storage and flexibility requirements and also how PSH requires government intervention.	**Plan an approach and market products:** Once Governments realise the value PSH, **policymakers need to design appropriate market or policy products that will ensure long-term visibility of revenues. This enables private investment in the most efficient low-carbon technologies**. There are many options to do so, including ensuring appropriate contract lengths, allowing for 'bundled' grid services products, introducing income cap and floor mechanisms, and/or availability-based payments. A well-defined timeframe for project development and the type of payments PSH can expect for its availability, as well as legal justifications for loans, can support facilitating private sector involvement and give confidence to lenders.

RISKS	RECOMMENDATIONS
Lack of modern plant performance understanding influencing grid planning and considering only short-term economics Often, PSH assets are not fully appreciated for what they provide or are modelled based on old plant technology that does not take into consideration the services that modern PSH can provide to the grid.	**Evaluating the real contribution of the PSH asset** to a TSO's decarbonisation strategy, while also informing the technical choices with commercial and economic inputs is vital for developers to consider. When planning for grid requirements including the plants' potential performance using modern equipment characteristics in the modelling is critical way to mitigate this. The modelling will have a knock-on effect on markets and revenue. Developers should work with the supply chain, including designers, Electricity System Operators and OEMs to assess project needs and baseline performance requirements. Establishing these early will reduce delays and allow all stakeholders to progress with a common understanding.
Value is greater than component parts – making PSH asset value and the derived benefit hard to quantify. Therefore, the worst enemy of PSH is an economic analysis that only considers the power to cost benefit analysis, rather than the holistic view, e.g., water security, ancillary services, long lifespan, grid stability and grid resilience. PSH for the same MW can be quite compact in comparison to chemical batteries. This is good in terms of environmental issues, but not widely recognised.	**When creating the business case for a PSH asset, it is important to include and value**, where possible, **the multipurpose benefits of PSH**, demonstrating flood, drought, grid, or other benefits that may support the community and region. While these may not have a defined financial benefit, it is good to recognise wider project positive impacts which may have stakeholder value.
Revenue lacks clarity, making investment in PSH a higher risk. Uncertainty of a PSH asset's secure revenue stream manifests in two primary ways: first, the immense difficulty of predicting revenue streams over long timeframes due to changing market conditions and emerging technologies, and secondly the existing regulatory and market paradigms where storage assets are only remunerated for a fraction of the benefits they can provide to the system Once built, PSH assets can participate in numerous electricity markets (depending on the jurisdiction); however, the payback period is longer than smaller, lower-CAPEX energy storage assets. It is therefore critical that PSH be planned within an electricity grid with rapidly increasing VRE penetration to avoid curtailment, or baseload generation like nuclear which is expensive to operate flexibly.	**Revenue models are important and need to be understood early when developing a PSH asset.** The revenue model will be determined by the local and/or regional market considerations. To support the revenue model, robust market studies are paramount to the success of the PSH project. It is therefore critical for clients and developers to consider the needs of the grid and how this will impact the type of revenue they consider. Where possible, TSO's should consider auctions for storage services and longer-term contracts that provide greater visibility for PSH project developers. Certain jurisdictions will limit the ability of TSOs to develop their own storage assets. Where PSH can participate in ancillary services markets, those market rules should be stress-tested to ensure they are not inadvertently excluding the most efficient technologies, and low carbon solutions should be prioritised. Remuneration for all services that PSH provides is critical, but in addition the timing of the payment can have an impact as if revenue is paid at the day-ahead-stage and subject to product or regulatory risk with uncertain outlook, then projects may still have a difficult investment decision. As PSH operates as a grid battery, the cost to procure the pumping energy must be obtained at an economical price, and the asset must also receive revenues sufficient to recover costs at a fair return on investment.
Lack of value placed on sustainability, especially embedded carbon, in energy contract auctions	**Valuing sustainability in energy contract auctions** As we progress towards a future where carbon calculations, and embedded carbon decision-making, are pivotal in evaluating project performance, TSO's are encouraged to implement auctions for energy storage services and establish longer-term contracts that appreciate the significance of embedded carbon and the lifetime over which these emissions are amortised. Governments have a special interest in adopting these measures as they strive to meet global emission reduction targets. The implementation of large-scale projects in the energy transition plays a critical role in this endeavour. Considering embodied carbon amortised over the full design life of a project as a criterion and success factor introduces a tangible value to what is currently an unquantified advantage, especially in PSH projects. This approach not only aligns with sustainability goals but also highlights the long-term environmental and economic benefits of reducing embodied carbon in energy infrastructure development.

Focus area 2: Project Development

The development and construction phases of PSH projects are long, complex, and capital intensive when compared to many other power or energy storage technologies. Technical, contractual, and physical interfaces on PSH projects are more complicated when compared with conventional hydropower, other renewable generation, or general civil works. Hydropower sits alongside nuclear and aerospace as sectors that have experienced projects with significant cost and schedule increases. This is at the opposite end of the scale to solar, wind, and thermal power projects which, at present, have more consistent, predictable outcomes. Issues in execution on major projects are often the result of insufficient planning and understanding of the interface challenges and constructability. It is important to understand the associated risks so they can be actively managed throughout development, design, planning, and construction.

Each project will face its own unique challenges, for which there will be project specific solutions. The working group focused on 'how' we can best get to de-risked solutions. The important takeaway is best explained through Figure 5. This is a generally well-known 'cost-influence curve', which depicts that the optimal time to influence cost, schedule, and risk is at the early stages of development. Decisions made at the onset of a project have far greater influence on cost than those made later. This may seem obvious but under the traditional method of construction delivery, the Owner commissions an engineer to prepare drawings and specifications, then separately selects a contractor by competitive bidding at a later stage in the project's development. In these cases, teams are focused on running a procurement process, rather than on forming a focused delivery team to optimise the project. This results in either proceeding with a project that is not de-risked and/or creating delays due to rework. As a rule of thumb, the more complex the project, the earlier the delivery team should be appointed – and PSH falls at the complex end of the spectrum. This early procurement, based on capability, capacity, and approach differs from traditional procurement approaches. However, on complex projects, the value created through this early team selection more than offsets the perceived value of an

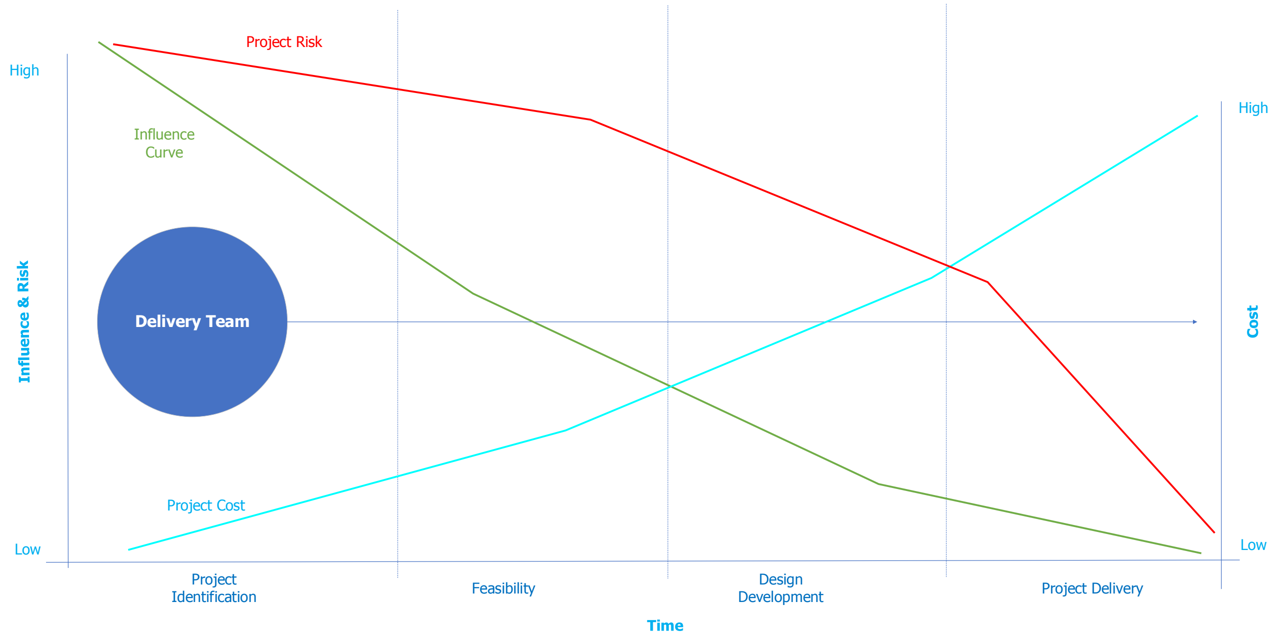


Figure 5: Cost-influence curve

Key considerations:

- **Appoint complete delivery teams early in the development process, including Owner, Operator, Designer, Constructor, OEM etc.**
- **Invest in development, including ground investigation to de-risk, and specialist expertise of delivery teams.**

extended competitive process, as it will allow for development and construction that is collaborative and focused on reducing risk and decreasing overall costs.

The development and construction of any large-scale infrastructure project needs to be managed in an appropriate manner. The value of experienced teams, with robust development processes and a history of delivering complex projects cannot be overestimated. Experienced leadership and supply chain teams, specific to the sector, is a key factor which contributes to the success of a PSH project. This is also why procuring capability early in the development stage is more important than procuring on price late in the process.

Owners must appreciate the investment costs required during development. If there is a desire to enter construction with a high level of confidence on project outcome, an appropriate level of investment is required. Having a strategy to invest in the right areas at the right time will help to reduce the likelihood of cost increases in the long-term. A single delivery team who is planning for execution will enable focused, efficient investment. Appropriate investment in project development is vital, including considering procurement strategies and selecting the delivery team early.

Project Development

Understand the risks specific to your project and invest in the key activities to best deliver through well-coordinated project teams[13].

- Do you understand the big site-specific risks for your project? (e.g., geological and subsurface conditions, topographic, hydrological, labour and equipment availability, etc.).
- When and what expertise do you need to bring in to address these risks? Are you engaged with the project stakeholders (e.g., investors, planning, local communities, etc.).
  - How can any risks or challenges associated with those conditions be addressed? Have you engaged with the supply chain market to align on how best to achieve this?

[13] For further reading on technical considerations for PSH, please see Technical Documents Log Annex

Risks and Recommendations for Project Development

RISKS	RECOMMENDATIONS
PSH requires good risk management. Each component of a PSH project is not uniquely complex, but combined into a major project brings interface and compounded risk. Key technical risks include: • Interfaces across different project areas • Ground conditions and geotechnical risk, particularly for underground works, dams and conveyances • Lack of understanding of modern plant performance • Grid requirements • Environmental / social / governance risks relative to the project (local, regional, national). • Permitting / consenting – especially on who is responsible for obtaining permitting or consents. • Water availability • Securing land rights • Optimism bias on cost and schedule estimates If the Technical risks are not understood and a risk strategy not put in place, this may make any mitigation measures more difficult. Furthermore, the technical risks will influence the design criteria, which in turn impacts constructability, cost, and schedule.	**Invest in project development to de-risk - The greater the investment, the more de-risked the project becomes.** From a technical perspective, the development stage is primarily an activity to obtain appropriate permits and achieve confidence in a cost estimate. It is important to follow an industry standard cost estimate classification guidance (e.g. AACE). This provides robustness to the development process and aligns all parties on how key input activities will impact the confidence in the estimate (e.g. level of design development, understanding of planning constraints, geotechnical information, construction planning). Projects which succeed will recognise that the value of early delivery team selection (still based on a competitive procurement) outweighs the value of running multiple competitive teams late into development. This value is generated through a single team being fully focused on de-risking the project; therefore the offer evaluation process is important for the procurement strategy. For PSH projects, this includes: • Investing in: • Robust market and grid studies - Grid decarbonisation contribution study - Grid connection - Ground investigations to inform the development of a geotechnical model to base line geotechnical risk for the project, i.e., a Geotechnical Baseline Report where appropriate. - Establishing preliminary designs to support more detailed design, - Value engineering, - Constructability - Cost and schedule confidence - Securing land rights - Obtaining permits • Early contractor and OEM involvement (e.g. for execution planning, early investment in plant performance, cost and schedule robustness). • Plant performance based on modern understandings of PSH (i.e. plant design for operation and maintenance stage). • Environmental enquiries and approvals pathways • Early Works - If an accelerated schedule is a project imperative and there is suitable confidence in the project proceeding, investing in Early Works can de-risk and maintain an aggressive critical path. This should be considered as an option during early constructability planning.
Poorly defined scope of works or scope defined later in the process. One of the most important elements is defining the scope of works, especially the plant performance guarantee parameters. Any organisations looking to develop PSH need to be able to provide clear instructions for the type of work they require to be undertaken, and this should be included at the start of project considerations. Lack of scope definition, or late scope change, will result in knock-on effects of re-work, adding cost and schedule to the development period.	**Projects need to define the scope of works clearly, unambiguously, specifically for PSH and as early and in as detailed a way as possible.** The business and value case of PSH needs to consider the station not as a power asset, but as an available capacity asset and an insurance policy for the grid. Because of this wider consideration, there will be added complexity for the equipment and operating specifications, e.g., power system ancillary services, head and flow ranges, sediment management, and selecting setting, arrangement and type of pump-turbines / generator motor sets. This is turn has an impact on the design and resulting constructability of the rest of the project. Where possible, scope of works should avoid ambiguity to ensure fully aligned understanding of desired outcomes and the amount of detail required. As projects are defining the scope of works, these should be defined as early and in as detailed a way as possible and be specific for PSH. Developers can and should consider taking advice from their Owner's Engineer, OEM, and Contractor to identify the required definition level.

RISKS	RECOMMENDATIONS
Lack of coordination and misunderstandings between the various actors involved can occur in PSH. These come in a number of varieties: • Lack of coordination between technical and commercial teams when choosing the design parameters. • Lack of clarity or understanding of good practices for PSH terms and development strategies can lead to misunderstandings of project requirements. • Cost uncertainties can arise from a lack of well-structured development plan, and this can lead to further cost overruns. • Scope gaps and/or lack of ownership can appear when there is a lack of a clear division of responsibility.	**Good Project Management is good risk management:** • **Ensure well-coordinated teams to support interface risk mitigation,** especially where there are multiple parties supporting the technical and commercial elements of project development. • **Follow industry guidance and international good practices**, terminology and standards so everyone has common understanding. e.g. AACE estimate classification for hydropower projects or other good practice standards to be included in the Employer's Requirements. • **Have a development plan** which takes a staged approach to derisking each of the key streams in a project (i.e., grid connection, permitting, geotechnical investigations and design stages, contracting and procurement), to better refine inputs to cost and schedule to inform a final investment decision. • **Have a clear division of responsibility** which is developed in collaboration with the key supply chain partners which may include: 1. Regular responsible ad hoc reporting 2. Rough time and cost control and construction site supervision 3. Adapted Quality Assurance Program
Lack of specialist experience. Not enough sector experience in a development team is a critical risk. Due to the lack of PSH projects being built over the past 30 years, there is more limited holistic experience in the PSH market. This leads to prevalence of unknown unknowns during development. Engaging the supply chain too late has the consequence that they are less able to influence the successful outcome of a project. There is limited designer and contractor capability and capacity, therefore attracting the required supply chain to your project is a substantial risk. Approaching the market with overly onerous risk transfer or an unattractive procurement strategy will risk the ability to attract the supply chain.	**Invest in project team capability, early in the development, attracting the best of the supply chain.** Developers need to make sure they attract teams who bring the "right" type of sector experience and lessons learned. Proven leadership talent is vital to success in PSH. This resource may be scarce and it is best deployed early in the development stage, as depicted by Figure 5. Projects that succeed will be the ones that recognise early that there is a need to secure their key supply chain early – designer, contractor, OEM. This will involve running a procurement strategy which attracts the leading capability through early market engagement, alignment on risk transfer in the delivery stage contract, and funding bid costs.

RISKS	RECOMMENDATIONS
Underestimation of the environmental and sustainability impacts and social concerns Environmental and Social considerations can have a detrimental impact on project success. These should be considered early in the process and can include: • Geology and soils • Sediment management • Hydrological quality and availability • Fish and aquatic habitat • Critical habitats and ecology • Indigenous communities • Resettlement and livelihood impacts • Waste disposal • Air quality • Land Uses / Management • Community Acceptance and Social License • Benefits sharing	**Review and implement relevant good best practice for environmental and sustainability considerations for PSH.** Utilising existing ESG guidance and tools[14] will help with social acceptance of projects, a critical issue that any large-scale infrastructure project must consider and address. E.g., the Hydropower Sustainability Standard can help assess and ultimately certify the sustainability performance of PSH projects. The HSS is a comprehensive and globally applicable assessment framework that covers 12 sustainability topics, including resettlement, biodiversity, climate change and hydrology. PSH projects that achieve HS certification can not only demonstrate their sustainability credentials but also increase their attractiveness to donors as a low risk and green investment. Include the local community early in the project, especially any considerations that need to be made for benefit sharing, resettlement, and protecting Indigenous groups. As we strive to harness the natural landscape and water resources for the energy transition, it is important to integrate the connections First Nations have with the land into core project principles. This ensures their territories are approached with respect and sensitivity. Prioritising benefits such as training, employment opportunities, and procurement contracts for First Nations businesses, and fostering a collaborative development process with these communities are essential steps in honouring these principles.
Interfaces with infrastructure providers or government departments over whom the project has no control and who may have conflicting agendas, with PSH stakeholder interests not always aligned or represented. These can include the following that may not in place in time and delivery of which is not within control of project: • Grid connections, • Transportation links, • Personnel accommodation PSH requires multiple departments to sign-off aspects that may sit outside of the scope of electricity regulators. It is therefore a risk if one of these other parties is disinterested in supporting the project, e.g., enabling infrastructure like roads or bridges.	**Political / governmental support for the project to facilitate and coordinate interfacing infrastructure providers is critical.** Where possible, the project team should work with government to streamline the process to make this enabling infrastructure and permitting as smooth as possible. Part of this issue falls to the interface of permitting.

[14] International standards include: The Hydropower Sustainability Standard and all IHA Guidance Documents, IFC Hydroelectric Power: A Guide for Developers and Investors, European Investment Bank "Environmental, Climate and Social Guidelines on Hydropower Development".

RISKS	RECOMMENDATIONS
Design mismatch occurs between project and grid requirements to promote decarbonisation and renewables: • Subjective or insufficient factual studies to justify technical choices e.g. powerplant size (MW/GWh), between fixed vs variable speed, hydraulic short circuit, number and size of power units, etc. • Competitive advantages over other storage technologies are not considered when taking the informed technical decision based on grid requirements.	**Design with grid requirements in mind based on modern PSH equipment.** As noted above, it is important for the project team to invest early in understanding the contract framing for the electricity market in which the PSH will operate in. This should be considered as part of the Markets and Revenues but is also important to consider as part of the overall project development phase. The markets in which the asset will seek to participate in will directly impact the choices for the civil and especially the electromechanical equipment, e.g., selection of variable speed turbines vs. fixed speed turbines.

Focus Area 3: Allocation of Risk

A critical element of pumped storage hydropower projects is managing and allocating risks, which is done through a well thought out contracting strategy. The contracting strategy sets the tone of where risk will sit and how the delivery team will think about cost and schedule. The type of contract will be influenced by a number of factors, including the governing law, owner requirements, supply chain appetite, as well as third parties such as financiers, lenders, and insurers. Financiers and lenders will need to assess all risks and spread them accordingly, and will place an emphasis on environmental and/or social aspects as these can introduce reputational risks[15].

There is no one-size fits all approach, although there are themes which should be common. This starts with a consideration of the preferred delivery model, and then consideration of where risk should sit.

The working group's discussions on this third area were complex, recognising that there are different market interpretations of risk and delivery models. The Group took the approach of considering what is the most appropriate way to de-risk the project and pumped storage hydropower in general at the sector level. Parties need to be clear that the balance of risk will be different in PSH projects than in other sectors. It is important to have these discussions early to avoid setting unrealistic expectations which can result in projects being delayed or cancelled.

Unlike wind and solar projects PSH risks will be allocated in a different manner between parties. PSH requires a different commercial structure, for example to address the

[15] ESG risks can be considered and proactively managed through existing industry good practice, such as the HSS and its supporting tools.

Key considerations:

- **Parties need to be clear that the balance of risk will be different in PSH projects than in other sectors**
- **Procurement and contract management should ensure fair, transparent, and economically most advantageous conditions of the project.**
- **Contracting strategy should reflect andfoster environmental and sustainability (E&S) aspects of the project.**

underground risk and overall complexities of the project. Owners need to consider this from the outset and consider how risk will be financed (e.g. on balance sheet, contingent equity, government backstop/support mechanism).

Allocation of Risk

Consider where the risk will sit and how the delivery team will think about cost and schedule.

- What is the delivery/commercial model and associated procurement strategy?
  - Does the Owner procure a Contractor under an EPCM (where construction management sits Owner side), EPC (where construction management sits with the contractor), or construction only (with the Owner keeping design responsibility) scope?
  - Should the OEM be contracted to the Owner (often referred to as split-contracts) or to the Contractor (often referred to as a wrapped contract)?
  - Are there parties engaged either by the Owner or the Contractor having special competences, such as the Engineer? And to whom should they be contracted?
  - Has the contract allocated risk in a considered manner between the appropriate parties? How much risk can be transferred from the Owner to the Supply Chain? Does the market for financing have requirements / limitations around where risk should sit?
- What responsibility does the Owner assume in respect of any designs, plans, or technical information as provided by the contractors? And how far can the Contractor rely upon information given by the Owner (Employer)?
- Is the contract based on a well-known standard form of contract?
  - Which commercial structure will be used (e.g. fixed price/lump sum, unit rate, cost plus, target cost)?
- Should the Owner have a one or two stage procurement process? (i.e. does the Owner keep multiple contractors in competition or appoint a preferred contractor relatively quickly and then negotiate a price with that preferred contractor as the project progresses)?

There is no single correct answer to these questions, as they need to be tailored to the specifics of an Owner/Project/Market. We provide some guidance in the recommendations below. As indicated in the timeline on page 17, a contracting strategy should be agreed on very early in the development process. This should be done in collaboration with the supply chain to ensure that the project is being set up in a way that will attract the best teams and can meet development schedules. Collaboration has become a well-used term in project delivery – but we must ensure that it must start at the earliest stages of project development and involve regular, open communication between owners and the supply chain (not undertaken as a tick-box, arms-length exercise).

Risks and Recommendations for Allocation of Risk

RISKS	MARKETS AND REVENUE RECOMMENDATIONS
Poorly allocated risk / commercial model. Inappropriate allocation of risk will not attract competent delivery organisations, in a heated market. If it is not recognised by an owner that PSH is not a lump sum/fixed price market, they will be proceeding with a project development that will be cancelled or delayed, and is not underpinned by a realistic financial model. While a particular organisation may be best placed to manage a particular risk, they will not necessarily be in a position to bear the consequences if a risk becomes a reality. If the risk holder cannot sustain the consequences of a risk, then that risk, in practice, has not been managed. There is often insufficient focus on the link between risk and cost. In a typical power project, much of the required revenue is in fact a long payment for risk. Risk premiums become built into supply chain contracts, cost of debt and equity increases.	**The allocation and management of risk is critical.** The concept of fair risk 'allocation', rather than risk 'transfer' is critical to PSH. It must be recognised that the concepts of 'managing risk' and 'bearing risk' are different. Owners should expect that once identified, risks should be minimised and managed by the party best able to manage it. However, risk should not be 'taken by the organisation best placed to manage it', **rather risks should be 'shared by organisations best placed to bear them'.** **Commercial model** Owners are typically proceeding under one of two models, each with an OEM contracted directly to the Owner: • EPCM, with a contractor managing multiple delivery packages, or • EPC, under either: - An incentivised target cost (ITC) contract with a painshare/gainshare for performance against an agreed target, or - A contract where different components of the project fell under different models. E.g. underground works are unit rate with change against a Geotechnical Baseline Report, while above ground works are fixed price, unit rate, or cost-plus. An ITC model can drive a more collaborative approach to development and delivery with financial risk sharing. The ITC model refocuses cost management from isolating individual risks and allocating them to one party, to managing and sharing risks on a whole of project basis. This is particularly beneficial on complex mega projects where there are a number of unquantifiable or uncontrollable risks, many of which may never materialise or may materialise in an unexpected way and result in disproportionate cost impacts. Under this model, Owners need to consider how any disproportionate cost impacts will be financed (e.g. on balance sheet, contingent equity, government backstop/support mechanism). Large impact risks and key commercial terms should be agreed early on in the process. These include: • Ground risk – A Geotechnical Baseline Report (GBR) should be prepared, to either provide a basis for change for a Target Cost, or for Unit Rate variations for changes in conditions, including rate adjustment if means and methods vary. • Market volatility/escalation – mechanisms to deal with the risk of price escalation (e.g. through a formula for key commodities, and confirmed pricing for major items) and labour availability beyond a certain tolerance level should be considered. • Contractor can assume Civil/OEM integration risk, although Generation Plant Performance should remain with the OEM. • Key commercial risk needs to be discussed early, e.g. total liability caps, liability for economic or consequential losses, liquidated damages, Capping painshare within an ITC contract • Grid connection delay remains as an Owner's risk • Materials and supply chain scarcity - the availability of equipment and raw materials, and their transportation. • In the allocation of risk between supply chain and Owners, it is important to recognise and adapt to insurers' specific contract requirements, particularly when there is a perceived imbalance on risk allocation towards the Contractor.

RISKS	MARKETS AND REVENUE RECOMMENDATIONS
Poorly executed procurement and tendering for services. The risk of poor procurement in PSH is similar to other complex infrastructure sectors. Insufficient early market engagement can result in owners coming to market with a misaligned and undeliverable commercial structure, resulting in delay or cancellation of projects. Owners must take a view on the respective risks of running a longer procurement, with multiple contractor teams developing parallel designs/estimates, as opposed to selecting earlier. The perceived risk of selecting early is the loss of competitive tension on estimate development. The risk of a longer procurement is that teams are more focused on the procurement process than on de-risking the project as one focused team. Value for money should always be a core tenant in procurement, although this should not detract from procurement being a mechanism to attract the best organisations to de-risk and deliver confidence in the project outcome. A lowest cost tender can negatively impact a project, especially if there is a lack of experience in PSH or commercial awareness. As the global PSH market grows, there is risk that there are more projects than competent supply chain partners to deliver them.	**Effective Procurement is a critical element to reducing risk on PSH projects and displays the following hallmarks:** • Collaboration, communication, transparency of the procurement process early and regularly, to ensure that the supply chain remains warm to the project. • Importance of flexibility in the procurement strategy, ensuring that the final development outcome aligns with market demands at the time of implementation. • Competitive tendering, irrespective of whether the organisation is private or public, is important because it instils confidence for project progression. • Procurement focused on selection of competency and capability to de-risk and present deliverable plans. • As noted in Figure 5, the larger, more complex a project, the earlier and more targeted the procurement should be. Procurement of complete delivery team (owner, designer, contractor, OEM, etc) should be completed as early as possible, to drive a one-team focus on planning the project (for design, delivery, and operations). A two-stage tendering process (where Contractor teams run parallel designs/estimates) can be considered although Owners should be prepared to reimburse full bid costs. Flexibility is crucial due to varying project requirements and financial considerations. • It is recommended that the procurement process provides clarity and alignment on required estimate classification development through the procurement. The Owner and Supply Chain should be aligned on the level of inputs which are required to achieve the estimate classification (e.g. percentage of design development, quantity of geotechnical investigations, clarity of planning constraints, level of broader supply chain engagement)
Management of and responsibility for interfaces. PSH involves multiple specialists which have complex interfaces. These include, interfaces between major scope items (e.g. civil, MEP, OEM, transmission), and responsibilities for obtaining permitting and necessary grid connection. An ill-defined interface management strategy can result in inappropriate risk allocation, scope gaps, and lack of confidence in execution plans and associated cost and schedule estimates.	**Management of and responsibility for interfaces** is a critical element of the contract in a PSH project. The contract will define the obligations of the interfaces. An integration strategy should be developed early in the development process and developed alongside the drafting of contract documents. This should include: • Splitting OEM & Civil contracts, but with early alignment on interface agreements, or assigning the OEM to the Civil contract under a 'managed subcontract' basis. • Clearly define which project members are responsible for obtaining licenses / permits as part of the interface risks.
Deviation from standard forms of contract, or heavy modification of standard forms, can lead to uncertainty as to the practical modified risk profile, which in turn can lead to too much uncertainty for funders, insurers, and the supply chain. Project Owners should consider: • Which form of standard contract should be considered (e.g. FIDIC/ NEC contracts), as well as what type of contracting arrangement, EPC, EPCM etc.	**Form of contract:** It is not the working group's place to promote a particular form of contract, however, we can recommend that Owners consider the use of forms of contract which are well understood by the market and are not heavily modified. As an example, in the UK and US, some Owners are using the NEC contract for Incentivised Target Cost or a FIDIC contract where they are seeking a mix of cost-reimbursable (also known as cost plus), unit rate (also known as re-measurable), and lump sum (also known as fixed price) components. It is recommended that Owners discuss form of contract and associated contracting principles, or heads of terms, early in the process.
Lack of transparent reporting may make owners and funders lack confidence that projects are not meeting the contractual requirements thereby raising the risk of investment decisions being aborted.	**Include transparent contractor reporting obligations** thereby supporting quality assurance programs. Consider early in the project the Employer's instruction rights and how these will be exercised.

Conclusion

As more governments consider the importance of long duration energy storage and flexibility as a fundamental part of achieving their climate mitigation and energy security targets, we anticipate that significant amounts of pumped storage hydropower will be developed. However, to meet the energy storage and flexibility demand when it is required, we need more projects to start construction and we need more confidence in cost and schedule outcomes.

This guidance note is intended to provide any persons considering, or in the process of, developing pumped storage hydropower with a better understanding of the challenges and the key framing principles to assist in turning an announced project into a successfully commissioned pumped storage hydropower asset.

Some of the overarching principles include:

- While the private sector is ready and able to deliver, to do so at the required scale the market needs to be **private sector developed but public-sector enabled**. Lack of clarity on government support mechanisms and revenue streams is stalling progress.
- PSH is at the more complex end of infrastructure development. **Owners must invest in project development to de-risk**. The greater the investment in preparation and the earlier a single, experienced delivery team (owner and supply chain) is focused on it, the more de-risked the project becomes.
- **Good project management is good risk management**: Ensure well-coordinated teams to support interface risk mitigation.
- Development of the right delivery and commercial model and associated allocation of risk is vital. Risk should not be taken by the organisation best placed to manage it, rather **risk should be minimised by those best placed to manage, and residual risk should be shared by those best able to bear it**.

Sustainability

We would encourage all who are developing PSH projects to align with the industry guidance as developed by the international hydropower community and managed by the Hydropower Sustainability Alliance. These guidance notes provide practical tools for ensuring projects are developed sustainably across numerous areas.

In addition, projects should apply the principles of the Hydropower Sustainability Standard, or equivalent technical standard (e.g., LIHI) early in their development. The HYDROSELECT Tool, which can be applied before or during the pre-feasibility stage. It evaluates projects based on the early-stage focus (hydrology, geology, finance), with ESG aspects, and includes three main parts 1) Fatal Flaws Analysis; 2) Additional Sustainability Risks; and 3) Sustainability Opportunities.

Any size or type of hydropower project, including PSH, can be certified by applying to be certified against the Hydropower Sustainability Standard which covers 12 environmental, social and governance topics over two levels of performance. In addition, the International Forum on pumped storage hydropower's Sustainability Working Paper includes analysis of existing tools for lifecycle analysis.

Technical Documents

There are many technical documents which should be considered. Some of these are included in the Documents Log Annex.

Policy tools

Further to this guide, the International Hydropower Association has developed several documents to support policymakers in assessing pumped storage hydropower. Including the International Forum on pumped storage hydropower's Policy and Markets deliverables, as well as a "Toolbox of pumped storage hydropower policy measures" which will provide case studies on the policies which, if used effectively, can best support national energy storage targets.

We hope that in developing this guidance note that we will see many projects developed and commissioned over the coming decades. We look forward to working with stakeholders to support their vision for a net zero future.

Appendices

Appendix 1 | Glossary

Aligning plant performance with market requirements risk	As part of developing a PSH project, it is critical for the electro-mechanical equipment, i.e. the turbines and pumps, to be aligned with what is required by electrical network requirements.
American Society of Civil Engineers (ASCE)	The American Society of Civil Engineers represents more than 160,000 members of the civil engineering profession in 177 countries. Founded in 1852, ASCE is the nation's oldest national civil engineering society.
Association for the Advancement of Cost Engineering (AACE)	Established in 1956, AACE International is the Association for the Advancement of Cost Engineering. Cost Engineering is a field of study using integrated means and methods to enable sound decision making in enterprise asset management.
Biodiversity & Ecology risk	Biodiversity and ecology impacts are important considerations when developing large infrastructure projects like PSH. Tools like the How-to Guide on Biodiversity are useful to assess impacts and identify mitigation strategies for PSH projects.
Blackstart	Involves restarting a power generation system, from a complete shutdown and island-operating state, without any power feed from the grid. The service is intended to restore the grid after a blackout event.
Capacity	The Maximum load which a generator, turbine, transmission circuit, apparatus, station, or system can supply under specified conditions for a given time interval, without exceeding approved limits of temperature and stress.
Capture price	The revenue captured by the indicated technology per unit of energy generation, e.g. the average electricity price (in $/MWh) that a project achieves according to its technology (wind / solar PV) and geographic-specific renewable energy resources (wind speed / solar irradiation) throughout a given period of time.
Charge / discharge ratio	The ratio of the average pumping load on a pump-turbine unit to its rated generating output.
Civil & OEM interface / integration risk	Interfaces refer to the points of interaction between two or more aspects of a project. The Civil and OEM interface integration is a risk for which the physical, contractual, commercial interactions take place to deliver the project.
Community support risk	The importance of considering the local community from the start in the project to ensure that the community benefits. This can be done most effectively during the preparation stage, as changes after this stage can become impractical and expensive
Constructor	A "constructor" is someone who undertakes a construction project for an owner (like a general contractor) and may also include an owner who undertakes the entire or partial project by themself.
Consumption	Measured in kilowatt hours, this represents the amount of electricity used over a certain amount of time, which is essential for pumped storage as it must "use" electricity to charge.
Contractor	An organisation (or sometimes a person), hired by the owner and/or client to execute the work required to complete the project.
Cost escalation risk	Cost escalation risk refers to the risk of inflation and supply chain shocks. As PSH projects are started 5-10 years before they are commissioned, the prices quoted at the start should consider how the material and labour costs may increase based on inflation or outside constraints.
Cost plus / Cost reimbursable contract	In the contract, the contractors are paid the actual cost for their works carried out, plus an agreed fee (sometimes stated as a percentage of the contract's full price).

Craft labour	Construction craft workers work mostly on construction sites. Their tasks include site preparation and cleanup, setting up and removing access equipment, and working on concrete and masonry, steel, wood and pre-cast erecting projects. They handle materials and equipment, and perform demolition, excavation and compaction activities.
Cultural heritage risk	Refers to properties and sites of archaeological, historical, cultural, artistic, and religious significance. Cultural heritage also refers to unique environmental features and cultural knowledge, as well as intangible forms of culture embodying traditional lifestyles that should be preserved for current and future generations.
Curtailment	The purposeful reduction of electricity output below the levels that it could otherwise have produced, a requirement to prevent system-wide oversupply.
Dam safety risk	The risk of a dam to experience structural collapse. The consequences of dam safety failing are classified as i) loss of life, ii) environmental and cultural heritage loss, and iii) property, infrastructure, and economic losses.
Demand	The maximum amount of electrical power that is being consumed by the electricity system at a given time, represents the rate at which electricity is being used in kilowatts.
Dunkelflaute	German word meaning "dark doldrums". Refers to a period of time in which little to no generation occurs from solar or wind power.
Engineering, procurement and construction (EPC)	Contractor scope includes the responsibility for design development, engineering, procurement and execution of the works.
Engineering, procurement and construction management (EPCM)	Contractor scope includes the responsibility for the management of the design development, engineering, procurement and execution of the works. The EPCM Contracts are structured such that the owner directly contracts with suppliers and trade contractors, which the contractor has procured through a tender process.
Environmental and social studies - risk	Environmental and social assessment aims to ensure that any project will incur the least negative environmental and social impacts on its area of influence. ESAs are an ongoing process, undertaken concomitantly with project technical planning and taken into account in project financial planning.
FIDIC	FIDIC is a French language acronym for Fédération Internationale des Ingénieurs-Conseils, which means the International Federation of Consulting Engineers. FIDIC is well known for its work drafting standard form Conditions of Contract for the worldwide construction industry, particularly in the context of higher value international construction projects, and such contracts are endorsed by many multilateral development banks (MDBs).
Fixed price / Lump sum Contract	A fixed price or lump sum contract is the most common type of contract. In this type of contract, the price is fixed and doesn't change regardless of what happens during construction. A fixed price, or lump sum, is agreed at the start before all works begin, hence being referred to as both "fixed price" and "lump sum".
Flexibility	The capacity of the electricity system to respond to changes that may affect the balance of supply and demand at all times. The capability of a power system to cope with the variability and uncertainty that VRE generation introduces into the system in different time scales, from the very short to the long term, avoiding curtailment of VRE and reliably supplying all the demanded energy to customers
Frequency Control	When technologies adjust their power output in response to an imbalance in supply and demand on the grid. Typically, the market requires primary and secondary frequency services, and in some cases, very fast frequency response (within 1 or 2 seconds) is a relatively new service.
Geotechnical investigation - risk	Geotechnical and/or geophysical investigations are those to determine potential risk zones and complement initial desktop geological mapping. The site investigations are carried out during the feasibility and design development stages to inform placement of tunnels.
Ground risk	The geological situation at a potential HPP site is of crucial importance for power plant construction and operation. Costs can rise substantially depending on site geological conditions. First, the foundations of all HPP structures must be adapted to existing geological conditions, especially those of the dam and the powerhouse. Second, if tunnels are required, excavation costs can vary widely based on geological conditions. And finally, for HPPs with a reservoir, porous ground conditions, such as the permeability of karst, can lead to significant water losses.
High voltage interconnection studies	Transmission line construction costs rise as the distance increases between the HPP and the closest grid connection point so a site closer to an existing connection point is preferable.

Hydraulics	The hydraulic design basis for a pumped storage project is concerned with the configuration and sizing of works such as intake structures, penstocks, hydraulic machinery, water passages, and spillways. The hydraulic design of these elements has great bearing on both the safety and operational efficiency of the project.
Inertia	Inertia in the context of the electric system is defined as the kinetic energy contained in rotating synchronous machines, like generators and turbines, that can immediately inject energy into the system in case of disturbances. As fossil generation is retired to meet clean energy goals, system inertia is decreasing, leading to possible grid instability. Inertia offers instantaneous support to grid frequency variations, traditionally through large rotating mechanical generators. The total rotating mechanical inertia is a huge kinetic energy storage system, and it is provided by synchronous electrical machines directly connected to the power grid, such as PSH units; whereas electronic-interfaced energy sources, such as batteries, can provide synthetic inertia, which is almost instantaneous.
Installed capacity	The sum of the capacities in a PSH powerplant, as shown on the nameplate ratings of similar kinds of apparatus, such as generating units, turbines, or other equipment.
In-water construction risk	Refers to the risks associated with constructing projects either in-water, dewatering a work area, or diverting flow to allow for construction
Labour availability risk	As the PSH sector experiences a dramatic increase in the number of projects being developed, there may be limits on the number of personnel available with the appropriate specialist skills to support projects; therefore, causing projects to be delayed.
Land acquisition and resettlement risk	Refers to IFC Performance Standard 5 - aiming to minimize or avoid negative impacts of project implementation resulting from economic and physical displacement, land acquisition, or land-use restrictions. IFC PS5 requires restoring or improving pre-project livelihoods and standards of living of project-affected persons, so that they are better.
Materials and supply chain scarcity risk	The equipment and raw materials for PSH are unique and often need to be scaled for each respective project. Similar to labour availability, should there be a breakdown in raw materials or equipment, this may cause an indirect impact in a project to proceed within the planned project timeline.

Offtake agreements	An agreement between two parties, with one acting as generator and the other buying electricity, e.g. a wind or solar farm which needs to sell electricity to another party to use the electricity, such as an electricity consumer or trader.
Original equipment manufacturer (OEM)	Refers to a company who provides the electro-mechanical equipment for a PSH facility. They will likely have some form of contract for the installation and maintenance of the units, including but not limited to set-up and review of the O&M concept and procedures, water intake management, unit start-up/shutdown, etc.
Owner	A project owner is a person or group responsible for initiating, funding, and overseeing a project. The party owns the final PSH asset.
Peaking capacity	The maximum peak load that can be supplied by a generating unit in a stated time period. This can be the maximum average load or a specific interval of time.
Permit approvals risk	Risk of not obtaining, or experiencing a delay in, planning or permitting from the appropriate authority may have a direct impact on labour and material resources for the project. Because PSH projects generally require permissions and licenses from multiple governmental departments, if permissions are delayed, this can lead to a delay in the project.
Plan for operability risk	As PSH projects are being developed, it is important that all components are considered with the operational lifetime in mind, e.g. ensuring that units can be accessed for routine maintenance.
Political support - policy implementation risk	PSH project delivery covers many differing governmental departments at national, regional, local scales which may have differing requirements. In addition, having limited or no governmental support can be a risk to independent financing.
Programme risk	As PSH projects are large-scale programmes with multiple projects, programme risk refers the importance of good project management regarding the inter-related projects within an overarching PSH project development or "programme".
PSH experienced delivery leadership risk	Appropriately qualified and experienced project staff that lead by example with experience in PSH project development are essential for project execution to reduce project optimism bias.

Rated capacity	The electrical load for which a generator, turbine, transformer, transmission circuit, electrical apparatus, powerplant, or power system is rated.
Reactive power control	Management of voltage levels on the grid and is an ancillary service that units can provide either automatically or manually.
Residual Load	The remaining demand for electricity that cannot be covered by wind and solar power as a difference between actual power demand and the feed-in of non-dispatchable and inflexible generators.
Revenue certainty risk	Lack of revenue certainty due to limited incentives or markets that do not remunerate PSH services is a risk.
Round-trip-efficiency	The combined efficiency of a full cycle from electrical energy input to energy withdrawn from a storage technology. It is given as the percentage of the energy put in.
Site access and impacts risk	All PSH structures under consideration require access using permanent or temporary roads, which if delayed in their construction can lead to project delays. Whether access roads exist, whether they are in good condition or require upgrading, or whether new roads must be constructed is something that could impact project development.
Spinning and fast ramping reserve	An electricity service where units are held in a ready state so that they can be ramped up or down in minutes to support grid balancing.
Technology readiness level (TRL)	A scale metric to determine the maturity of a technology to be commercially used from 1 to 9, where TRL 1 signifies further research and development may be required and TRL 9 signifies the technology can operate in a commercial environment.
Transmission system operator (TSO)	An organisation that transports electrical power on a national or regional level. The TSOs function may be owned by the transmission grid company, or may be entirely independent. The roles of the TSO in a wholesale electricity market can include managing the security of the power system in real time and co-ordination of supply and demand for electricity that avoids fluctuations in frequency or interruptions of supply. TSOs are often wholly or partly owned by state or national governments.
Unit	A "unit" refers to the turbine and/or pumping generator situated within a powerhouse of the PSH facility.
Unit rate contract	A unit rate is where the contractor provides unit rates for specific scope items, taking productivity risk, and the customer takes quantity risk.
Water availability and quality risk	Water availability is important to fill the storage reservoirs in a pumped storage project and compensate for water lost through evaporation and seepage etc. The quality of the water, in terms of chemistry or sediment content, can impact on the environment or the project structures such as waterways and turbine components.
Weather risk	As sites are located remotely, significant changes in flow arising from more intense weather events can create additional risks relating to erosion, sediment movement, bank collapse, landslides and mudslides. These can cause costly impacts to projects that are under construction or operational.

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Working group Scope: *The scope of the working group was to consider greenfield pumped storage hydropower projects and develop a guidance note that would support greenfield pumped hydro site development.*

Working group Members

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[16] Listed in alphabetical order by company. All WG members who have attended at least one meeting have been included, unless they otherwise indicated.

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