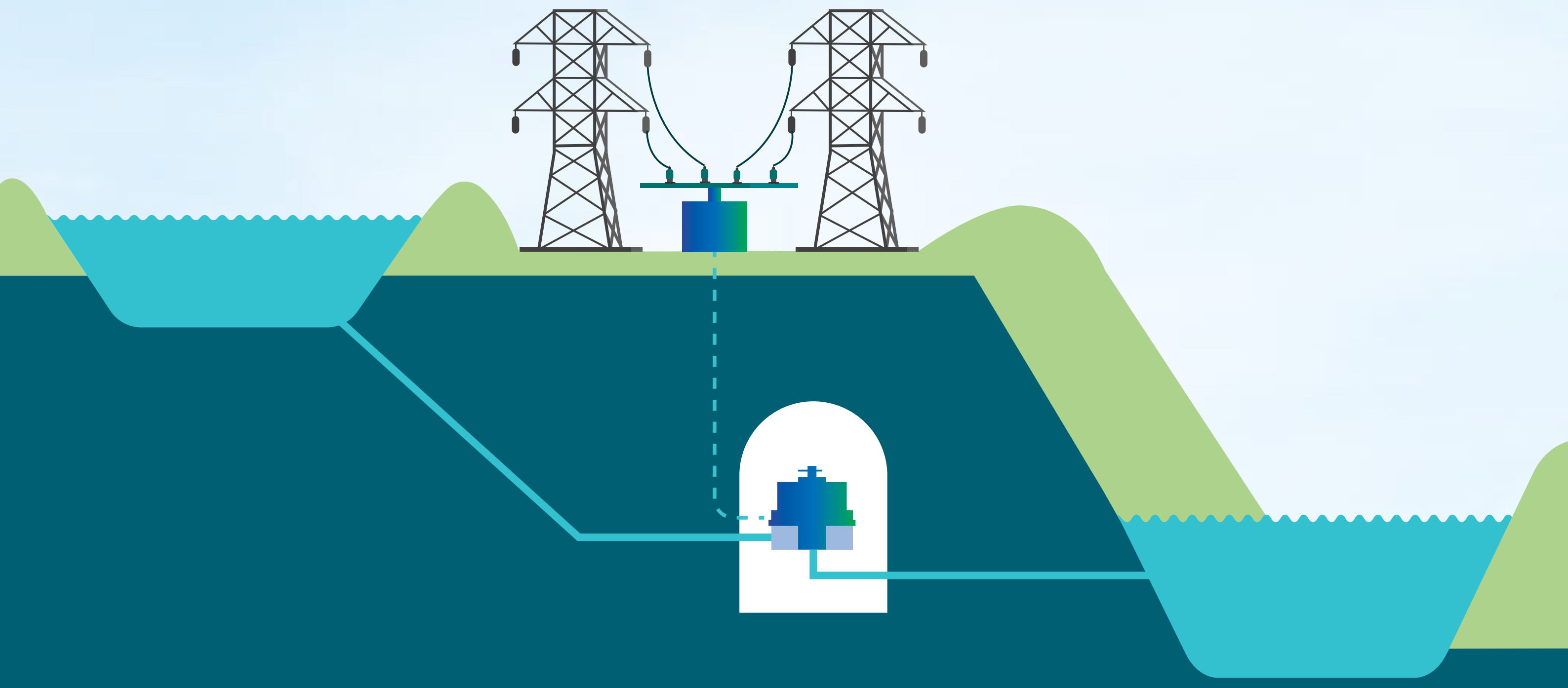
10 YEARS
IESA
India Energy Storage Alliance

Presents

Knowledge Paper on

PUMPED STORAGE PROJECTS IN INDIA



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Abbreviations

AWIA	America's Water Infrastructure Act
CAPEX	Capital Expenditure
CCEA	Cabinet Committee on Economic Affairs
CEA	Central Electricity Authority
COD	Commercial Operation Date
COP26	26th UN Climate Change Conference of the Parties
DELWP	Department of Environment, Land, Water and Planning
EIA	Environmental Impact Assessment
ESS	Energy Storage System
FERC	Federal Energy Regulatory Commission
GoI	Government of India
GW	Giga Watt
HPO	Hydro Power Purchase Obligation
IESA	India Energy Storage Alliance
IHA	International Hydro Association
INR	Indian Rupees
ISTS	Inter State Transmission System
JICA	Japan International Co-operative Agency
kW	Kilo Watt
LDES	Long Duration Energy Storage
LHP	Large Hydro Project
MSPGCL	Maharashtra State Power Generation Company Limited
MW	Mega Watt
MWh	Mega Watt Hour

MNRE	Ministry of New & Renewable Energy
MOEF&CC	Ministry of Environment, Forest and Climate Change
MOP	Ministry of Power
MU	Million Units
NEA	National Energy Administration
NEP	National Electricity Plan
O&M	Operation & Maintenance
PSP	Pumped Storage Projects
RE	Renewable Energy
RLDC	Regional Load Despatch Centre
RPO	Renewable Purchase Obligation
RTC	Round-the-clock
R&R	Rehabilitation and Resettlement
TANGEDCO	Tamil Nadu Generation and Distribution Corporation
THDC	Tehri Hydro Development Corporation
US DOE	United States Department of Energy
WBSEDCL	West Bengal State Electricity Distribution Company Limited
WRD	Water Resource Department

Executive Summary

India has pledged ambitious international commitments to reach 500 GW of non-fossil fuel-based energy capacity by 2030 and boost the share of renewables in installed capacity generation to 50%. Wind and solar energy are already among the most affordable renewable energy sources, but because of their inherently variable, unpredictable, and intermittent character, integrating substantial amounts of renewable energy while ensuring grid stability is extremely difficult. Flexible Energy Generation is the key to meeting India's constantly changing energy needs to engage in assets with the capacity to offer Base Load and Peak Power both economically and efficiently. India has a large economic opportunity from energy storage.

Pumped Storage Projects (PSP) are becoming more crucial in providing peak power and preserving system stability in the power systems of many countries, even though numerous types of energy storage systems have been constructed globally. Pumped storage technique is the time-tested, financially viable, highly effective. Along with this, it is important to consider the timely completion of PSPs for making the project financially viable.

This paper covers the global scenario of PSP to understand the status of capacity addition and various measures undertaken by the countries for development of PSP. China is leading in terms of installed capacity followed by Japan and United States. Further development of PSPs in Indian context is explained with respect to the different phases of project such as installed, under construction and under survey & investigation project and policy support provided by government for enhancement of PSP capacity in energy mix.

Technology can play significant role in faster deployment of PSP. This paper covers various technological advancements and innovative concepts of PSP around the globe. With technological advancement, PSP can be installed with lower capacity with lesser gestation period. Considering the variability of RE and its increasing share in India’s generation mix, there will be an immediate requirement of storage capacity, and PSP can become one of the options with such technological advancement.

Considering the various challenges faced during the deployment of PSPs in India, like regulatory, delays in environmental and forest clearances, land acquisition issues, rehabilitation and resettlement issues, geology uncertainties, power evacuation issues due to delay in forest clearances, etc., the prolonged delay in the commissioning of PSPs in India could not cater the actual requirement of energy storage in India. The time required for obtaining the approval till the commissioning of projects is prolonged which results in significant cost overrun. To assess this, few case studies has been mentioned in the paper to understand the timelines and cost overrun incurred in projects. Also, few case studies has been considered to highlight the effective utilization of PSP which is critical for getting its benefit for intended application.

Therefore, PSP should be considered as a key enabler of the clean energy transition, alongside other energy storage technologies only when its timely commissioning of projects. It is also important to consider the geological aspects which considering the feasibility of the projects, as the project should not hamper the socio-economic aspects and long-term local benefits that should be taken into account while evaluating their sustainability. Future projects/ tenders should be evaluated based on the realistic approach considering its techno-economic assessment, to avoid the delays and cost overruns to achieve the intended objectives.

1. Introduction

Over the last few decades, India's electricity sector has transformed from a vertically integrated monopoly to an unbundled sector with private sector participation along with focus on one nation-one grid-one frequency. Government of India (GoI) has set an ambitious target for 2030 which includes reducing CO2 emissions by 33–35 per cent from 2005 levels and increasing the share of renewable energy in the generation mix to 40 percent[1]. By 2022, GoI plans to install 175 GW of renewable energy capacity, of which 100 GW is solar, 60 GW is wind, 10 GW is biomass, and 5 GW is small hydro power. At COP26 world leaders' summit, India presented five commitments towards climate action include:

The intermittent nature of Wind and Solar energy poses challenges to grid operator for managing the grid balancing and stability with increased variability of renewable energy. System operators require flexible tool to manage variability of renewable energy such as Energy Storage System (ESS) which has capability of large-scale integration of variable renewable energy into the grid.

In the figure below, the system power rating and discharge time are compared. The Y-axis shows the Discharge Time at Rated Power, which ranges from seconds to hours. The X-axis shows the System Power Rating, with plant sizes ranging from 1 kW to 1 GW.

ESS can be used for several applications such as load balancing, renewable energy integration, ramping, frequency regulation, congestion relief, black start reserve and ancillary services. Pumped Storage Project (PSP) is a matured technology available for managing variability of RE sources. Ramping capability of generating station is the important parameter to define the flexibility. PSP provides flexibility in terms of overload capability, fast ramping, and peaking support which has immense value for grid balancing and reliable operation. However,

1. IEA Report 2020

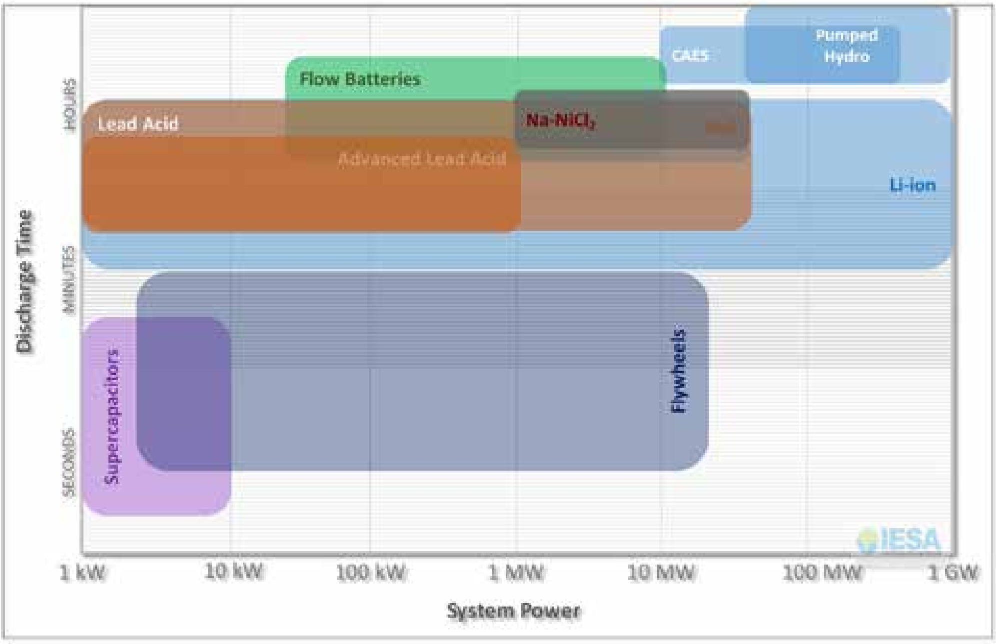

Figure 1: Storage Technologies based on Discharged Time and Rated Power (Source: IESA)

development of PSP requires long-term planning due to certain challenges such as long gestation period, seasonality, long process of approvals and clearances, geographical limitations, etc.

Long duration energy storage can deliver storage for 10+ hours. Long duration storage technologies are required as more renewable energy capacity will be deployed. Long duration storage offers so many benefits including load following, ancillary services, black start, replacement of fossil fuels etc. Technology agnostic approach for longer term is better including pumped hydro, advanced batteries, gravity storage and other technologies. This will avoid competition between different technologies because the pace at which the technologies are evolving.

ESS technologies in terms of round-trip efficiency, life span, development period, operating cost, maturity, and applications are compared in the below table.

Table 1: Storage Technologies based on Duration, Maturity and Applications

Energy Storage System Attributes	Li – Ion	NaS	Flow Batteries	PSP
Round trip Efficiency	80-90%	75-80%	70-75%	70-80%
Life span	10-15 years	10-15 years	Up to 20 years	40 years
Development & Construction Period	6 months - 1 year	6 months - 1.5 year	6 months - 1.5 year	5-15 Years
Operating Cost	Low	Moderate	Moderate	Low
Estimated Space Required	Small	Moderate	Moderate	Large
Maturity of Technology	Commercial	Commercial	Early to moderate	Mature
Applications	Power quality, Frequency regulation	Time shifting, Frequency regulation, RE integration	Peak shaving, Time shifting, Frequency regulation, RE Integration	Load levelling, Peak shaving, RE integration

2. Overview of Pumped Storage Project (PSP)

2.1 Global Scenario of PSP

According to the Hydro Power Status report published by the International Hydropower Association (IHA) at the end of 2021, there were over 161.6 GW of PSP operational around the world by end of 2021. Most of the capacity is in China with 36 GW, followed by Japan at 27.5 GW and the United States at 22 GW[2].

China - PSP has seen a lot of growth in recent years, and in 2021 China announced plans to increase national capacity to 120 GW by 2030. In less than ten years, this would represent a roughly fourfold increase from 32 GW in 2021. China's National Energy Administration (NEA) issued the medium- and long-term PSP development plan from 2021 to 2035 in September 2021. This plan estimates that PSP will have an installed capacity of at least 62 GW in 2025 and a capacity of about 120 GW in 2030. The first two pump turbine units of the Jilin Dunhua 1.4 GW PSP in China entered operation in June and October 2021 and was completed in April of 2022 when the fourth of its 350 MW units went into operation. The first units of Fengning's 3.6 GW PSP scheme were put into service in December 2021, delivering 600 MW to serve the Winter Olympics.

Australia - Australia announced that financial closure was reached on the Kidston Stage 2 project in May 2021. When completed, the 250 MW PSP will be able to store and discharge energy for up to eight hours. The plant will convert a decommissioned gold mine into a reservoir and provide rapid-response, emissions free flexible power to Australia's National Electricity Market, and is set to be completed in 2024.

East Asia - In September 2021, Indonesia announced its first pumped storage plant. The World Bank-supported project, Upper Cisokan PSP, is expected to be 1,040 MW and located between Jakarta and Bandung. It will provide important system flexibility to the electricity in the region. At the 2021 Hydropower Industry Day, the South Korean Hydropower Industry Association announced the construction of three new projects with a total capacity of 1.8 GW in Pocehon, Hongcheon and Yeongdong, which are set to be completed by 2034.

USA - The United States added about 70 MW of PSP in 2021. Additionally, the US Department of Energy unveiled a fresh tool to support PSP development in November. The Valuation Tool is a web-based platform designed to assist developers in precisely determining the entire potential of a PSP, particularly within the broader power system.

Africa - The African Development Bank granted a US$86 million funding in October 2021 for the second stage of the 1 GW Lesotho Highlands Water Project, which will give the tiny nation in southern Africa crucial energy storage. The project, which is a collaboration between Lesotho and South Africa, would boost water security and generation in the Gauteng region.

Europe - The 880 MW Gouves PSP facility, which is a part of the Tâmega Giga Battery project in Portugal, was officially put into operation in early 2022 after completing the final phase of construction in 2021. At the Dniester location in Ukraine, the largest PSP in Europe began operation in December 2021 with an initial capacity of 324 MW of 1,296 MW installed capacity and 1,684 MW in pumping mode. The plant will eventually have a total capacity of 2,268 MW.

2 IHA report, 2022

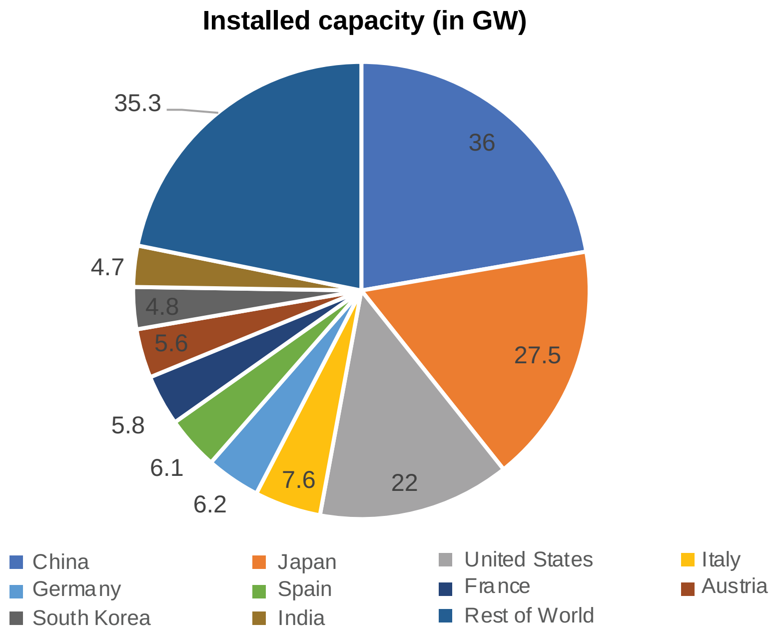

Figure 2: Country wise installed capacity by 2021 of PSP (Source: IHA report, 2022)

2.2. PSP Scenario in India

2.2.1. PSP Project in India – Installed, Under Construction and Under Survey & Investigation

As per CEA report, the total installed capacity of PSP in India is 4745.60 MW as of Nov 2022[3]. Currently, 2700 MW capacity of plant is under active construction and construction activities of Koyna Left Bank PSP in Maharashtra is stalled since 2015 and 19960 MW capacity comprising of 17 plants is under survey and investigation.

Out of 4745.60 MW installed capacity of PSP, 3305 MW capacity is working under pumping mode whereas, 1440 MW capacity is not working under pumping mode. Two units of Kadana PSP were commissioned in 1990 and 1998 respectively. Machines operated in generation mode till 2004 and trial pump mode operation was done during in 2004-05. However, operation in pumping mode was not taken up subsequently due to vibration problem in machine. Sardar Sarovar PSP project is not working in pumping mode as the lower reservoir at Garudeshwar weir was not operational and the equipment required to operate it in pumping mode were also not installed.

Table 2: Status of Installed PSP in India (Source: CEA)

Project	State	Capacity (MW)	Commissioning Year	Pumping Mode	Remarks
Bhira	Maharashtra	150	1949	Working	-
NJ Sagar	Telangana	400	1985	Working	-
Kadamparai	Tamil Nadu	250	1989	Working	-
Kadana	Gujarat	240	1998	Not Working	Vibration problem
Srisailam	Telangana	900	2003	Working	-
Sardar Sarovar	Gujarat	1200	2006	Not Working	Tail pond dam under construction
Purulia	West Bengal	900	2007[4]	Working	-
Ghatghar	Maharashtra	250	2008	Working	-

3 CEA
4 https://www.wbsedcl.in/irj/go/km/docs/internet/new_website/PPSP.html

Table 3: Status of Under Construction PSP in India (Source: CEA)

Project	State	Executing Agency	Capacity (MW)	Original Commissio-ning Schedule	Anticipated Commissio-ning Schedule
Tehri PHP	Uttarakhand	THDC	4 X 250 = 1000 MW	2010-11	Oct-2023
Koyna Left Bank	Maharashtra	WRD, Maharashtra	2 X 40 = 80 MW	2014-15	2027-28 (Subject to re-start of work)
Kundah PSP (Phase I, II & III)	Tamil Nadu	TANGEDCO	4 X125 = 500 MW	2022-23	Dec-24
Pinnapuram	Andhra Pradesh	Greenko Energy	4 X 240 + 2 X 120 = 1200 MW	2024-25	Mar-25

Recently private developers are actively involved in development of PSP in India. Out of 17 projects under survey & investigation, nine projects with cumulative capacity of 12,260 MW are by the private developers such as Greenko, Adani Green Energy Ltd and JSW Energy and rest of the 8 projects with cumulative capacity of 7,700 MW are through the State Governments entities.

Table 4: Status of PSP Under Survey & Investigation (Source: CEA)

Name of Project	Capacity (MW)	State	Sector	Agency	Date of submission of proposal	Target date of DPR preparation
Upper Indravati	600	Odisha	State	OHPCL	18 April 2018	March 2023
Saundatti	1260	Karnataka	Private	Greenko	29 Nov. 2019	March 2023
MP 30 Gandhi Nagar	1440	Madhya Pradesh	Private	Greenko	06 Sept. 2020	March 2023
Warasgaon	1200	Maharashtra	State	WRD	12 July 2021	January 2023
Gandikota	1000	Andhra Pradesh	Private	Adani Green Energy Ltd	10 August 2021	March 2023
OWK	800	Andhra Pradesh	State	NREDCAP	10 August 2021	March 2023
Somasila	900	Andhra Pradesh	State	NREDCAP	10 August 2021	March 2023
Chitravathi	500	Andhra Pradesh	Private	Adani Green Energy Ltd	10 August 2021	March 2023
Kurukutti	1200	Andhra Pradesh	Private	Adani Green Energy Ltd	11 August 2021	March 2023
Karrivalsa	1000	Andhra Pradesh	Private	Adani Green Energy Ltd	11 August 2021	March 2023
Yerravaram	1200	Andhra Pradesh	State	NREDCAP	01 Nov. 2021	March 2023
Bhavali	1500	Maharashtra	Private	JSW Energy	07 March 2022	December 2023
Sukhpura off-stream	2560	Rajasthan	Private	Greenko	29 June 2022	June 2024
Paidipalem East	1200	Andhra Pradesh	State	NREDCAP	18 August 2022	June 2024
Singanamala	800	Andhra Pradesh	State	NREDCAP	30 August 2022	June 2024
Paidipalem North	1000	Andhra Pradesh	State	NREDCAP	10 Oct. 2022	June 2024
Shahpur	1800	Rajasthan	Private	Greenko	12 Oct. 2022	June 2024

2.2.2 Policy Measures for Development of PSP in India

Recently, Government of India (GoI) has announced in the budget 2023-24 for creation of separate framework for development of PSP in India, which will boost the energy storage through hydro power and provide guidelines for effective execution of projects. GoI has initiated various measures through upgraded policy/regulations to boost the growth of PSP through various incentives. Some of the key measures by GoI are as below:

- **Amendment in National Wind-Solar Hybrid Policy**: Ministry of New & Renewable Energy (MNRE) has issued amendment to the National Wind-Solar Hybrid Policy on 13th August 2018 to broaden the ambit of energy storage to other technologies such as PSP, flywheel, compressed air, etc, which was earlier restricted to battery storage only.
- **GoI Measures to Promote Hydro Power Sector:** On 08th March 2019, Ministry of Power (MoP) has notified the following measures to promote the hydro power sector in India.
  - Declaring Large Hydro Projects (LHP > 25 MW) as Renewable Energy Source. However, LHPs are not eligible for relaxation in availing statutory clearances such as Forest clearance, Environmental clearance, etc as available for small hydro.
  - Hydro Power Purchase Obligation (HPO) is notified as separate component within non-solar Renewable Purchase Obligation (RPO).
  - Tariff Rationalization to bring down hydropower tariff – To improve the viability and to bring down the tariff measures such as flexibility to developer to back loading of tariff after increasing the project life to 40 years and increasing debt repayment period to 18 years and introducing escalating tariff of 2%.
  - Budgetary Support to Cost of Enabling Infrastructure, i.e., road/bridges - In Principle approval has been accorded for budgetary support to cost of developing infrastructure such as road/bridges through the budgetary grant of MoP. The limit of the grant would be INR 1.5 crore per MW for projects up to 200 MW and INR 1.0 crore for projects above 200 MW.
- **Waiver of Inter-state Transmission (ISTS) Charges:** MoP vide order dated 21st June 2021 has extended the exemption on Inter-State Transmission System (ISTS) charges to electricity generated from PSP after electricity generated from wind and solar source of energy. Accordingly, provision was proposed in the order as, Waiver of ISTS charges shall be allowed for PSP to be commissioned up to 30th June 2025, if at least 70% of the annual electricity requirement for pumping of water is met by electricity generated by wind or solar power plant.
- **Budgetary Support for Flood Moderation/Storage Hydro Electric Projects:** Ministry of Power had issued budgetary support to flood moderation of PSP to be set up in future vide Office Memorandum dated 28th September 2021. The objective is to reduce tariff of hydropower projects by ensuring that consumers are charged for the power component only. This budgetary support is applicable to all eligible projects which shall be taken up for construction by 31st March 2030.
- **Clarification regarding usage of Energy Storage System (ESS) in various applications across entire power value chain:** Ministry of Power on 29th January 2022 has issued notification for clarification of status of Energy Storage System (Battery Energy Storage System, PSP, Phase change energy system including energy storage in the form of Green Hydrogen/Ammonia) under entire power value chain. It is clarified that –
  - The ESS is a part of the power system under sub-section (50) of Section 2 of the Electricity Act, 2003.
  - ESS can be used on standalone basis or complementary with generation, transmission, and distribution.

3. Technological Advancement in PSP

3.1 Current Technology in PSP

3.1.1. Fixed-Speed PSP Technology

The majority of PSPs that are now operational use conventional fixed-speed (or single-speed) technology. They use a motor-generator called a synchronous machine, which runs in sync with the grid frequency. Synchronous machines are only used as generators in other technologies; in PSP, they are also used as motors. When the PSP unit is in pumping mode, the synchronous machine serves as a motor, drawing power from the grid to move water into the upper reservoir. When the water is discharged from the higher reservoir, reversing the direction of rotation, the same synchronous machine is utilized as a generator to produce power for the grid.

A fixed-speed PSP unit with a reversible pump-turbine can alter the amount of power it produces in the generating mode, but when it is pumping at a given head, it always uses the same amount of grid power. Fixed speed PSP units can offer regulatory and spinning reserve services for the grid when operating in the generating mode. However, they are unable to give regulation service when pumping since they are unable to adjust their pumping power. By entirely stopping pumping, which is the same as adding the same amount of generating capacity to the power system, spinning reserve service can still be offered.

3.1.2. Adjustable or Variable Speed PSP Technology

Variable or adjustable speed PSP technology was initially implemented at the Yagisawa PSP facility employing power converters with semiconductor technology, which was developed in Japan in the early 1990s. The main impetus behind this was the requirement for more flexibility in the power system at night. Because there is less demand of power at night, baseload generation continues to be used primarily to supply that need. PSPs are particularly desirable in this scenario as, by pumping additional night-time demand for baseload units, they can maintain more baseload capacity that must run overnight. PSPs with variable speeds can provide regulation service while operating in the pumping mode since they have the ability to alter the amount of grid electricity they utilise for pumping. For power systems with a significant proportion of baseload generation or, on the other end of the spectrum, for power systems with a high penetration of variable renewables, the adjustable-speed units have a range of other operational and performance qualities that make them particularly desirable. For this reason, a number of adjustable speed PSPs were constructed in Japan, as well as in several European countries and a few other countries around the world. However, in addition to the energy and capacity markets, developers of various new PSPs are taking ancillary services markets into consideration.

The latest generation of modern fixed-speed PSPs has been enhanced to have faster responses (i.e., fast ramp rates, short mode change times) and larger operating ranges (lower minimum load, wider working head range). Fixed speed PSP technology is particularly adaptable in the generating mode. However, adjustable speed PSP technology still has several operational advantages. The main benefits of variable speed units over fixed-speed units are:

- Ability to regulate service when operating in pumping mode by varying pumping power consumption. The normal operating range for PSPs with variable speed is in between 70% and 100% of their rated pumping capacity.

- Slightly improved generating mode operating efficiency, particularly at partial load operation This is due to the adjustable-speed machine's ability to alter its rotating speed to the head and flow rate passing through the turbine.
- A smaller rough zone (if any) compared to fixed speed technology, because the rotor speed may be changed to accommodate the flow rate.
- A larger operational range than fixed-speed units is made possible by a lower technical minimum load, as low as 20–30% of the rated capacity.
- Adjustable-speed units suffer less wear and tear because they run at nearly optimal speed even under partial loads. As a result, they are projected to last longer than fixed-speed units.
- Due to the electrical decoupling of active and reactive power through a frequency converter, adjustable-speed units can offer the power system more flexible voltage support.
- In the event of grid disturbances, adjustable-speed units respond more dynamically than fixed-speed devices. This helps to increase the reliability of the power system and reduce frequency drops brought on by unexpected generator or transmission failures.

However, since adjustable-speed units need more power electronics and other equipment, the cost is significantly more than fixed-speed units of the same size.

3.1.3. Ternary PSP Technology

Ternary technology employs three components, a motor-generator, a separate turbine, and a separate pump. Before the reversible pump-turbine was created, this was a typical PSP arrangement. However, contemporary ternary technology is frequently built with capabilities for so-called "hydraulic short circuits," which offers significant operating flexibility. A clutch can mechanically separate the pump and turbine, but when they are coupled, they both run simultaneously and rotate in the same direction.

The capacity of ternary PSP units to run the pump and turbine simultaneously when in hydraulic short-circuit mode adds to their operational flexibility. Since the pump and turbine are mounted on the same shaft and rotate in the same direction, the ternary unit does not need to halt and reverse its direction of rotation when switching from pumping to generating, and vice versa. Depending on the hydraulic parameters of the location, Francis or another type of turbine could be utilised in ternary units instead of the more common Pelton turbines.

Table 5: Comparison of Operating Parameters of Existing PSP Technologies[5]

Parameters	Fixed-Speed PSP	Adjustable or Variable Speed PSP	Ternary PSP with Hydraulic Bypass and Pelton Turbine
Generation Mode			
Power output (% of rated capacity)	30–100%	20–100%	0–100%
Standstill to generating mode (seconds)	70	75–85	65
Generating to pumping mode (seconds)	240–420	240–415	25
Frequency regulation	Yes	Yes	Yes
Spinning reserve	Yes	Yes	Yes
Ramping/load following	Yes	Yes	Yes
Reactive power/voltage support	Yes	Yes	Yes
Generator dropping	Yes	Yes	Yes

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Parameters	Fixed-Speed PSP	Adjustable or Variable Speed PSP	Ternary PSP with Hydraulic Bypass and Pelton Turbine
Pumping Mode			
Power consumption (% of rated capacity)	100%	60–100%	60–100%
Standstill to pumping mode (seconds)	160–340	160–230	80
Pumping to generating mode (seconds)	90–190	90–190	25
Frequency regulation	No	Yes	Yes
Spinning reserve	No	Yes	Yes
Ramping/load following	No	Yes	Yes
Reactive power/voltage support	Yes	Yes	Yes
Load shedding (pump dropping)	Yes	Yes	Yes

3.2 Potential Advancement in PSP

With the advancement in the technology, industry, PSP developers, and energy storage academics are all currently working on a variety of cutting-edge PSP concepts and technologies in addition to the configurations and technologies that already exist.

- **Bendigo Underground Pumped Hydro:** Bendigo has a long history as gold mining town, which includes a significant amount of now unused underground mine workings. As part of a broader push to transition Bendigo to renewable power sources, the Bendigo Sustainability Group (BSG), City of Greater Bendigo and DELWP are investigating the possibility of a pumped hydro energy storage system in the mine workings. This concept has a generation capacity of 30 MW and can store 6 hours or 180 MWh of energy with a round-trip efficiency of approximately 70%[6].

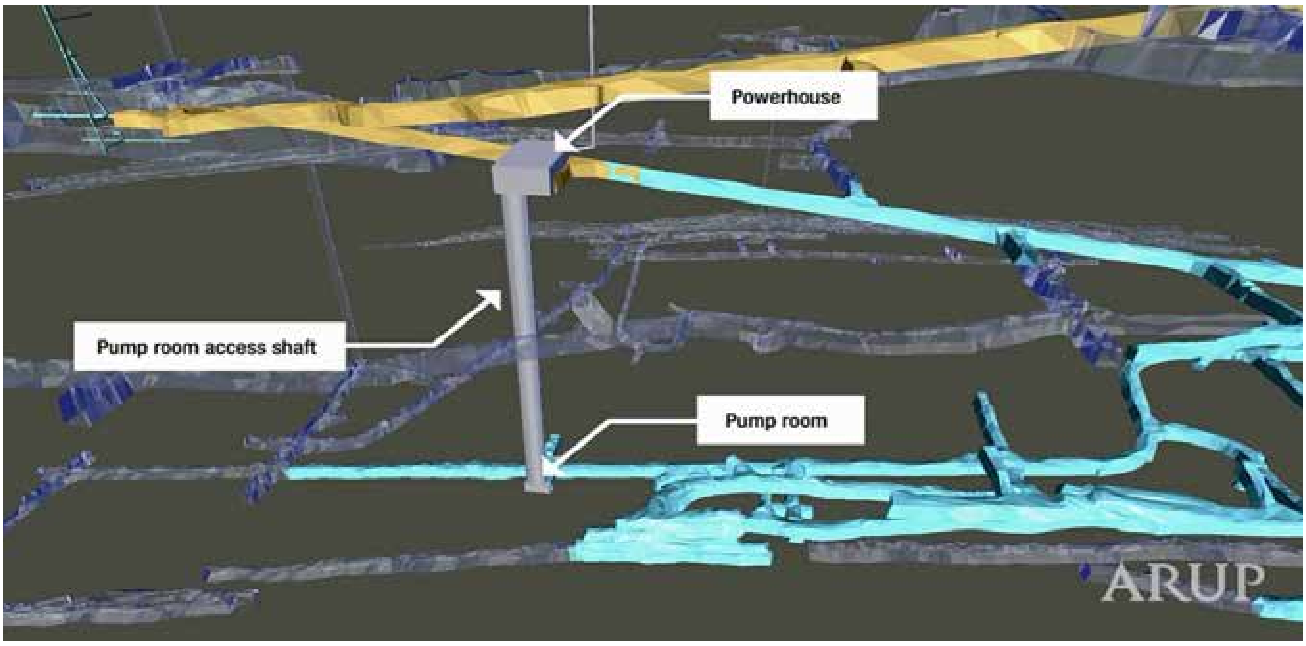

Figure 3: Bendigo Underground PSP

6 https://www.arup.com/projects/bendigo-underground-pumped-hydro

Also, some of the new and innovative PSP technologies as mentioned below, may be able to meet a variety of energy storage requirements, from small, distributed energy storage to large, bulk power system applications.

Table 6: New and Innovative PSP Technologies[7]

Sr. No.	New Technology	Construction Time	Scalability
1	Small PSP with Reservoirs of Corrugated Steel and Floating Membranes	Approx. 2 – 3 years	Plant size estimated at 1–10 MW, average size 5 MW
2	PSP Using Submersible Pump-Turbines and Motor-Generators	Approx. 3 – 4 years	Unit sizes can range from less than 1 MW to about 100 MW; typical plant size estimated at 10–200 MW, average plant size 75 MW
3	Geomechanical PSP	Approx. 1.5 - 2 years	Plant size estimated at 16–320 MW, based on multiples of unit sizes (4–40 MW per unit)
4	Hybrid PSP and Wind Plant	Approx. 2 – 3 years	Plant size of 16, 24, or 32 MW, with a total energy storage of 70–150 MWh
5	Integrated PSP and Desalination Plant	Approx. 4 – 5 years	Plant size estimated at 100–500+ MW, with an average size of 300 MW
6	Underground PSP Using TBMs for Storage Excavation	Approx. 5 – 6 years	Project size is scalable, but the economics are better for larger plants and energy storage; plant size estimated at 500 – 1,000+ MW
7	Underground Mine PSP	Approx. 3 – 5 years	Typical plant size is estimated to be 20–100 MW
8	Open-Pit Mine PSP	Approx. 3 – 5 years	Plant size from can vary from under 100 MW to over 2,000 MW
9	Hybrid Modular Closed-Loop Scalable PSP	Up to 2 years	Plant sizes are small, 10 MW or less, and more likely to be connected to the distribution network
10	Pressurized Vessel PSP	Approx. 1 – 2 years	Plant size can vary from 1 to 300 MW

3.3 Technical Details of PSP in India

In India, favourable site-specific characteristics including steep slopes and high plateaus are the main criteria used to identify PSP locations[8]. In addition to the site-specific factors, there are some more aspects that affect PSP design as mentioned below.

➲ Configuration of PSP

- **Four units:** In this configuration, a generator is coupled to a separate pump that is also a motor and a turbine. Since this arrangement would need significant space and hence is not currently in use.
- **Three units:** A single reversible motor/generator, a pump, and a turbine are all united in this configuration. This improves both the pump and the turbine's efficiency.
- **Two units:** A reversible pump/turbine and a reversible motor/generator make up the two-unit configuration. Comparatively, this configuration needs less space than other. However, this configuration poses the issues oof reduced efficiency.

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- Hydraulic energy is transformed into mechanical energy using turbines. Impulse and response turbines are two different types of hydraulic turbines.
  - **Francis turbine:** Applications requiring medium-head and medium-discharge are ideally suited for Francis turbine. It has a power rating that spans from 0.25 to 800 MW per unit and is employed at head ranges of 20 to 750 metres.

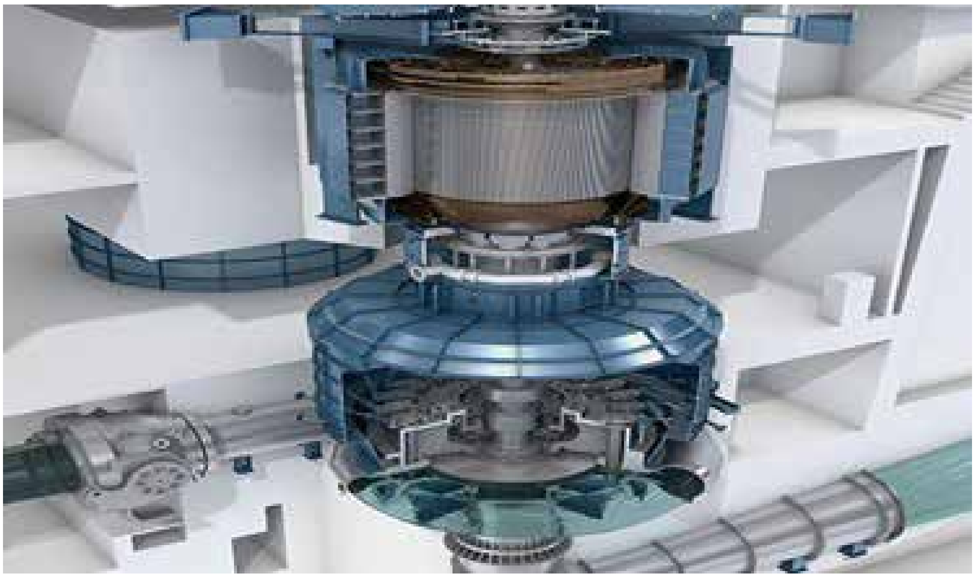


Figure 4: Francis Turbine (Source: GE Renewable)

  - **Pelton turbine:** Pelton turbines are widely utilized in high-head applications. Since there is no pressure drop in the buckets, it is categorised as an impulse turbine. When water is delivered from the high head through a conduit, the flow is axial (which is called a penstock).

Figure 5: Pelton Turbine (Source: GE Renewable)

- Kaplan turbine: A reaction turbine suitable for a lower head range is the Kaplan turbine. Since the guide vanes and runner blades in the Kaplan turbine are load adjustable, it offers higher efficiency.

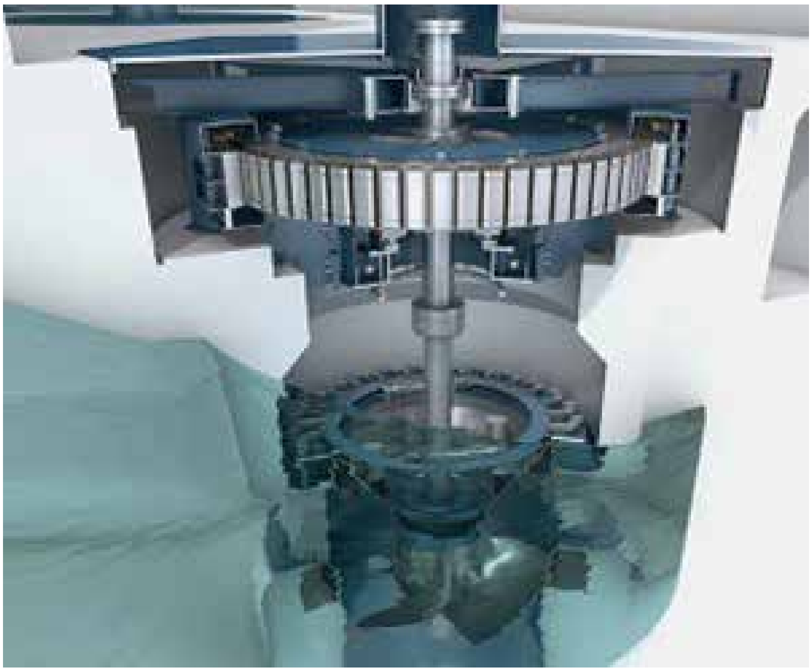


Figure 6: Kaplan Turbine (Source: GE Renewable)

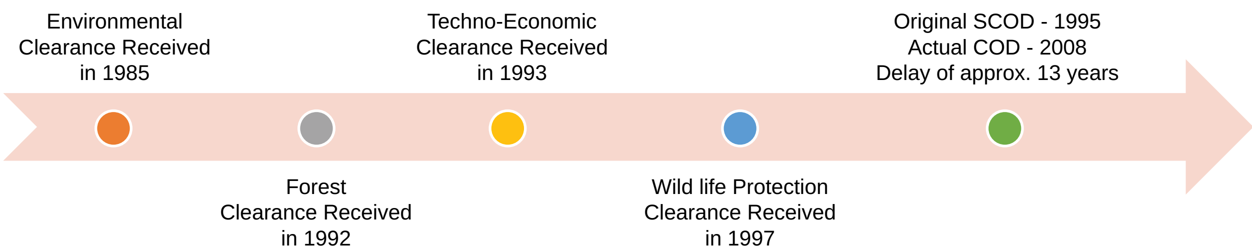
Presently, the projects which are under Survey & Investigation stage in India, most the developers are planning to opt for Vertical Francis reversible turbine with combination of fixed and variable speed turbine units. The variable pump turbine required extensive civil work and cost is high compared to fixed speed turbine.

4. Key Issues and Challenges for Development of PSP

4.1 Timeline for Development of PSP in India

- **Timeline and Cost Overrun:** Duration for development (from obtaining clearance, approvals, construction of project to commissioning) of PSP is one of the impediments for timely commissioning of plants. The delay in obtaining these approvals and clearances can be one of the major reasons for the cost overrun from original cost of project. Details of few PSP are mentioned below to understand the original timeline versus actual execution of the project with respect to its cost overrun incurred in the projects. Such type of delay in the commissioning of project will not only lead to the cost overrun but also defer from achieving the India's RE target of 450 GW by 2030. The funds invested in the projects and its overrun cost would have been allotted to the other RE project which will increase the RE contribution in energy mix.

  - **Ghatghar PSP –** Ghatghar PSP has been developed by Water Resource Department, Maharashtra. Currently, Maharashtra State Power Generation Company Ltd (MSPGCL/MAHAGENCO) is responsible for its operation. The plant has total installed capacity of 250 MW with 2 units of 125 MW each. The project was financed by Japan International Co-op Agency (JICA) with initial project cost of INR 288.83 crore which was revised to INR 1535.26 crore which accounts to cost overrun of 431.54%.[9]

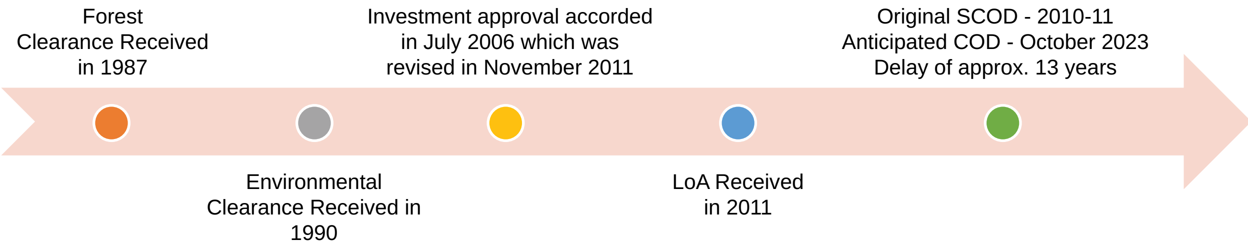


Thus, time taken from receiving the environmental clearance (1985) to actual COD (2008) is approx. 23 years.

Figure 7: Approval and Commissioning Timeline of Ghatghar PSP – 250 MW

  - **Tehri PSP –** Tehri PSP envisage 1000 MW capacity with 4 units of 250 MW. The original cost of the project as approved by CCEA in 2006 was INR 1657.60 crore but due to certain reason such as poor geology, local agitation at Asena Quarry, revision of lay out of machine hall due to poor geology and funds constraints with contractor, the cost has been revised to INR 4835.60 crore[10] which accounts to cost overrun of 191.12%.

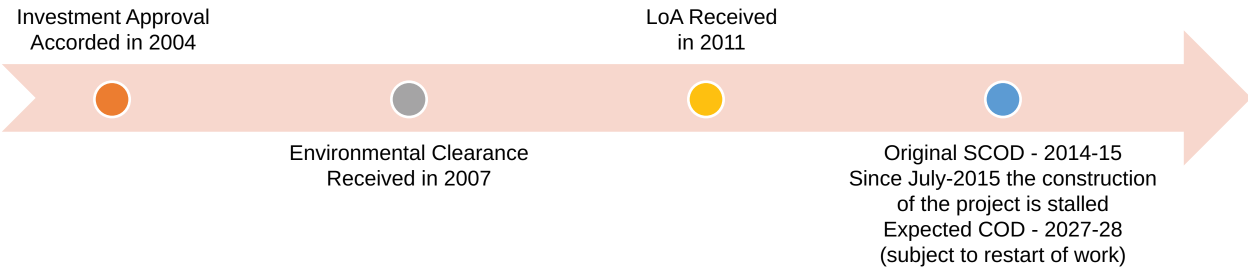
9 https://www2.jica.go.jp/en/evaluation/pdf/2012_ID-P53_4_f.pdf
10 CEA Report



Thus, time taken from receiving the forest clearance (1987) to anticipated COD (2023) is approx. 36 years.

Figure 8: Approval and Commissioning Timeline of Tehri PSP – 1000 MW

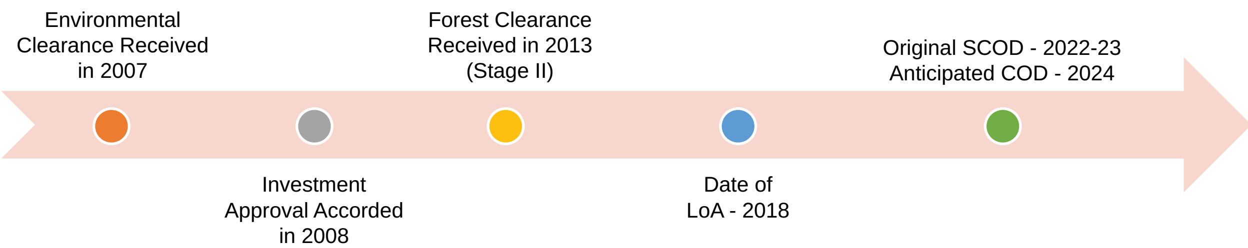
- **Koyna Left Bank PSP –** The Water Resource Department, Maharashtra is developing this plant with installed capacity of 80 MW (2 X 40 MW). The cost of the project originally approved was INR 245.02 crore which has been revised to INR 1403.77 crore[11] which accounts to cost overrun of 472.92%. Thus, there is a delay of around 12 years with respect to the scheduled commissioning date (subject to restart of work).



Thus, time taken from receiving the investment approval (2004) to expected COD (2028) is approx. 24 years (subject to restart of work).

Figure 9: Approval and Commissioning Timeline of Koyna Left Bank PSP – 80 MW

- **Kundah PSP (Phase I, II & III) –** Kundah PSP has been developed by TANGEDCO with capacity of 500 MW. The original project cost was INR 1216.59 crore which has been revised to INR 1831.29 crore[12] which accounts to cost overrun of 50.52%.



Thus, time taken from receiving the environmental clearance (2007) to anticipated COD (2024) is approx. 17 years.

Figure 10: Approval and Commissioning Timeline of Kundah PSP – 500 MW

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12 CEA Report

➲ Long Process of Approvals, Permits and Clearances

Large PSP must go through a prolonged approval, permits, and clearances procedure from the central and state governments and other authorities. PSP development may require several years to complete. In India, the permitting and licencing process for new PSP may take 3-6 years depending on the geography of the projects, which is significantly longer than most other energy storage technologies. In the United States, the permitting and licencing process for new PSP may take 3-5 years[13] . The costs and development risks associated with this extended timeline are higher.

Table 7: Permits and Clearances Required for the Installation of PSP in India

Clearance	Act	Scope & Objective	Key Agencies
Environmental Clearance	Environment (Protection) Act, 1986	To provide for the protection and improvement of Environment An umbrella legislation; supplements pollution laws	Central Government nodal agency MoEF&CC can delegate powers to state departments of Environments
	EIA Notification, 2006	Environmental Impact Assessment, Environmental Protection	Project Developer, State and Central government
Forest Clearance	Forest (Conservation) Act,1980, 1988	To consolidate acquisition of common property such as forests; halt India's rapid deforestation and resulting Environmental degradation. Regulates access to natural resources, state has a monopoly right over land; Restriction on de-reservation and using forest for non-forest purpose	State Government and Central Government
Wildlife Clearance	Wildlife (Protection) Act, 1972,1993	To protect wildlife Creates protected areas (National Parks/ sanctuaries) categories of wildlife which are protected	Wildlife Advisory Boards; Central Zoo Authorities
Water Resources Clearance	Water (prevention and Control of Pollution) Act, 1974, 1988	To provide for the prevention and control of water pollution and enhancing the quality of water Controls sewage and industrial effluent discharges	Central and State Pollution Control Boards
Air Pollution Related Clearance	Air (Prevention and Control of Pollution) Act 1981, 1987	To provide for the prevention and control of air pollution Controls emissions of air pollutants	Central and State Pollution Control Boards
Land Acquisition Clearance	The Right of Fair Compensation and Transparency in Land Acquisition, Resettlement and Resettlement Act 2013	Resettlement and Rehabilitation of Project affected people. Address Social issues	Central Government

13 IFPSH, 2021

➲ Utilization of Installed PSP

PSP contribute for stabilisation in a way by meeting peak load demand and balancing requirement. PSP generates electricity during peak hours and utilises electricity in off peak hours for pumping the water back in upper reservoir. Utilization of these assets for its intended application is important to incur the expected benefits. Some of the case studies of PSP which are currently working in India, with respect to its actual utilization aspects are mentioned below.

For the case study data of units generated and units consumed in pumping mode is considered from the reports of respective RLDCs of the jurisdiction of PSP. The season wise data for month of summer, monsoon and winter has been considered for plants to understand the working of the plants.

- **Ghatghar PSP:** Ghatghar project has been on long term lease to MSPGCL who is responsible for its O&M. Each unit of plant consumes 150 MW during pumping mode and generates 125 MW as a generator. Under normal condition, the plant operates 7 hours in pumping mode during off peak hours (from Monday to Sunday) and 6 hours during peak in generation mode[14]

Month	FY 2021-22		FY 2020-21	
	Generation (MU)	Pumping (MU)	Generation (MU)	Pumping (MU)
May	8.35	11.93	0	0.44
August	15.63	13.8	0.04	1.15
November	2.62	3.21	24.21	31.12

  In the month of May of FY 2020-21, the plant has not been working either in pumping or generation mode. Whereas in for the same month in FY 2021-22, the plant has operated with efficiency of around 70%. In August month, the plant has high generated units in both the years whereas for pumping electricity consumption is very less. The potential reason of low pumping consumption can be high rainfall in the region which may have filled the upper reservoir.

- **Purulia PSP:** The installed capacity of Purulia project is 900 MW comprising 4 units of 225 MW each and it is operated by West Bengal State Electricity Distribution Company Ltd (WBSEDCL). The plant operates under generation mode for 6 hours whereas it operates in pumping mode for 8 hours. To understand the operating efficiency of the plant data for units generated and consumed in pumping mode[15]. As per data, it can be concluded that the plant is working under both generation and pumping mode throughout the seasons with average efficiency of around 78%.

Month	FY 2021-22		FY 2020-21	
	Generation (MU)	Pumping (MU)	Generation (MU)	Pumping (MU)
May	92	116	94	121
August	105	136	124	157
November	94	119	81	102

- **SriSailam PSP:** Srisailam PSP commissioned in 2003 with installed capacity of 900 MW comprising 6 units of 150 MW. To understand the operating efficiency of the plant data for units generated and consumed in pumping mode[16].

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14 Western RLDC Report
15 Eastern RLDC Report
16 Southern RLDC Report

Month	FY 2021-22		FY 2020-21	
	Generation (MU)	Pumping (MU)	Generation (MU)	Pumping (MU)
May	0	0	0.59	0
August	529.58	0	475.7	0
November	181.62	0	148	0.52

The above-mentioned data indicates that the plant has been utilised only for the generation as like a conventional hydro power project and not in pumping mode by consuming the power in off peak hours. The reasons for not working the plant in pumping mode is unknown but this will dilute the potential benefits, that the plant may offer such as absorbing the excess generated electricity by working in pumping mode.

4.2 Challenges and Barriers

Other than forest clearances and necessary approvals, some of the major issues involved in the slow pace of PSP development in India are:

- **Land Acquisition Issues:** For the construction of PSP in India, land acquisition is a major hindrance. Negotiations with local governments and communities are a routine component of the process of acquiring property for such projects, which can be time-consuming and lead to confrontations. Lack of a clear legal framework for land acquisition, resistance from local communities due to displacement and loss of livelihoods, and challenges in obtaining necessary permits and approvals from government organisations are some of the major problems encountered when acquiring land for PSP. A project's overall cost could go up and become unprofitable due to the high cost of land acquisition and compensation for impacted stakeholders.
- **Geological Issues:** Geological surprises can pose a significant challenge in the construction of pumped hydro storage projects in India. Unforeseen geohazards such as landslides, earthquakes, or unstable rock formations, poor soil conditions, water scarcity, changes to water flow patterns, erosion, and effects on regional ecosystems, are some of the major geological concerns. The recent crisis at Joshimath, Uttarakhand has been affected by geological phenomenon-land subsidence. With the various development activities at Joshimath like hydro power projects and other construction, the city has been affected and became vulnerable to land slide, earthquake, erosion, etc. The root cause of land subsidence is still undergoing investigation.
- **Rehabilitation & Resettlement Issues:** Rehabilitation and Resettlement (R&R) concerns are crucial while building PSP in India. These project' development may result in the uprooting of local people and the loss of their means of subsistence, which may cause social and economic disruptions as well as resistance and opposition from the impacted communities. Inadequate compensation, lack of job prospects post rehabilitation, and the loss of cultural and natural legacy are few of the major R&R concerns.
- **Capital Investments:** Most PSPs are typically substantial projects, with capacities ranging from a few hundred to over a thousand megawatts. This necessitates a substantial financial investment for project development and occasionally cooperation of numerous owners/off takers. Large initial CAPEX extends the investment payback period, raises project development risks, and makes it more challenging to close funding. Many PSP developers (including utilities and IPPs) are risk adverse and prefer projects with lower investment requirements and quicker return times, as are financial lending institutions. Considering lowering the cost of energy storage is acknowledged as one of the main difficulties, DOE has announced the Long Duration Storage Shot effort, with the aim of lowering the cost of LDES by 90% by 2030.

- **Environmental Issues:** As open-loop operations that entailed erecting a dam on a river or lake and affecting aquatic and other ecosystems, many PSP around the world encountered public opposition. According to the America's Water Infrastructure Act (AWIA) and FERC guidelines, closed loop PSPs may have less negative environmental effects and can proceed more quickly through the licencing and permitting process. Closed-loop PSPs, in contrast to open-loop PSPs, primarily use artificial reservoirs, avoid damming rivers, and lack a continuous connection to natural water bodies or waterways. The man-made reservoirs of closed-loop projects are typically devoid of fish and aquatic life, whether they are newly built or rebuilt by repurposing abandoned mines or other brownfield sites. As a result, they barely affect the biological ecology. Since many environmental groups are aware of this, they are now more open to the development of new closed-loop PSP initiatives.

5. Way Forward for Streamlining PSP

Government of India Future Planning for PSP

As per the Optimal Generation Capacity Mix report, the projected installed capacity of PSP by end of 2029-30 will be 10,151 MW[17]. Central Electricity Authority (CEA) has issued draft National Electricity Plan (NEP) 2022 depicting source wise target capacity addition required till 2031-32. As per the plan, PSP based storage capacity of 6806 MW is required to meet the projected peak electricity demand and energy requirement in 2026-27 and 12,020 MW is required during 2027-32 to meet the peak demand and energy requirement for the year 2031-32.

Table 8: Projected All India Installed Capacity of PSP till 2031-32 (Source: Draft NEP 2022, CEA)

Sr. No.	Details	Capacity in MW
1	Total installed capacity as on 31.03.2022	4746
2	Total capacity addition in 2022-27	2060
3	Additional capacity requirement by 2027-32	12,020
4	Projected All India installed capacity (2031-32) (1+2+3)	18,826

The projected all India installed capacity of 18.82 GW is required to meet the peak electricity demand and energy requirement in 2031-32. To achieve this capacity addition, CEA has estimated funds of INR 43,099 crore in between 2022-23 to 2026-27 and INR 35,532 crore in between 2027-28 to 2031-32 will be required.

Reduction in Clearance and Execution Timelines

Most of the cost overrun which are incurred in the PSP happens because of the delay in environmental clearance and forest clearances. These approvals take much duration due to criticality of environmental aspects as explained above. To counter this the closed-loop PSP should be promoted considering the lesser forest, environmental and R&R impact.

Timely Execution of Projects and Tender Timelines

The timeline for commissioning of PSP is plays a critical role in achieving the ambitious target set by GoI. Also, the recent tenders issued and concluded by various authorities for stationary storage, for assured peak power supply requirement or Round the Clock Supply (RTC), has commissioning timelines of 18 or 24 months. Whereas as some of the PSP projects are under construction and some are still at survey and investigation stage and may take 4-5 years to come in full operation mode. This delay in commissioning of projects will dilute the objective of tender and may not achieve the desired result. Future tenders should be formulated considering these aspects to meet the desired objective.

17 Report on Optimal Generation Capacity Mix for 2029-30.

Realistic PSP targets and Techno-commercial Assessment

Considering the important aspects involved in evaluation of PSP and the timelines required for its execution, it is important to set realistic targets. PSP requires lot of investment and as seen in mentioned above, most of the projects have significant cost overrun due to several reasons such as long time for obtaining environmental and forest clearance, poor geology, local agitation, etc. Hence, evaluation of techno-commercial assessment should be taken into consideration with complete due diligence to avoid the cost overruns.

Consideration of Technological Advancements for Future Projects

PSPs can be used for varied range of application such as peak shaving, ancillary service application, black start reserve, etc. Considering the huge potential in India and with the technological advancement, PSP can be developed for small capacity (1-10 MW or 200 MW) which will have lesser execution timelines and can play important role in supporting energy storage applications which will suffice the intended requirements.

Summary

About India Energy Storage Alliance (IESA)

India Energy Storage Alliance (IESA) is a leading industry alliance focused on the development of advanced energy storage, green hydrogen, and e-mobility technologies in India. Founded in 2012, by Customized Energy Solutions (CES), IESA's vision is to make India a global hub for R&D, manufacturing, and adoption of advanced energy storage, e-mobility, and green hydrogen technologies. The alliance has been at the forefront of efforts seminal in shaping an enabling policy framework for the adoption of energy storage, electric mobility, green hydrogen, and emerging clean technologies in India. With close to a decade of experience, IESA provides its member network a holistic eco-system to network and grow their business in India and world-over by providing in-depth analysis of the market, facilitating dialogue between industry and government stakeholders, and providing the latest skill-development training. Over the years, IESA has launched several initiatives that support its member companies to stay ahead of the curve. IESA is a proud network of 170+ member companies, encompassing industry verticals from energy storage, EV manufacturing, EV charging infrastructure, green hydrogen, microgrids, power electronics, renewable energy, research institutes and universities, and cleantech startups.

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Notes

IESA Members Network

LC

Amara Raja (Gotta be a better way), Customized Energy Solutions (Analyze · Simplify · Implement), epsilon advanced materials, exicom power systems, Exide Industries Limited, L&T Power, Livguard energy unlimited, nexcharge (Exide Leclanche Energy Private Limited), PRIMET Precision Materials

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