SAARC Webinar
on
“Pumped Storage Hydropower: Opportunities and Challenges in SAARC Region”

Potential, Opportunities and Challenges of Pumped Storage Hydropower Technology

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Energy Transition

- There is a paradigm change in Power System operation now with the large scale variable renewable energy (RE)

- In the past, fully controllable power generation was following non-controllable load demand. now with renewable energy sources, power generation is no longer fully controllable.

- The variability of RE resources due to characteristic weather fluctuations introduces uncertainty in generation output on the scale of seconds, hours, and days and needs adoption of grid scale energy storage technologies to complement these sources. .

Drivers for energy storage

- **Global movement toward renewables:** Support for renewable energy and emissions reduction, renewable energy (solar and wind) is variable and intermittent.
- **Cost and performance improvements:** Particularly relating to lithium-ion batteries, driven by expanding electric vehicle markets and related manufacturing economies of scale, costs are dropping while performance is improving.
- **Grid modernization**: Grid modernization efforts, including the transition to smart grids. EV charging reducing the peak
- **Participation in wholesale electricity markets:** help balance the grid and improve power quality, wholesale market structure to provide capacity and ancillary services.
- **Financial incentives:** Financial incentives for storage.
- **Phase-outs of feed in tariffs or net metering**
- **Self-sufficiency:** Motivations for independence from utilities, resiliency, and technical curiosity
- **National policy:** Many countries are turning to renewable energy storage to reduce dependence on energy imports, enhance the reliability and resiliency of their systems, and move toward environmental and de-carbonization targets.

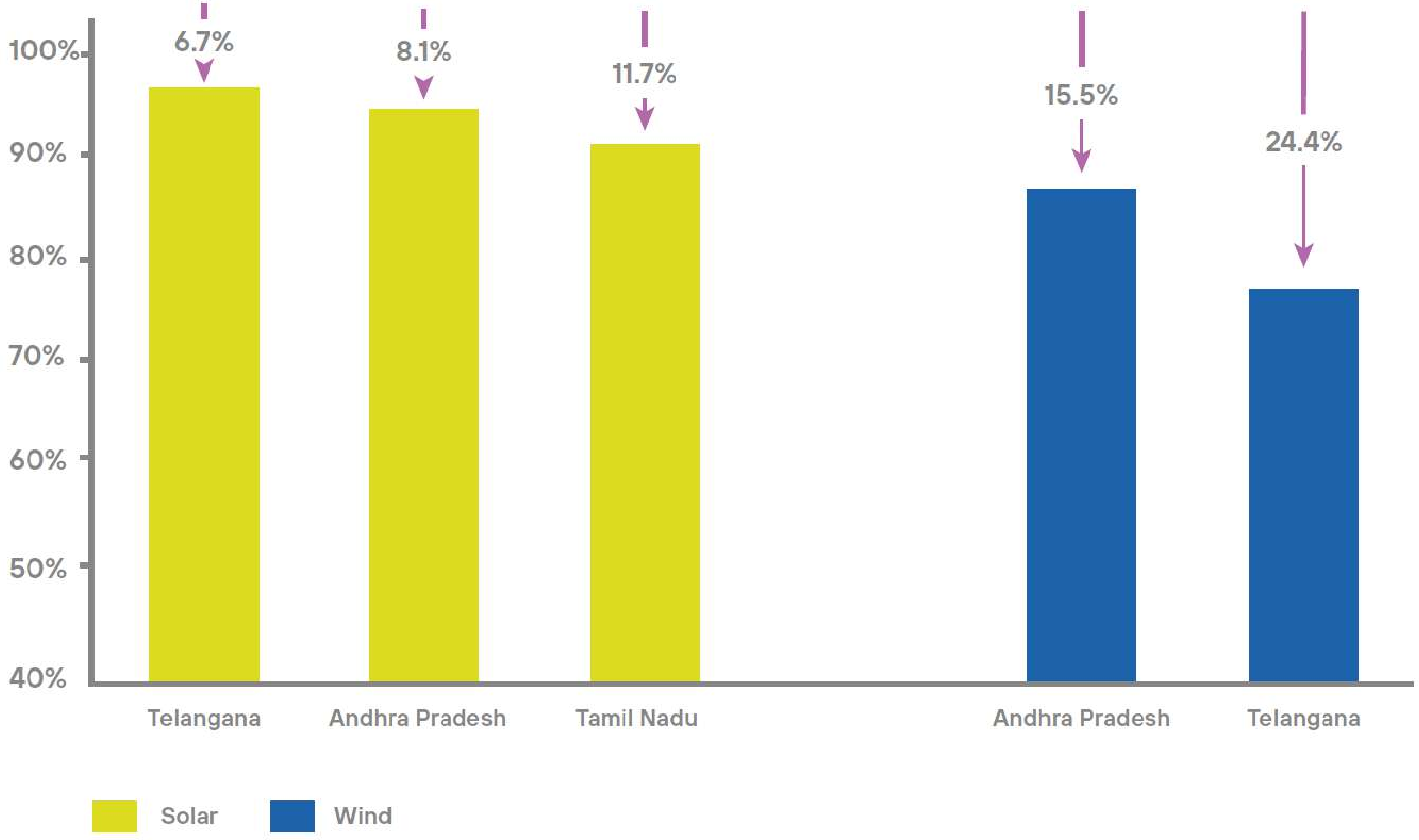
Drivers for energy storage

- The grid infrastructure (generation, transmission, and distribution) is sized for infrequent peak needs and therefore most assets are under-utilized most of the time.
- Energy storage can support peak load reduction to provide significant cost reduction opportunity to electricity customers.
- Utility asset infrastructure is aging and peak load reduction may extend asset life and offer opportunity to consider investment in new technologies.
- Peak plants are only used a fraction of hours per year and energy storage is being considered as peaking capacity in generation planning.

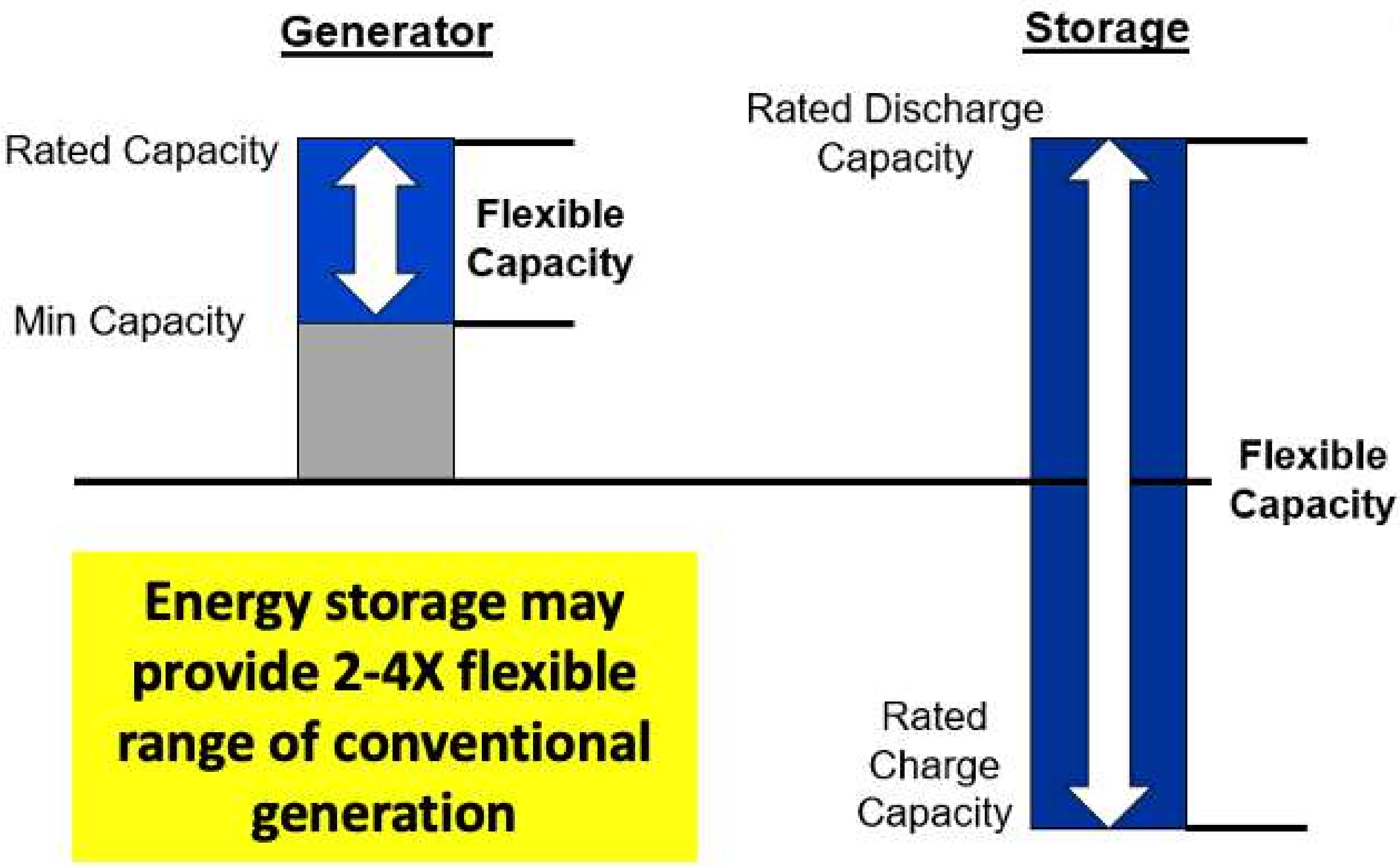
Energy Storage Utilization Across the Grid

- **Capacity Resource:** to provide power that is reliable and firm, so that it can be dispatched when needed.
- **Flexibility Resource:** Energy storage has the ability to increase (charge), or decrease (discharge), the total load on the grid at different times very quickly.
- **Backup Resource:** reservoir for energy used when it is needed.
- **Power Quality Resource:** to affect the voltage or the VARs at a particular point on the grid.

Why storage- To avoid VRE Curtailment



Source: TATA Cleantech Capital Limited, Research and Posoco, Renewable Integration and Curtailment: Causes, Solutions and Impact on Project Bankability, Nov 2020

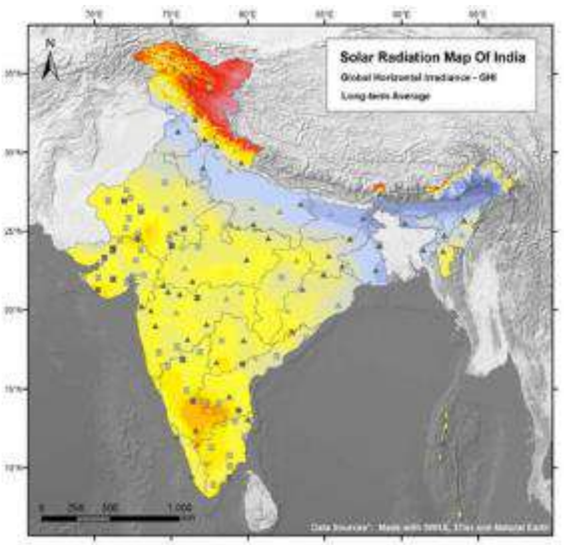

Generator
Storage
Rated Capacity
Min Capacity
Flexible Capacity
Rated Discharge Capacity
Flexible Capacity
Rated Charge Capacity
Energy storage may provide 2-4X flexible range of conventional generation

Need for long duration energy storage

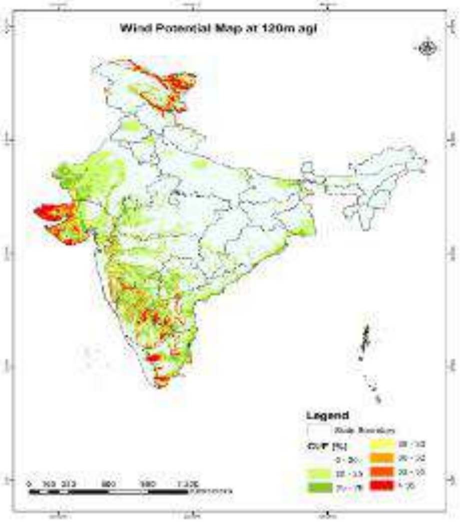
- VRE drought events, longer than 8 hours, are already happening
- The magnitude / impact is likely to increase in future due to climate change
- Resources adequacy measures will need to evolve from current standards to ensure enough capacity to meet energy needs over a period of time instead of capacity needed to meet peak demand

Clean Energy Transition Underway in India

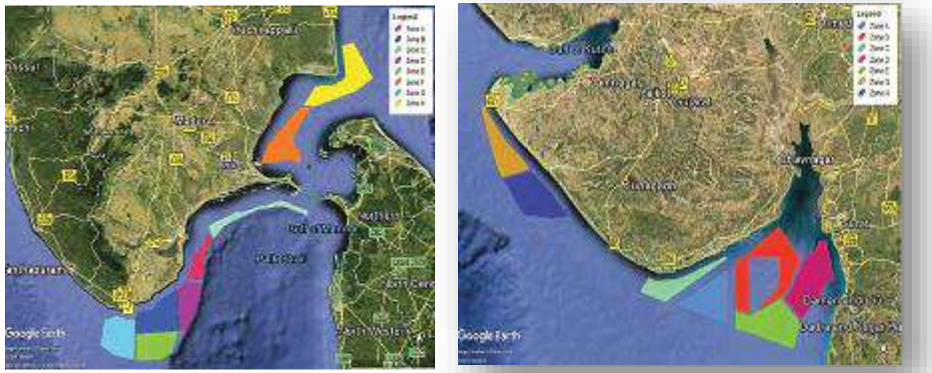
Solar Radiation Atlas



Wind Atlas



Offshore Wind



Solar and wind dominated India's power generation capacity growth in 2022, accounting for 92% of total capacity additions. Coal accounted for only 5%.

Source: ग्रिड-इंडिया GRID-INDIA

Present Total Installed Capacity ~416 GW
Present Renewable Installed Capacity ~ 172 GW
Present Solar + Wind Installed Capacity ~109 GW

Solar Potential ~ 750 GW,
Wind Potential @ 120 mtr agl ~ 700 GW
Off-shore wind potential ~ 70 GW (coast of Gujarat & Tamil Nadu)

RE PENETRATION			
Region/State (FY 2023-23)	Annual VRE Penetration (Energy Terms) (%)	Maximum Daily VRE* Penetration (Energy Terms) (%)	Maximum Instantaneous VRE Penetration (MW Terms) (%)
Rajasthan	14.57	35.81	56.00
Northern Region	10.56	18.36	46.75
Gujarat	15.44	35.80	55.80
Madhya Pradesh	11.01	32.40	53.90
Maharashtra	10.10	23.00	37.21
Western Region	11.03	23.10	35.13
Karnataka	27.52	65.38	132.00
Andhra Pradesh	20.50	58.59	81.00
Tamil Nadu	18.42	50.08	77.00
Telangana	12.17	17.63	49.00
Southern Region	16.91	36.32	61.00
All India	11.01	20.40	31.80

*VRE:Wind and Solar only

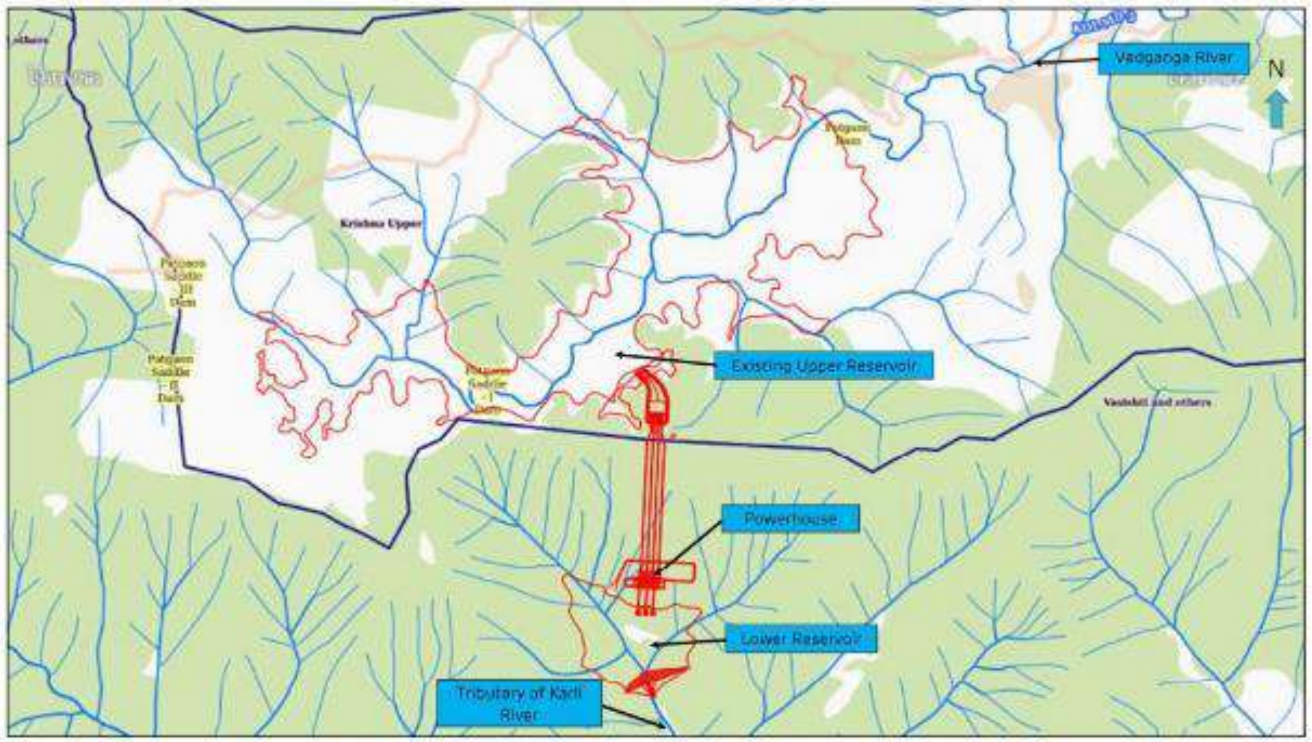
Energy Storage Technologies

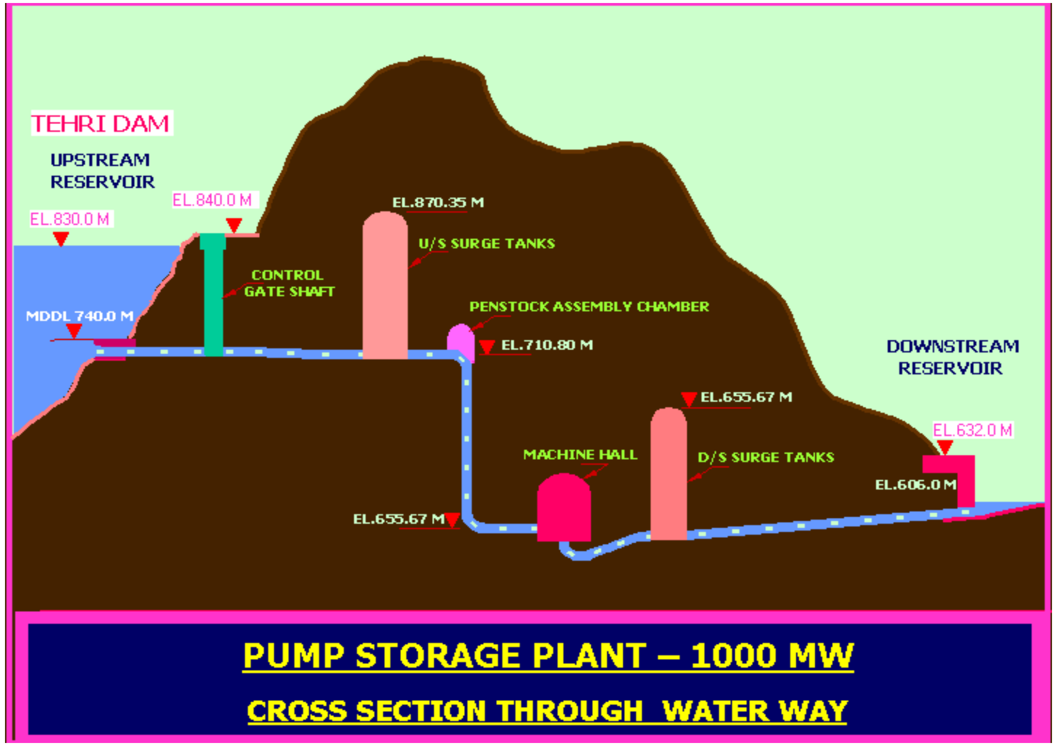
- **Mechanical**
  - Pumped Storage Hydro
  - Compressed Air
  - Solid Gravity
  - Flywheel
- **Electrochemical**
  - Lead-acid
  - Lithium-ion
  - Sodium-Sulphur
  - Sodium-Nickel-Chloride
  - Flow Batteries (Vanadium Redox and Zinc-Bromine)
- **Thermal**
  - Sensible-molten salt
  - Chilled water
  - Latent-ice
  - Phase change materials
  - Thermo-chemical storage
- **Electrical**
  - Supercapacitors
  - Superconducting magnetic coil energy storage
- **Chemical**
  - Power-to-Power (Fuel cells)
  - Power to Gas (Electrolysis)
  - Biofuels

Classification of PSPs

CEA guidelines, June 2023 , **Pumped Storage Schemes** may be classified into **three types:**

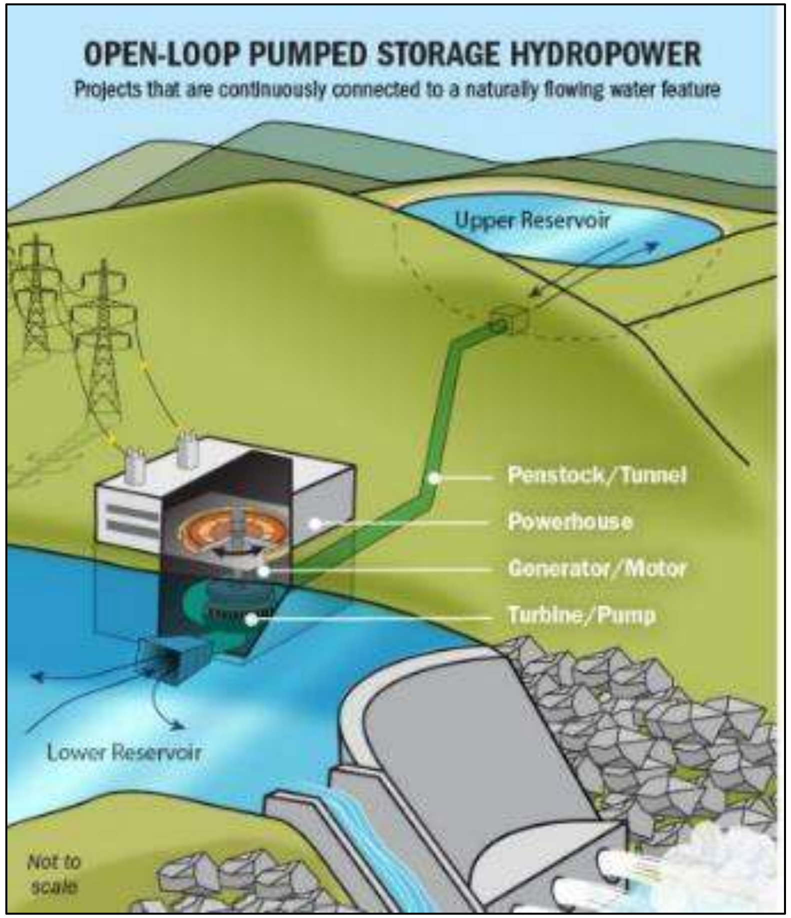
(a) **On stream open loop pumped storage scheme-** <u>Both reservoirs </u>are located on a single or more river/ stream/ nallah.





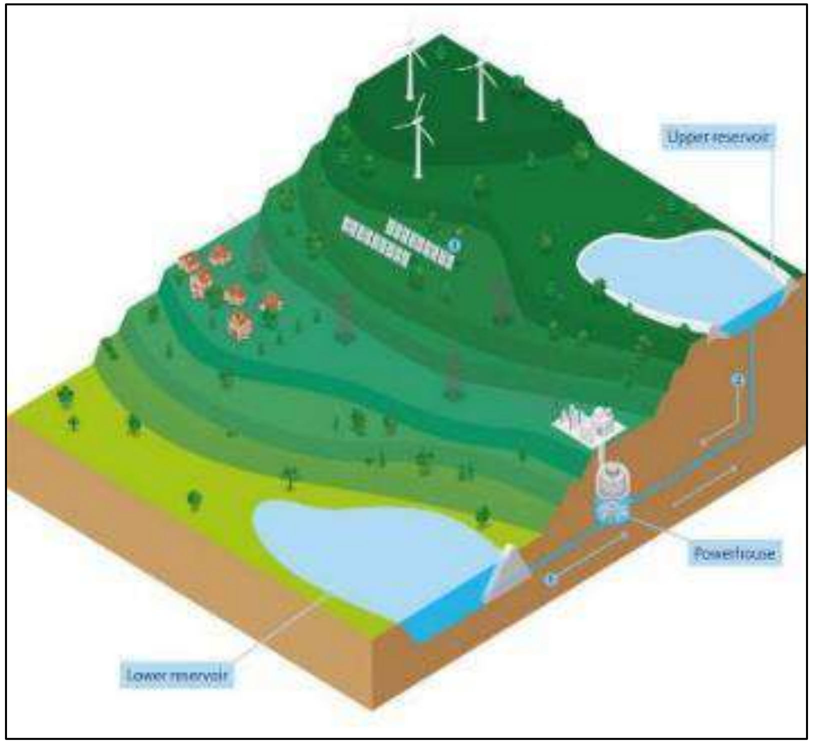
Off-stream open loop pumped storage scheme-

One reservoir is located on river/ stream/ nallah. Other reservoir (off-stream reservoir) is not located on any river/ perennial stream/ perennial nallah.



Off-stream closed loop pumped storage scheme

None of the reservoirs is located on any river/ perennial stream/ perennial nallah



Erzhausen – Pumped Storage, Germany
Outside the Leine River system

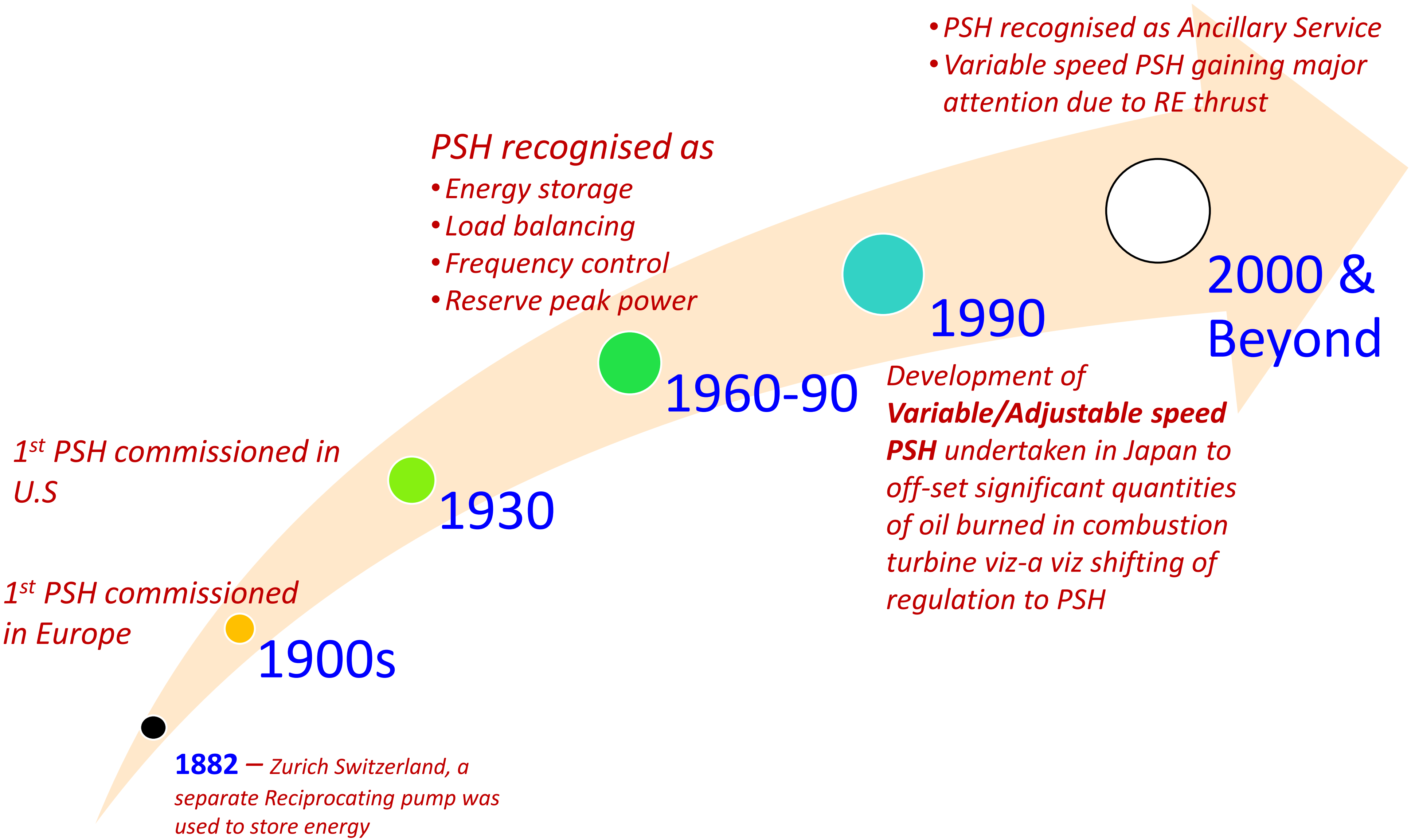
Relevance of PSP in increasing VRE penetration..

Application	Particulars
Time shifting/ storage	▪ Storage of surplus power during off-peak hours and supply of power during peak demand hours.
Ramping Capability	▪ Quick-start and ramping capability of ~200 MW/ min, taking just a few minutes. ▪ Savings in start-up and shutdown costs of thermal plants and steadier operations.
Peak Shaving	▪ PSPs can meet peak demand in a short period due to their high ramping capability ▪ Can enable supply-demand balancing.
Black Start	▪ Utilization of PSPs for energizing the Grid in case of cascaded tripping ▪ The power supply can be made available to the power system within few seconds of a grid blackout

Relevance of PSP in increasing VRE penetration

Application	Particulars
Frequency Response	▪ PSPs can follow frequency within the given margins by continuous modulation of active power and meeting moment-to-moment fluctuations in the system's power requirements
Spinning Reserve	▪ PSP can support in maintaining grid stability in case of unexpected load changes or sudden outages or failure of any generator by facilitating stored energy.
Reactive Power and Voltage Control	▪ PSP can provide voltage control services by rendering reactive power balancing services. ▪ PSP can operate in lead or lag modes to meet the Grid's reactive power requirement. PSP can also work in synchronous condenser mode to improve the system power factor.

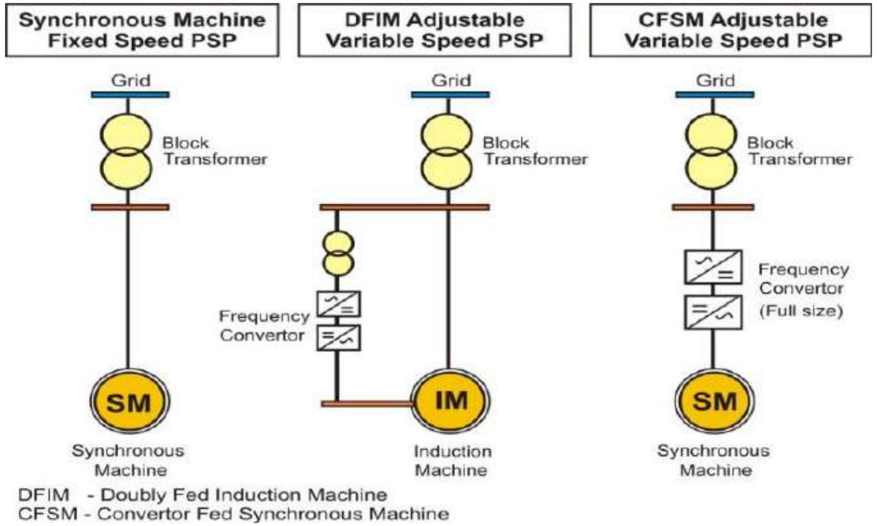
HISTORICAL EVOLUTION OF PSP



Courtsy Prabodh Mallick, Marubeni Co.

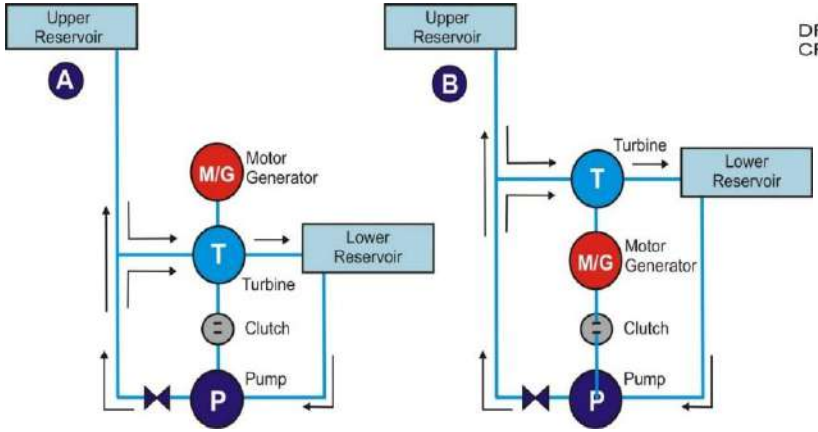
TECHNOLOGICAL DEVELOPMENTS IN PUMPED STORAGE HYDROPOWER

- **Fixed-Speed PSP Technology**
- **Variable Speed PSP Technology**
  - o Doubly fed induction machine (DFIM)
  - o Converter-fed synchronous machine (CFSM)



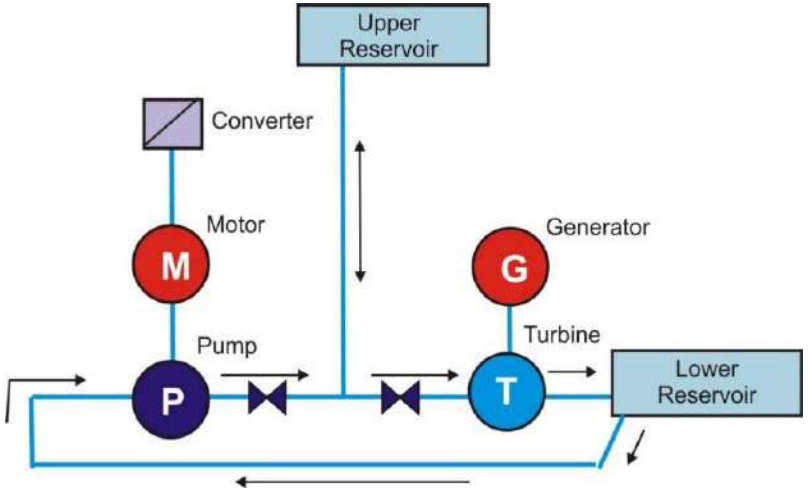
Configurations of fixed-speed and DFIM and CFSM Adjustable variable speed PSP units

- **Ternary PSP Technology**



Ternary PSP plant configurations with Hydraulic Bypass

- **Quaternary PSP Technology**



Quaternary PSP plant configuration with Hydraulic Short Circuit

Overview of South Asia

Country	Total Population (Million)	Total Electricity Installed Capacity (MW)	Hydropower installed capacity (MW)	PSP	Number of large dams
Afghanistan	40.87	661	-497	0	23
Bangladesh	165.00	22,482	230	0	2
Bhutan	0.77	2,343	2,343	0	8
India	1417.20	4,10,339	47,000	4,740	6,138
Nepal	30.30	2,685	2,538	0	8
Pakistan	233.13	40,783	10,612	0	183
Sri Lanka	21.77	5,192	1,827	0	100
Total		**175,293**	**75,203**		
China	1450.00	25,67,330	4,00,000	54,540	24,089
USA	339.00	11,89,492	80,000	22,170	10,158
Japan	124.97	3,18,560	22,538	21,817	3,135

Primary sources of value of energy storage in SAARC countries

Afghanistan	**✓ Import dependency reduction** **✓ Ancillary services** **✓ Production cost reduction** **✓ Resource adequacy**
Bangladesh	✓ Fuel oil displacement ✓ Ancillary services ✓ Production cost reduction
Bhutan	✓ Exports optimization ✓ Regional RE integration
India	✓ Energy time-shifting ✓ System balancing ✓RE integration ✓ Ancillary services ✓ Resource adequacy
Maldives	✓ Fuel oil displacement ✓ Ancillary services ✓ Production cost reduction
Nepal	✓ Exports optimization ✓ Domestic hydro- power utilization
Pakistan	✓ Energy time-shifting ✓ System balancing ✓ RE integration ✓ Ancillary services ✓ Resource adequacy

World wide Pumped storage Hydropower projects

S. No	Country	No of projects			Total Installed Capacity (MW)			ToRemarks
		Operational	Announced	De-commi-ssioned	Operational	Announced	De-commiss-ioned	
1	China	50	26		54,540			Status Aug. 2024 IWP, 2024; GESDB, 2020
2	United States	39	12		22,170	6,950		Offline/ under Repare – 1 Contracted – 2 Status 2023/ GESDB, 2020
3	Japan	41	1	1	21,817	400	30	Status 2024/ GESDB, 2020
4	Germany	29			9,379			Offline/ under repair – 1 Status 2023/ GESDB, 2020
5	Italy	18	1		7,156	572		Contracted – 1 Status 2023/ GESDB, 2020
6	France	10		1	5,812		82	Status 2023/ GESDB, 2020
7	Spain	22			5,650			Status 2023/ GESDB, 2020
8	India	8	45		4,746	61,060		As on 30.6.2024 (CEA, 2024) Under Construction – 5; DPR Concurred – 3 Under investigation – 37,
9	Israel	1	1		300	344		Status 2023
10	Brazil	1			20			Status 2023/ GESDB, 2020
	Total	341	100	2	180,286	79,122	112	

Factors Enabling Development of storage globally

Country / Factors	China	Japan	Australia	Germany	USA
Policy push to be carbon neutral and construct storage for the absorption of RE	Yes	Yes	Yes	Yes	Yes
Option with consumers for ToU at low-voltage level	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Status of the ancillary market – frequency, network, black-start, and others	Evolving	Evolving	Operational	Operational	Operational
Identity of storage in markets	**Grid Asset**	**Generating Asset**	**Bi-Directional Asset**	**Generating Asset**	**Bi-Directional Asset**
Energy arbitrage opportunities	Low	Behind the meter	High	High	High
Tariffs/ Fixed rates	Fixed Tariff	Internal Accounting	Market Based	Market Based	Market Based
Grants/ subsidies to develop storage / grid fee incentives	**Available**	**Available**	**Available**	**Not Available**	**Not Available**
The mandate to maintain reliability and reduce RE curtailment	Initiated	Available	Available	Available	Available
The mandate for priority access to VRE in case of oversupply	Not Applicable	Applicable	Not Applicable	Applicable	Not Applicable

Erzhausen – Pumped Storage, Germany

Outside the Leine River system

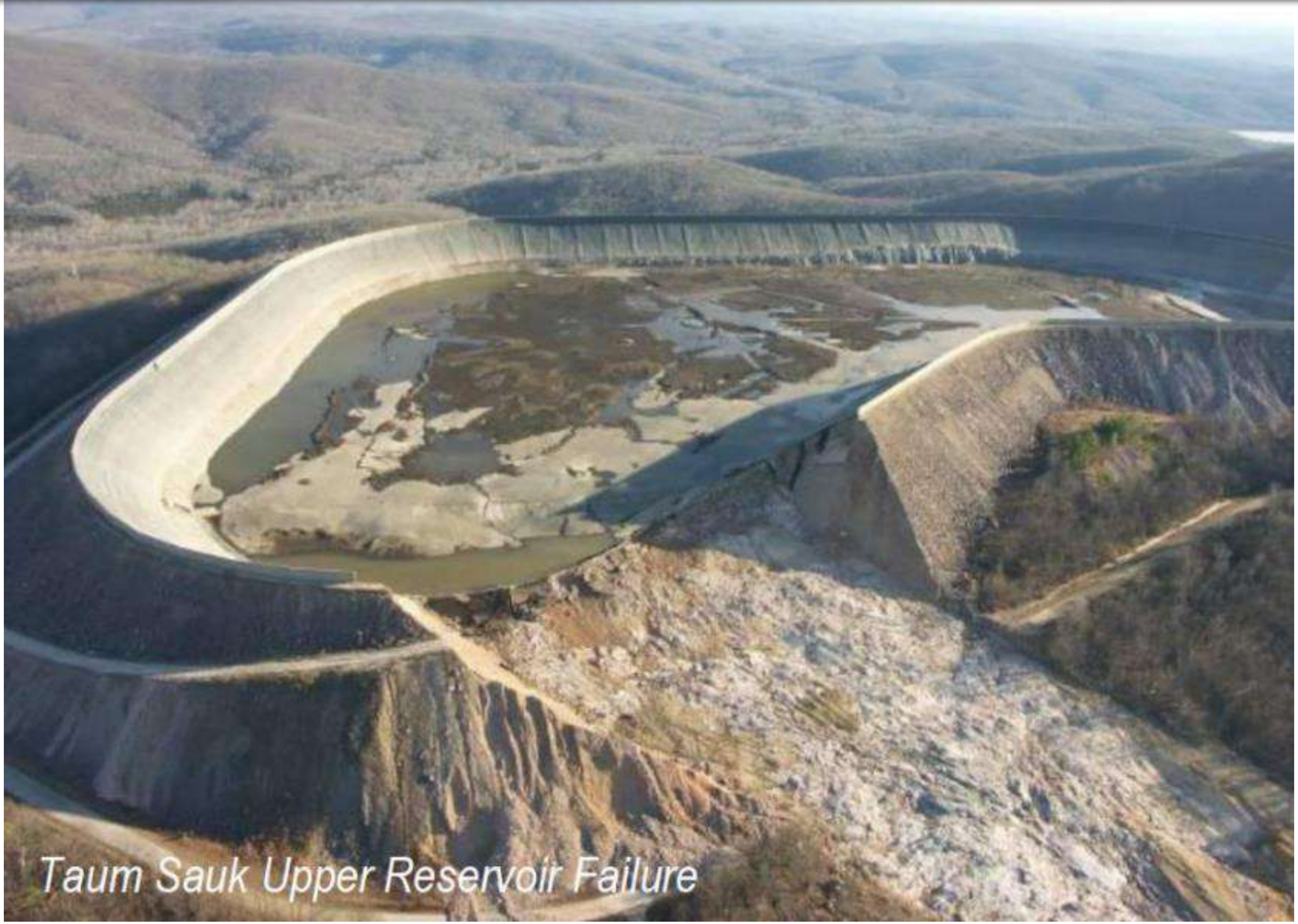
Goldisthal pumped-storage power plant, Germany (1053 MW)

The Porąbka-Żar pumped-storage power plant, Poland

The upper reservoir - 250 m x 650 m.
The total volume of the reservoir is 2.3 million m3.

Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963

Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963, failed 2005, restarted 2010



Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963

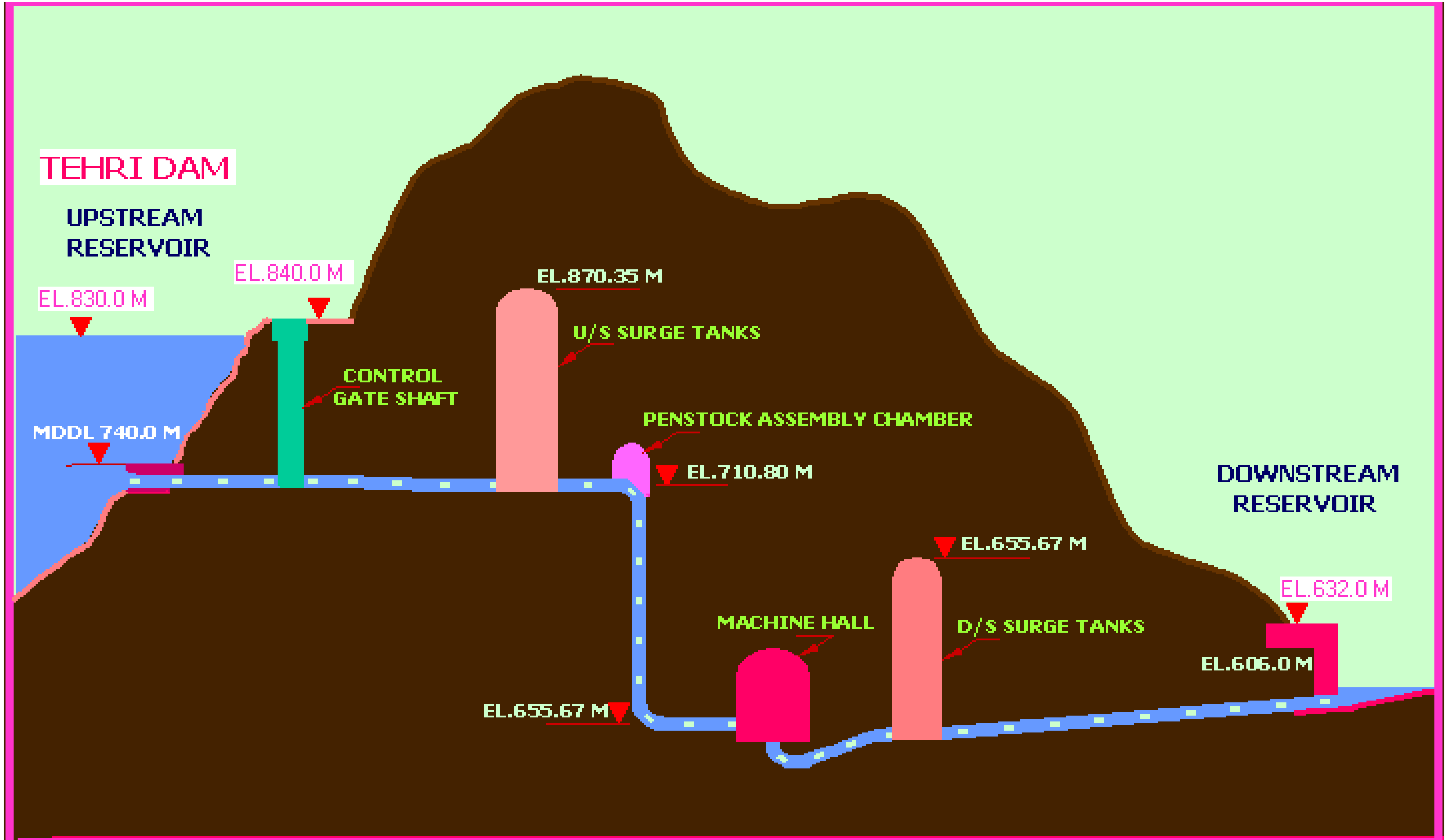
PSP Key Facts

General Performances	**5 to 500 MW**	Output/Input
	> 8 hours full load	Storage capacity
	10 to 2000 m.	Head Range
	> 80%	Cycle efficiency
Reaction Time	**~ 15 s.**	50% to 100% Generation
Ancillary Services	**25% to 100%**	Production adjustment range
	70% to 100%	Pumping power adjustment range (Variable speed machines)

Status Of Indian PSP Development In India (Sept 2024)

Status	On River		Off-River		Total	
	No of Schemes	Installed Capacity (MW)	No of Schemes	Installed Capacity (MW)	No of Schemes	Installed Capacity (MW)
In operation	6	3,305.6	-	-	6	3,305.6
Not working in Pumping mode	2	1,440	-	-	2	1,440
Under Construction	3	2,850	1	1,200	4	4,050
Construction held-up	1	80	-	-	1	80
Concurred by CEA	1	1,000	-	-	1	1,000
Under S & I	6	7,440	38	52,610	44	60,050
Total	19	16,115.6	39	53,810	58	69,925.6

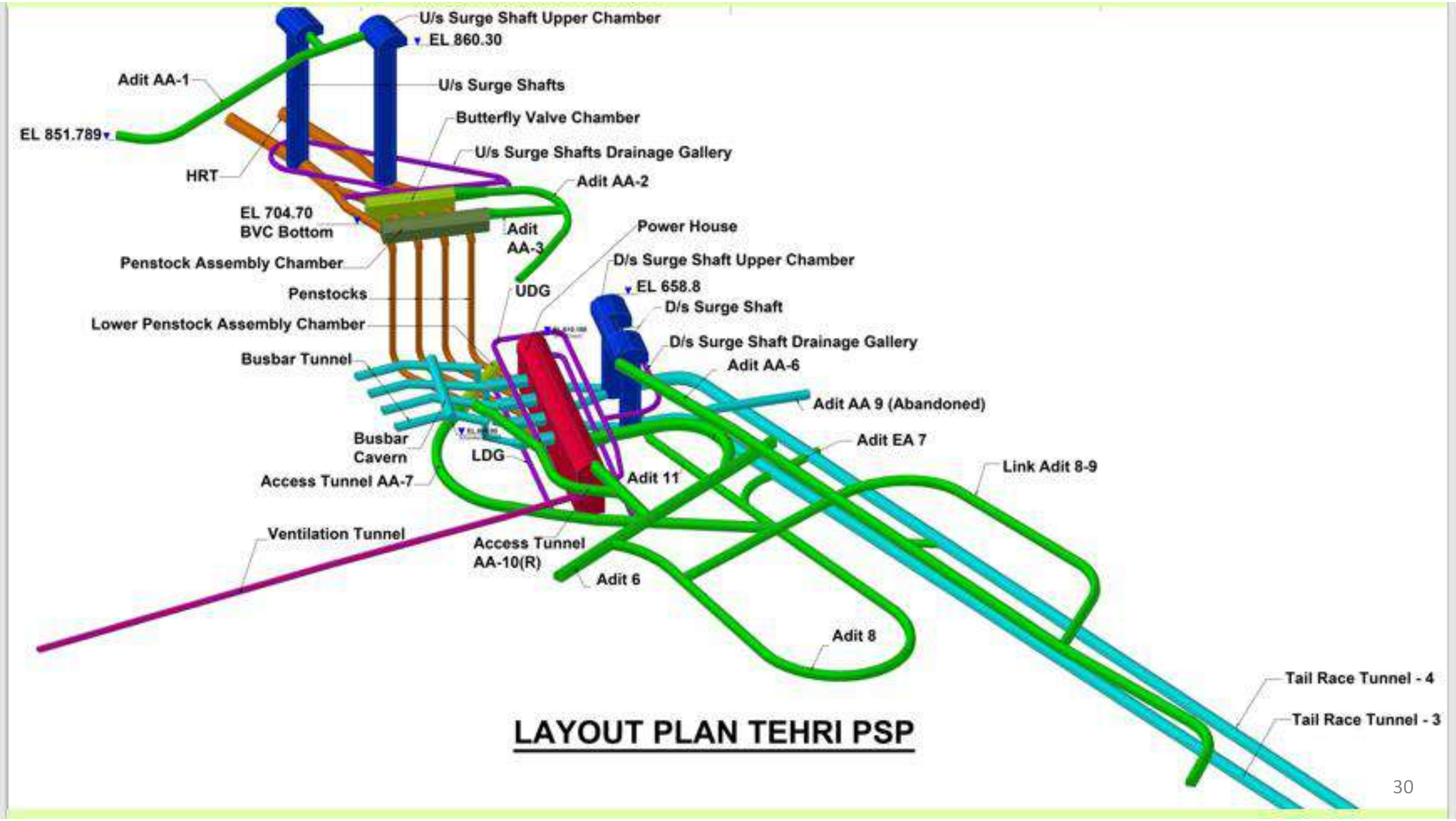
Source: CEA (2024)



PUMP STORAGE PLANT – 1000 MW

CROSS SECTION THROUGH WATER WAY

TEHRI PSP LAYOUT (1000 MW)



Guidelines for Promotion of PSPs

- Allotment of project sites:
  - On nomination basis to CPSUs and State PSUs
  - competitive bidding
  - Tariff Based Competitive Bidding
  - Self – Identified off-stream
- Timelines for Start of Construction work after award – 2 yrs
- No Upfront Premium for Project Allocation
- Market reforms
- Financial Viability
- Taxes and duties
- Exemption from Free Power obligation
- No Local Area Development Fund
- Support through concessional climate finance.
- Speedy clearances for off river PSP and shorting period
- Sovereign green bonds for mobilizing resources for PSPs utilizing RE
- Central Electricity Authority (CEA)- optimal mix report by the year 2030 envisages about 18 to 25 GW PSP 22 to 49 GW of BESS under different scenario - On river 21 GW, off river 57 GW
- **With these initiative and guidelines, 52 GW – 40 projects under surveys and clearances**

F. No. 15-14/9/2022-H-II(Part)
भारत सरकार / Government of India
विद्युत मंत्रालय / Ministry of Power
Shram Shakti Bhawan, Rafi Marg
New Delhi - 110001, Tel: 011-23705841

Dated: 10th April, 2023

To

1. The Secretaries of all the Ministries / Departments of Government of India
2. The Chief Secretaries of the State Governments & Union Territories
3. Principal Secretaries (Energy / Power) - All the State Governments & UTs
4. CMDs - PGCIL, NTPC, NHPC, SJVN, THDC, NEEPCO, Grid India, PFC, REC
5. The Chairman - BBMB, DVC

Sub: Guidelines to promote development of Pump Storage Projects (PSP) - reg.

Sir / Madam,

This has reference to Ministry of Power's letter of even number dated 15th February, 2023 vide which the draft PSP Guidelines were circulated for comments / suggestions. Subsequently, a webinar was held on 23rd February 2023 on the topic of "Green Growth", wherein, inter alia, suggestions were also received on the framework for Pumped Storage Projects in the country.

2. Based on the comments / suggestions received from the stakeholders, the Guidelines to promote development of Pump Storage Projects in the country have been finalized. A copy of the PSP guidelines is enclosed herewith for information and necessary action.

This issues with the approval of Hon'ble Minister of Power and New & Renewable Energy.

Yours sincerely,

10/4/23
(Mohd. Afzal)
Joint Secretary
Email: afzal_mdp@nic.in
/hydro2-mop@gov.in
Tel.: 011-23714000

Copy to:-

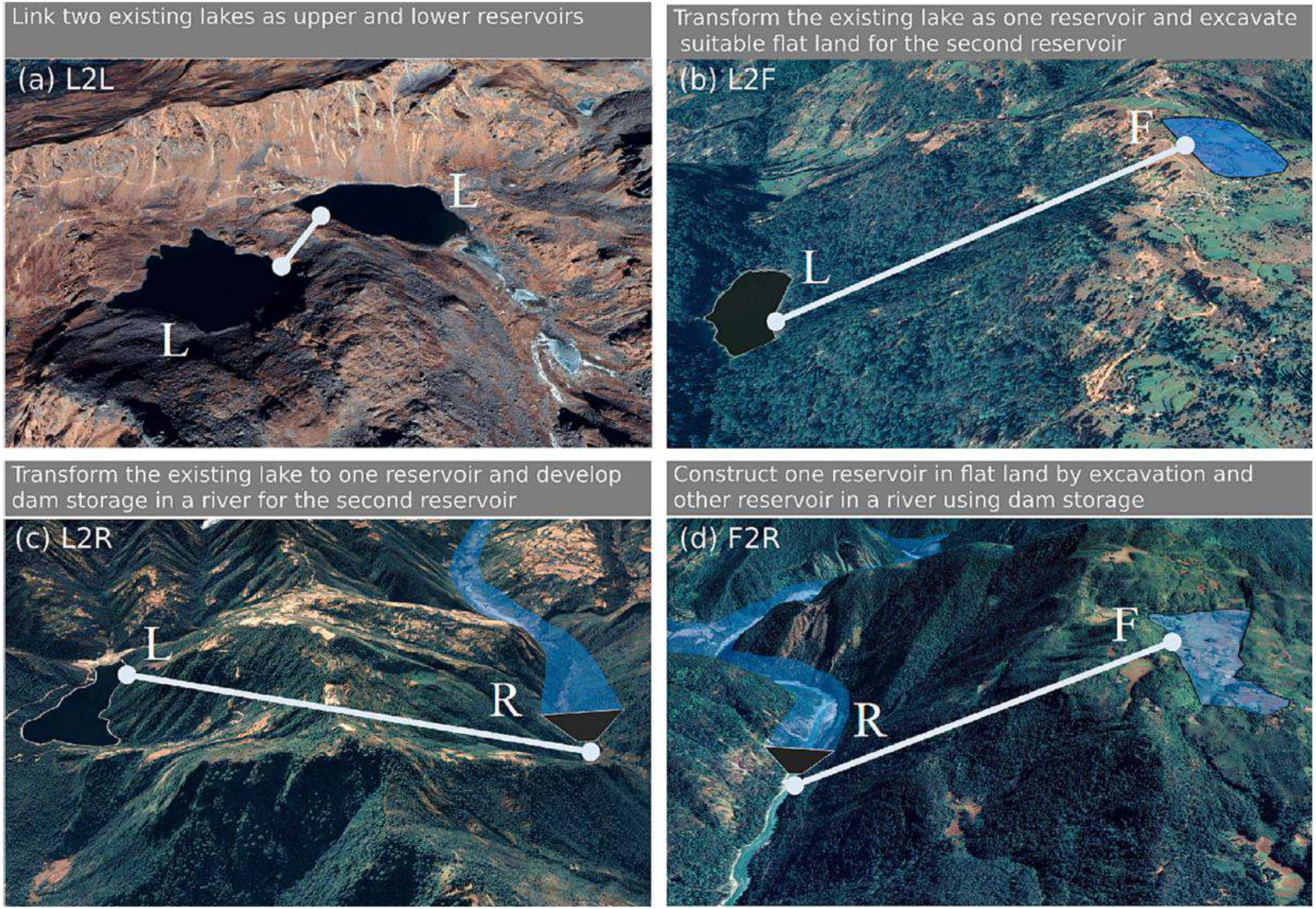
1. CEO, NITI Aayog
2. Secretary, CERC / All SERCs
3. Chairperson, CEA
4. Chairperson, CWC

Copy also to:

In-charge, NIC Cell, MoP: with request to upload the Guidelines on the website of the Ministry of Power.

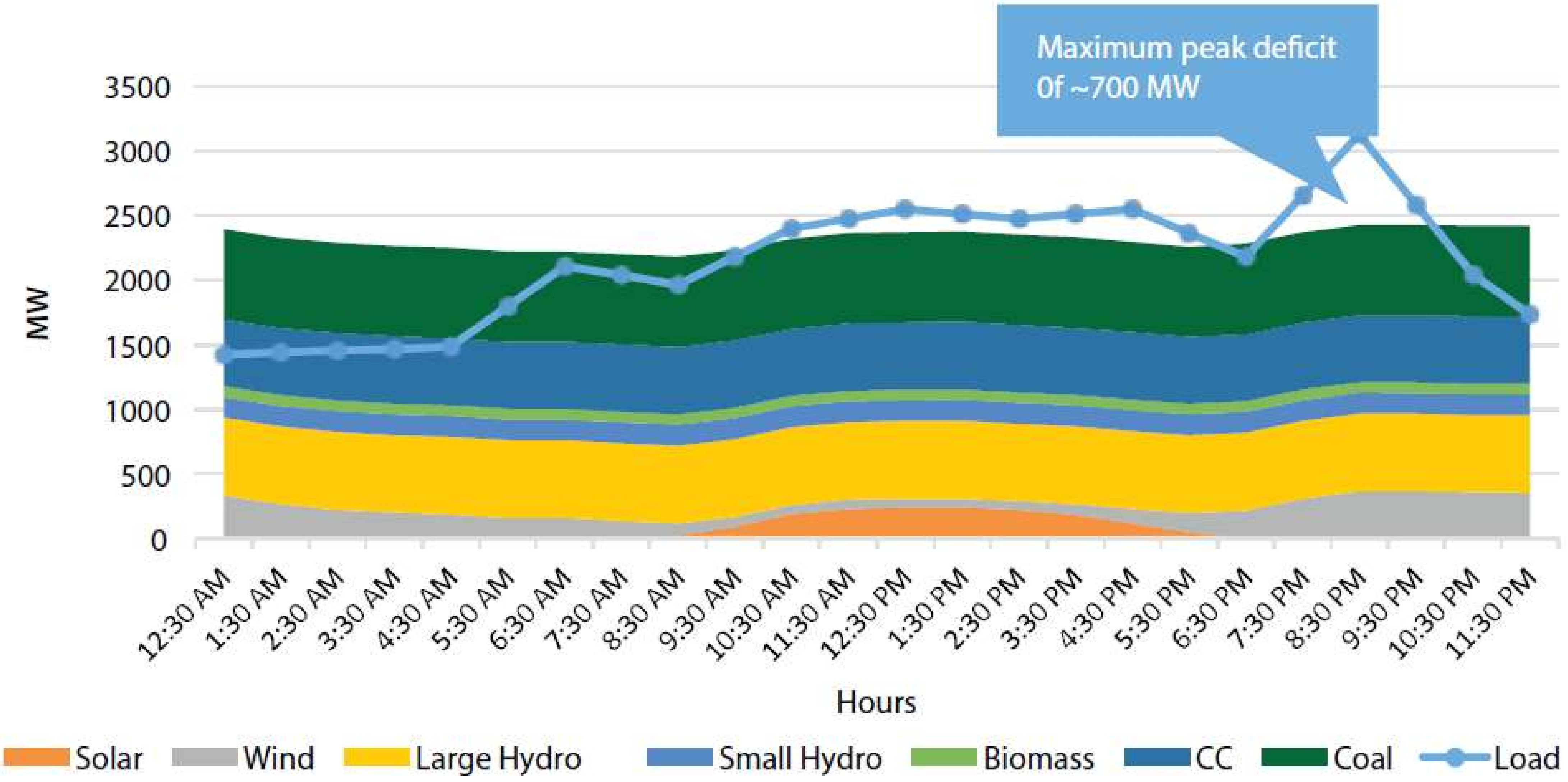
Nepal

Reservoir configurations investigated

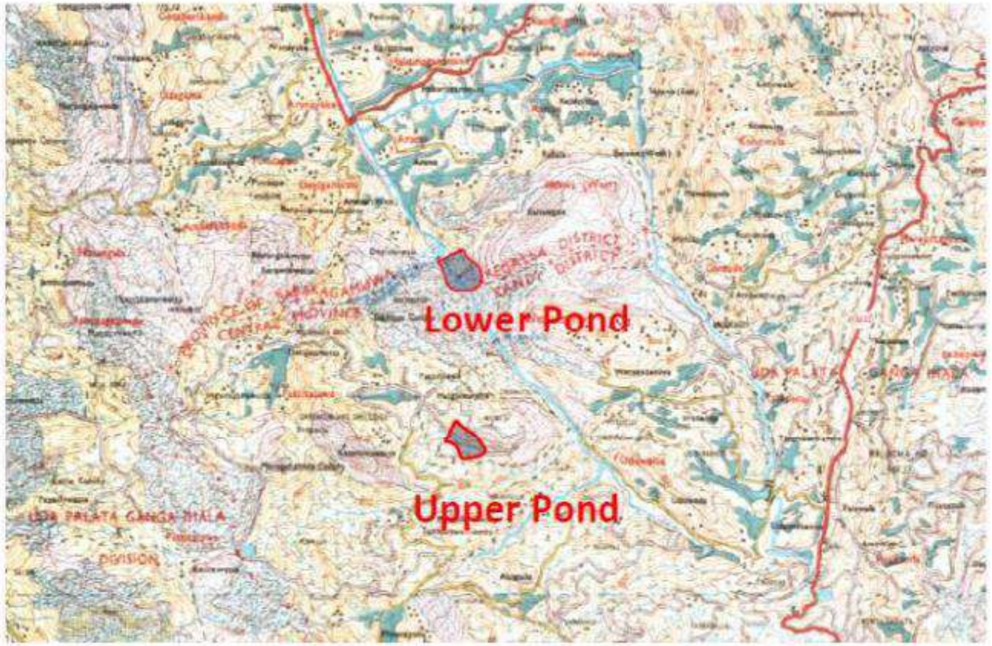


Sri Lanka's Daily Electricity Load Curve

2020 - Typical daily demand-supply scenario



Maha-Oya Site, Sri Lanka



Suitable sites for Pumped Storage Power plant

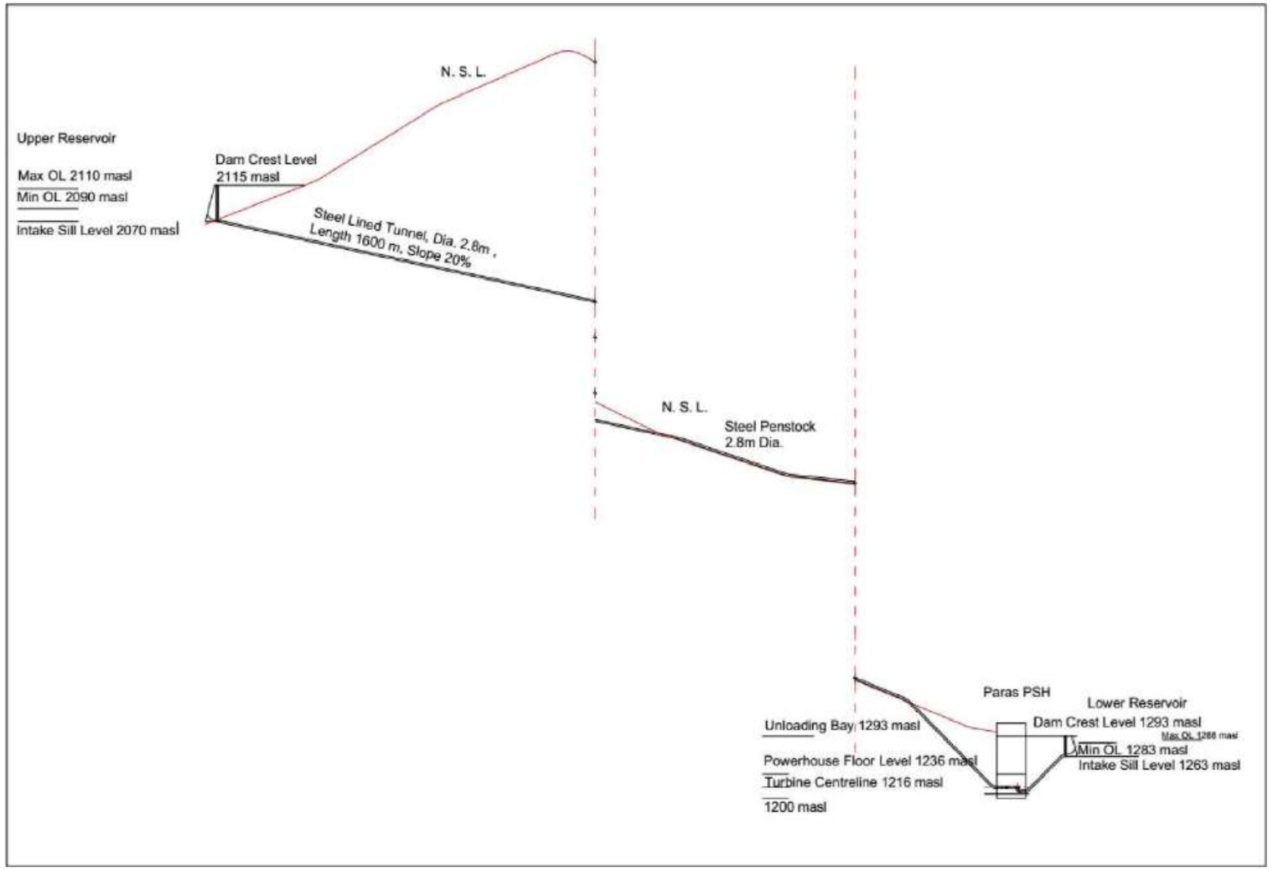
No.	Name	Project Features				1:50,000 Map No.
		Capacity (MW)	Length L (m)	Height H (m)	Ratio L/H	
1.	Kiriketi I	500	1,180	770	1.5	76
2.	Kiriketi II	500	2,300	720	3.2	76
3.	Kiriketi III	500	2,700	1017	2.7	76
4.	Halgran	500	3,500	575	6.1	62
5.	Maha	500	3,750	520	7.2	61
6.	Gurugal	400	4,600	620	7.4	61
7.	Dambagasta	300	3,030	440	6.9	68
8.	Agra	300	3,330	420	7.9	68

Wewathenna – Victoria Site

Potential Water Resources for PHS Plant

Pakistan

- The system comprises a lower reservoir (reservoir of Balakot HP will be utilized), a powerhouse, electrical–mechanical equipment, an upper reservoir, and a connecting waterway.
- The upper reservoir has a maximum operation level of 2110 masl, a steel-lined tunnel with a length of 1600 m and diameter of 2.8 m is proposed whereas it will connect to open penstock afterward to connect with the proposed PSH.
- The proposed PSH will be connected to the Balakot reservoir, and it will serve as a lower reservoir for PSH.
- Paras PSH (Pakistan) is planned a weekly storage scheme.



Longitudinal profile

New Technology layouts for PSP

Further PSH Potential

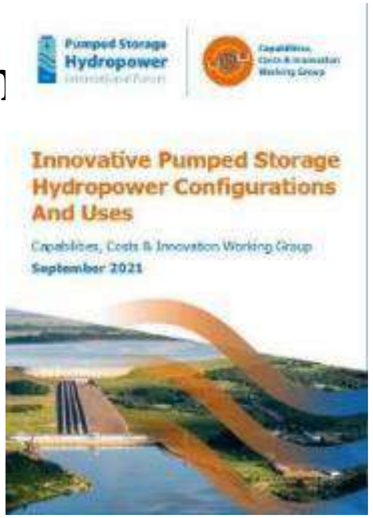
- Off-river Pumped Hydro Energy Storage
- Geo-mechanical Pumped Storage
- Seawater Pumped Storage System
- Underground Pumped Hydroelectric Storage (UPHS)

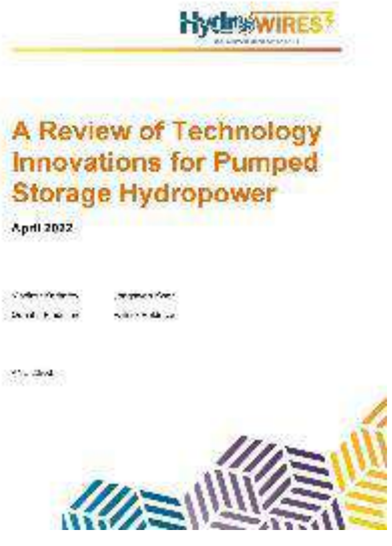
Retrofitting and Upgrading

- Retrofitting existing hydropower reservoirs
- PSH on open pit mine and underground mine
- Obermeyer Pump Turbine

Hybrid Systems

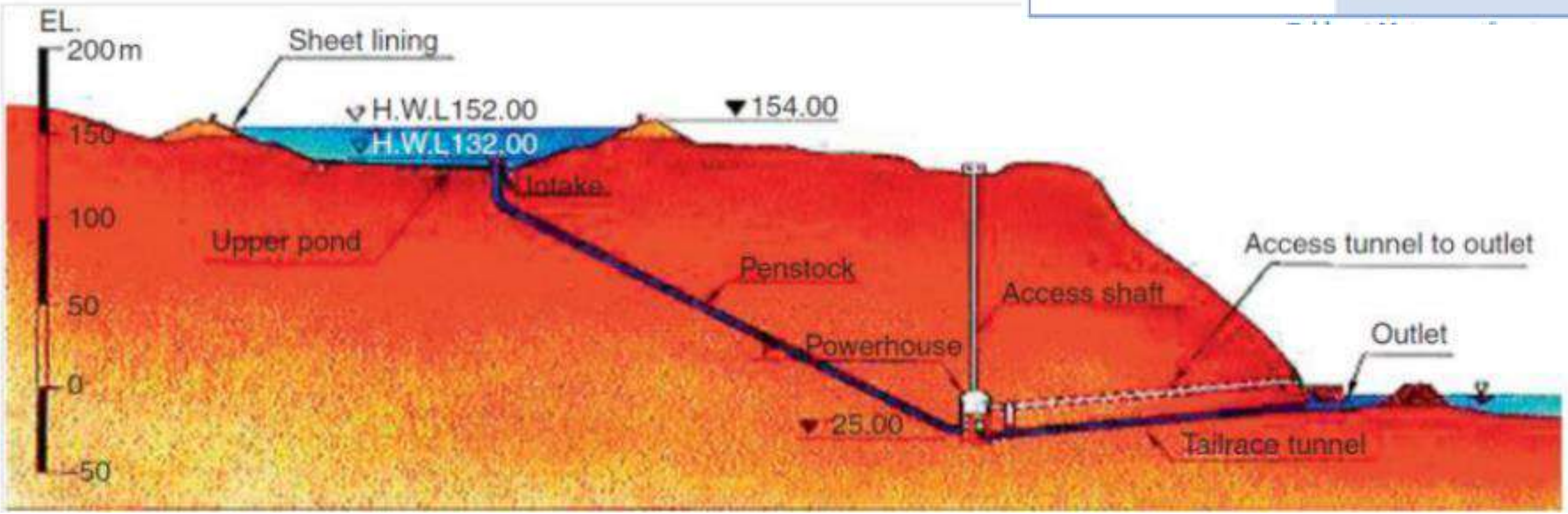
- Hybrid Renewable Modular Closed-Loop Scalable PSH System
- Hybrid Pumped Storage Hydropower-Battery Storage
- Integrated Pumped Hydro Reverse Osmosis System
- Solar PV hybrids
- Thermal Pumped-Storage Hydropower





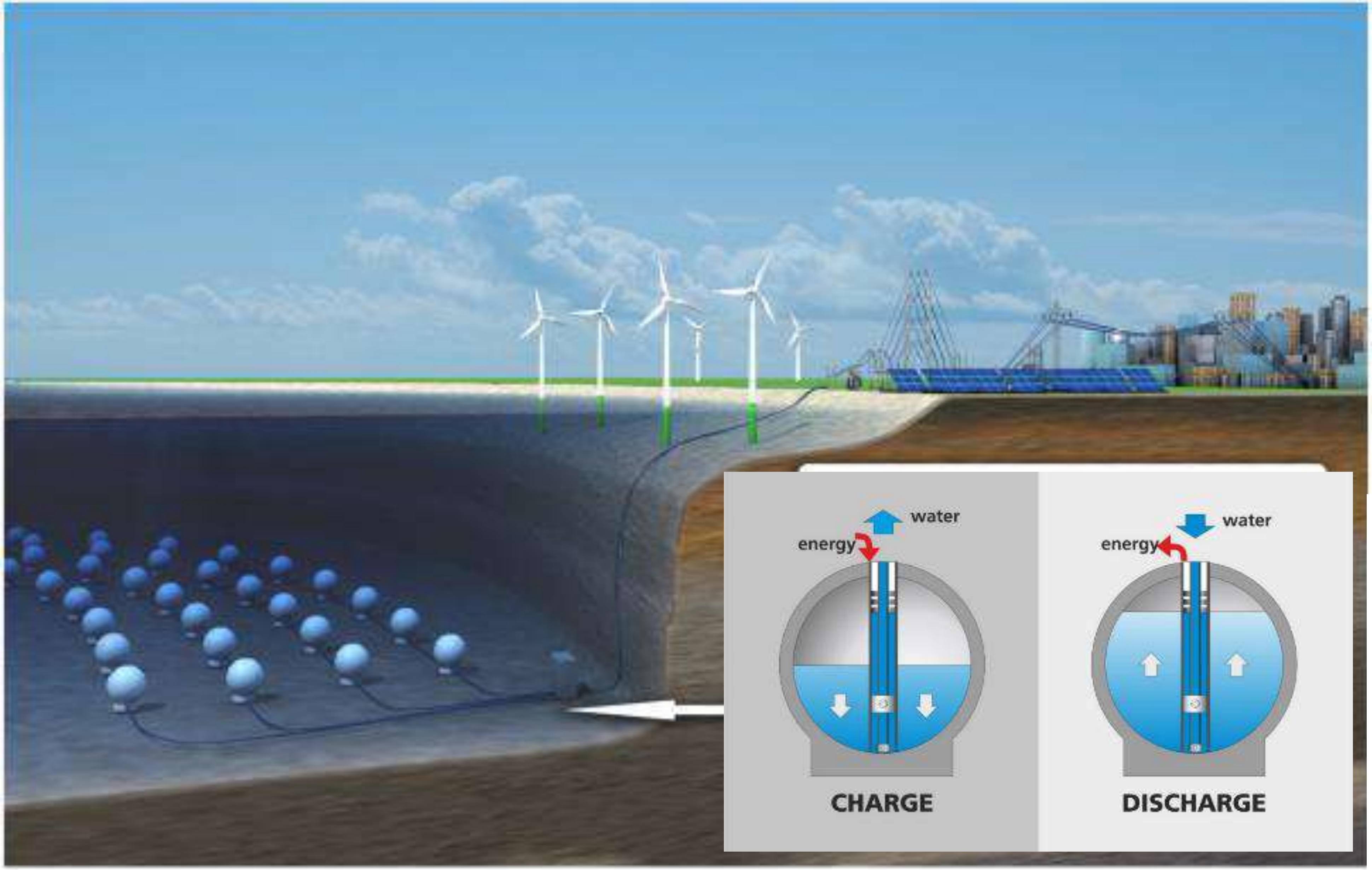
Okinawa Seawater Based PSP, Japan

Okinawa Yanbaru Power Plant		Specification
Power plant	Max. Output	30 MW
	Max. Discharge	26 m³/s
	Effective head	136 m
Upper regulating pond	Type	Excavated type, Rubber sheet-lined
	Max. embarkment height	25 m
	Crest circumference	848 m
	Max. Width	251.5 m
	Total storage capacity	0.59x106 m³
	Max. depth	22.8 m
Waterway	Penstock	Inside dia. 24 m Length 314 m
	Tailrace	Inside dia. 27 m Length 205 m

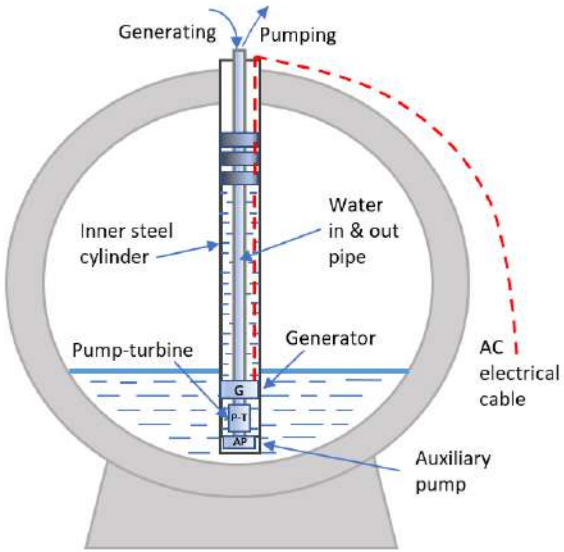


Originally built as a testing facility, obtained beneficial results from more than 10 years of study, and closed the plant was made after considering every aspect of the operation.

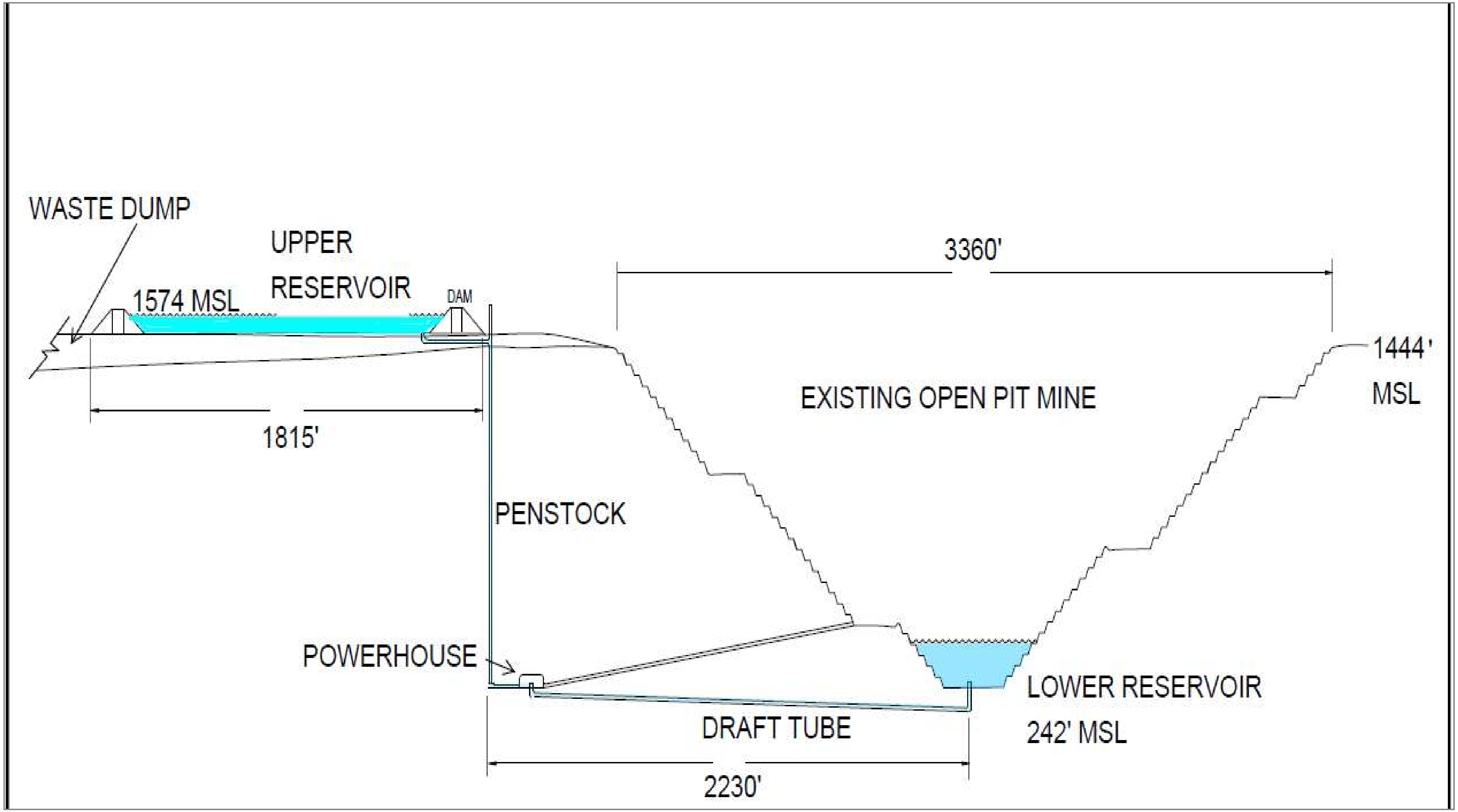
Underwater PHS (Stensea Project)



30-m dia spheres anchored at the seabed each of 20 MW



PSH IN DISCARDED MINE SITES



A conceptual layout of a PSP in abandoned Open-pit mine

Base image: Ranger Uranium Mine
Northern Territory Australia

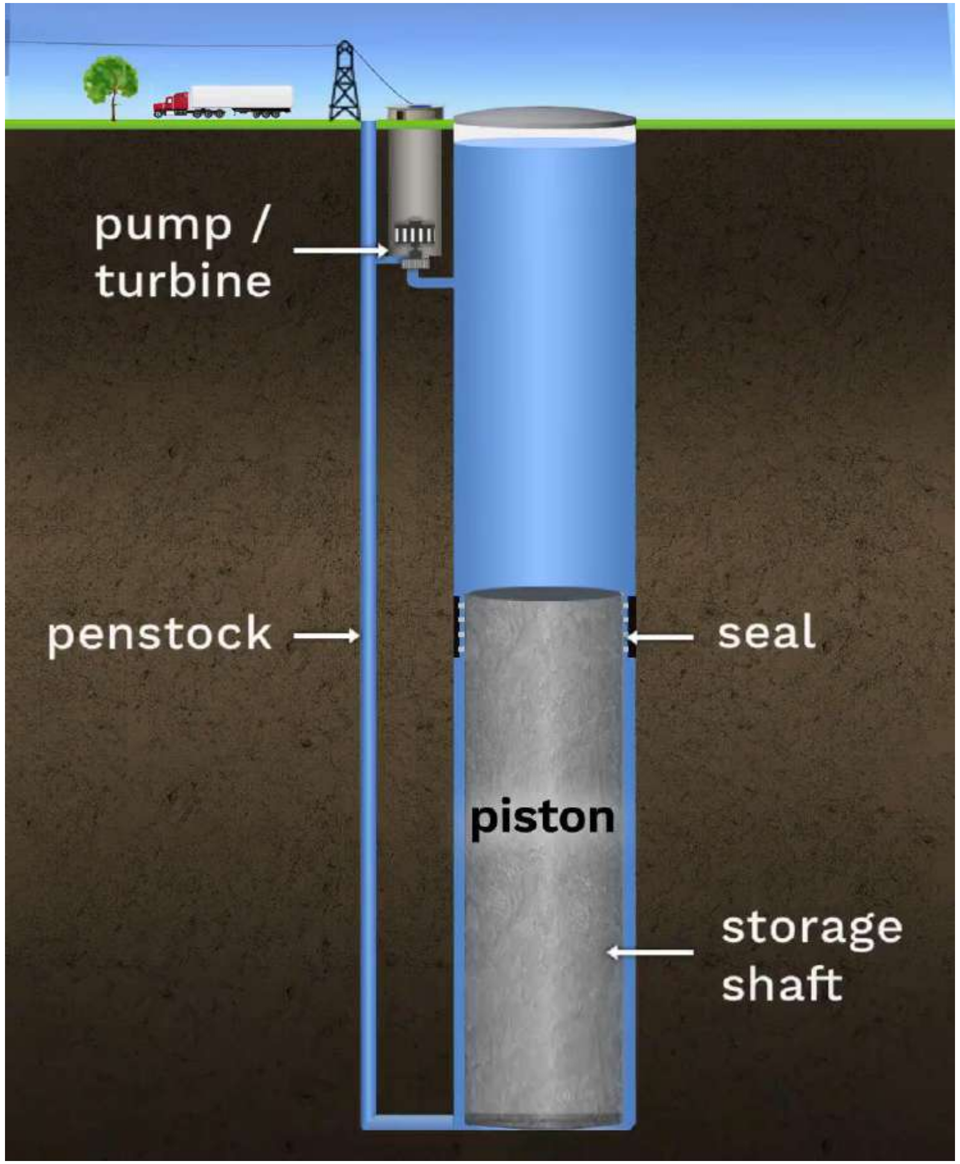
JUNA KUNADA (Chandrapur, Maharashtra)

Google Earth Pro image

Site picture

Underground Gravity Pumped-hydro

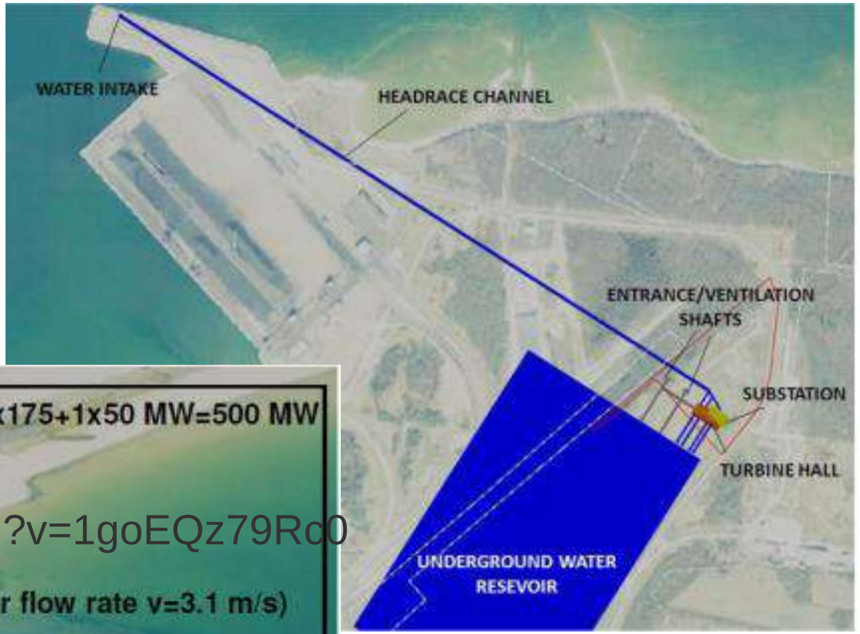
- Gravitricity's system in an underground shaft uses an electric winch to lift a 500-to-5000-tonne weight, which when lowered turns the winch motor as a generator.
- The system generates 10 MWh
- Excavate a deep shaft, using standard technology from the mining industry.
- Build a piston of reinforced rock in the shaft.
- Add water and cap it, creating a closed loop system, with no additional water required.
- As the piston drops, it forces water up the penstock and through the turbine, to produce electricity

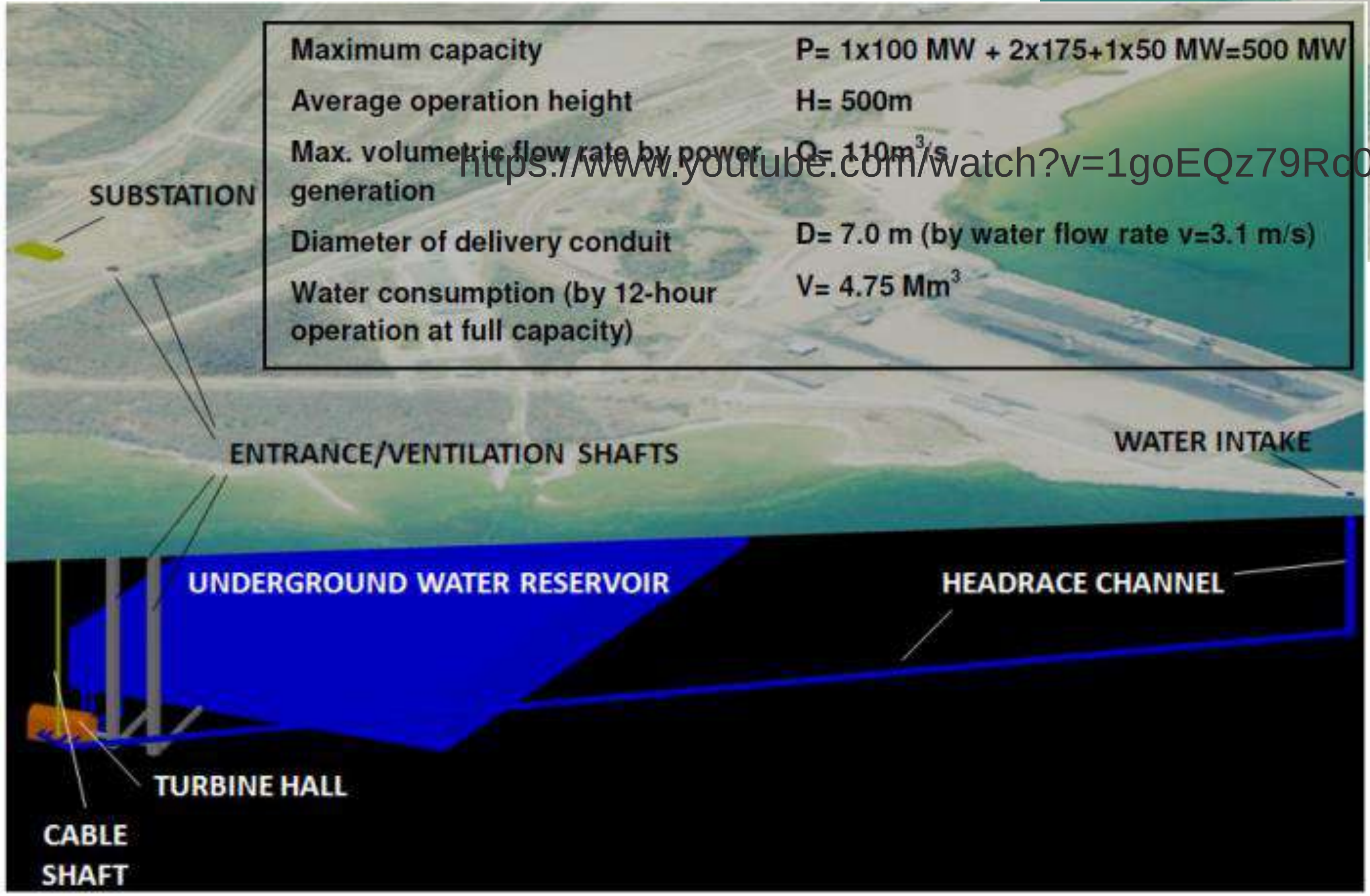


Energiasalv PHES in Paldiski bays on Estonia)

(tender for construction issued in April 2024)

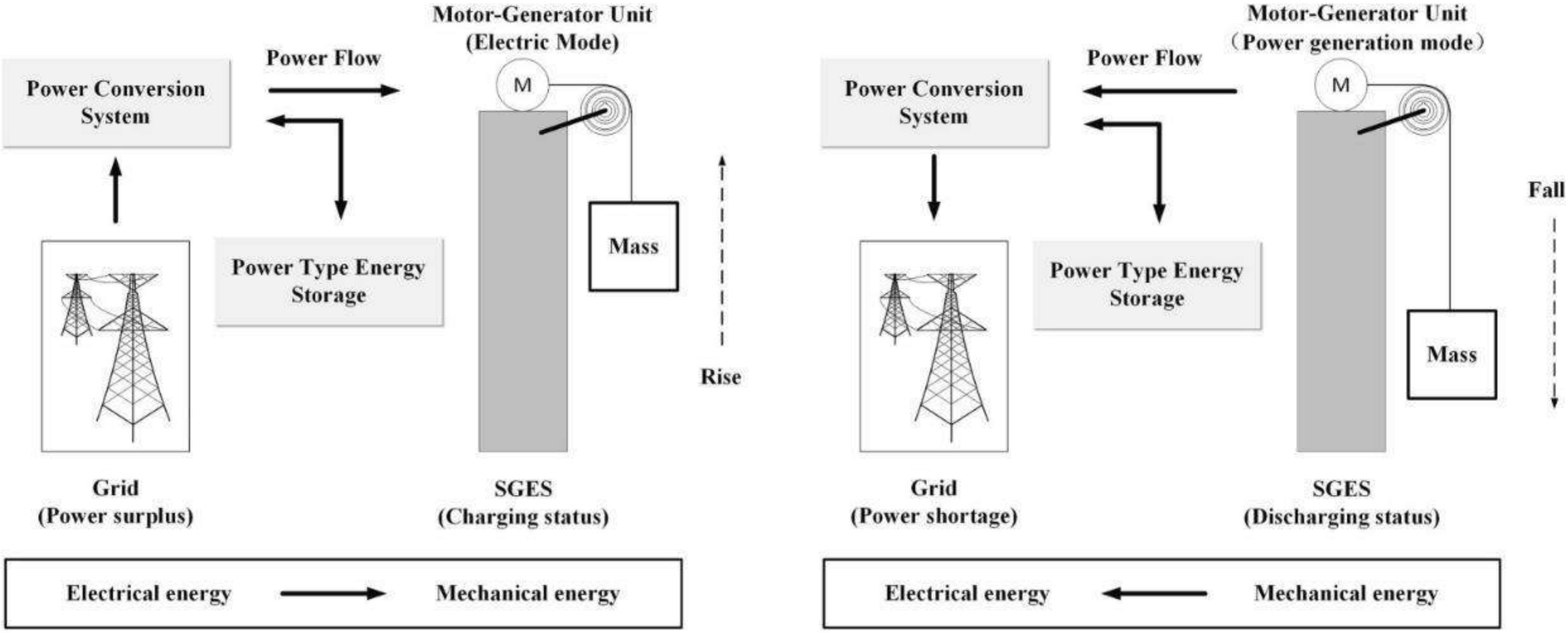
https://www.youtube.com/watch?v=1goEQz79Rc0



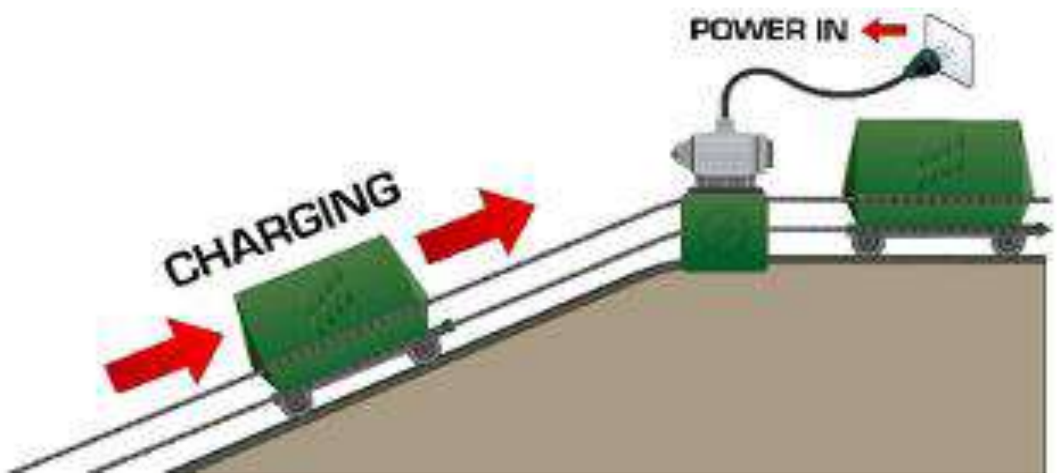


https://www.youtube.com/watch?v=1goEQz79Rc0

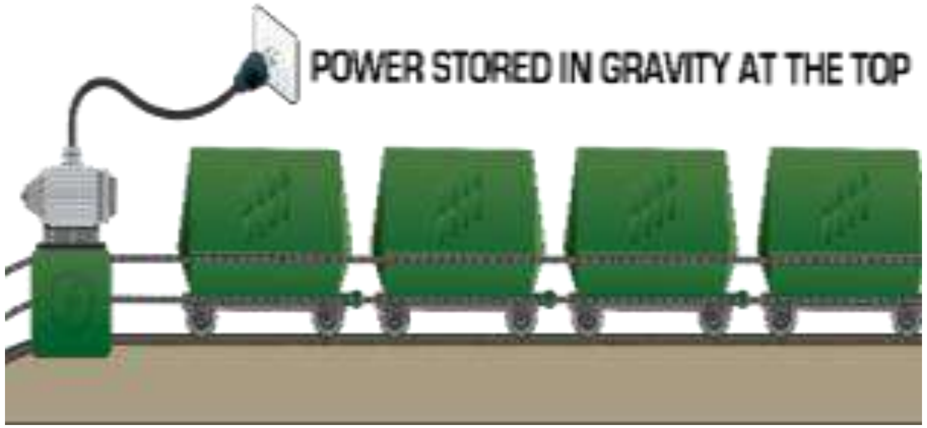
Solid Gravity Energy Storage Technology Operating Principles



（a） （b）

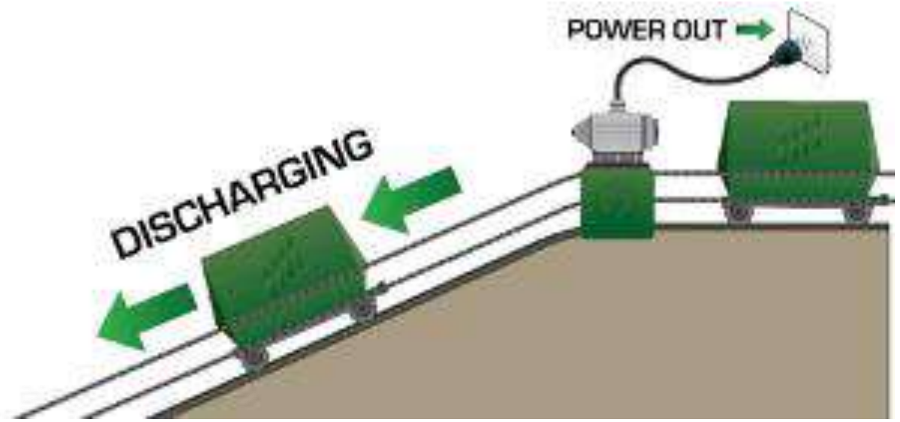


Electricity is pulled from the grid to turn a highly efficient electric motor lifting a heavy mass car uphill.



The mass car at maximum elevation resulting in maximum potential energy.

- Lifted Weight Storage (LWS) technology uses surplus energy to mechanically lift solid weights vertically, typically on a pulley system.
- When extra energy is needed, the mass is lowered, and the pulley turns a generator



Electricity is re-produced as the mass car is lowered turning the reversible motor backwards and acting as a generator of power

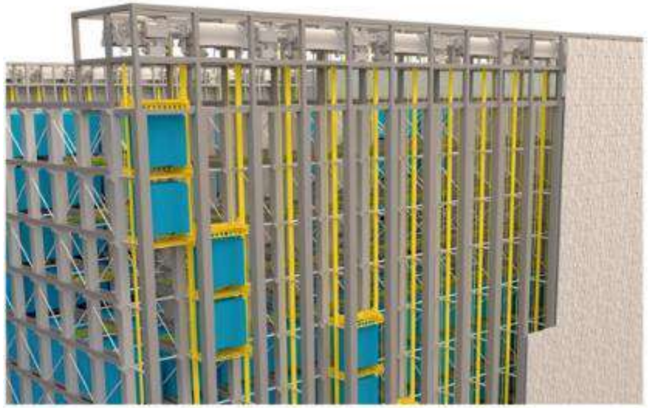
Energy Vault's and Test Tower 2021

A kinetic storage system that consists of multiple cranes and cement, concrete blocks.

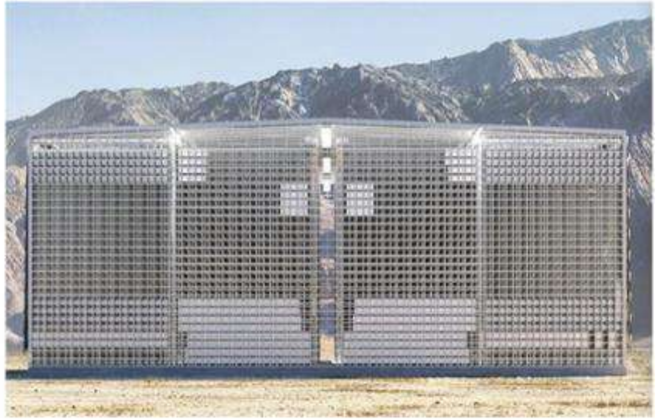
- Energy is stored by lifting blocks and stacking them at a height, then utilizing their gravitational potential energy to fall back to the ground and drive a generator.
- Standard systems are built with 35 MWh of storage and a power rating of 4 or 8 MW, consisting of a 150 meter high tower and up to 7,000 blocks.
- The weight can also be dropped quickly for a small burst of power.

(a)

(b)

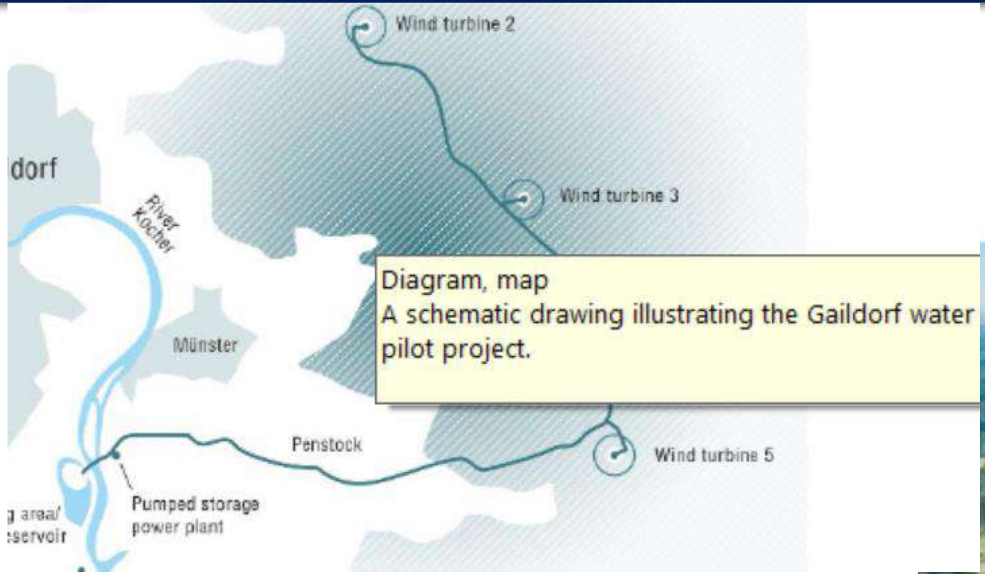


(c)



(d)

Hybrid PSP and wind plant – Photograph showing Gaildorf Pilot Project in Germany



4 wind turbines of 3.4 MW each=13.6 MW
PSH plant= 16 MW, closed-loop PSH system using an underground penstock.
Head: 200 m.

Source:
https://www.mbrenewables.com/en/pilot-project/

Challenges

a. **Approvals, Permits and Clearances taking long time**

b. **High Capital Costs, Long Gestion Periods, time & Cost Overruns:**

c. **Land Acquisition:**

d. **Technical and Geological Challenges:**.

e. **Regulatory & Policy Framework:**

f. **Market Structure & Revenue Streams:**

g. **Competition from other Technologies:**

h. **Water Availability and Competing Uses:**

i. **Grid Interaction Challenges**

Mitigation

a. **Early Engagement with Stakeholders and Simple Legal Procedure**:.

b. **Integrated Approval Processes**

c. **Secure Funding Early and Flexible Financing Option**:

d. **Robust Project Management:**

e. **Community Engagement**:

f. **Long-term Contracts and Contingency Funds**.

Recommendations for PSP Development

- **To frame appropriate regulations** to monetize ancillary services and develop peak and off-peak tariffs. These actions to be finalized by regulatory bodies.
- **Allotment of technology and sites:** A transparent process for meeting energy storage requirements at state, regional and national level.
- **Supply chain and manufacturing drivers**
- **Financial institutions to** treat storage projects at par with RE projects.
- Government **to provide R&D support** for developing globally competitive energy storage technologies.
- **Pilot plants** be supported.
- Regulators **to declare and enforce energy storage obligation (ESO)** for all RE power for GENCOs and DISCOMs as declared for RPO.
- To develop **Model Regulations** for all the State Regulators.
- **Market-based mechanisms** to identify right price for energy & capacity

Potential Benefits of Regional Energy Infrastructure & CBET in SA

1. Economic & Financial
- Access to Competitive Power
- Export Revenues
- Economic Extension of grid
- Regional Cost Optimization & Economic growth

2. Technical & Operation
- Larger grid, better grid
- Intra-seasonal differences
- Peak Time/Time zone differences
- Better Hydro - Thermal Mix
- Regional Balancing

3. Environment & social
- Regional Hydro Power Development,
- RE/Clean Energy Development
- Reduced CO2 Emission, RE based CBET
- Improved Energy & Environmental Security

4. Regional Energy Market
- Competitive Energy Market
- Fair & Transparent Price Discovery
- Choice -Different Products
- Consumer Benefits & Social Welfare

5. Mobilising Investment
- New Investment Avenues
- Enhanced feasibility due to larger market
- Return on Investment
- Innovative Financing Mechanism

Source: Jiwan Acharya, "Promoting Cross Border Electricity Trade in South Asia", South Asia Department, ADB, June 2023

Cross Border Electricity Trade in South Asia

Particulars	Source	Type
India → Bangladesh (~1160 MW)	250 MW NTPC	G-G
	250 MW Market	Commercial
	160 MW Tripura	G-G
	500 MW Market	Commercial
Bhutan → India (2260 MW)	1020 MW Tala	G-G
	336 MW Chukha	G-G
	60 MW Kurichhu	G-G
	126 MW Dagachhu	Commercial
	720 MW Mangdechhu	G-G
India → Nepal (800-1000 MW)	237 MW India	G-G
	660 MW Market	Commercial

- ~3760 MW of power trade in SA region with 70% agreements through G-G mode and 30% through commercial CBET
- Cross Border power trade in the SA region has doubled in the last 6 years

Source: Jiwan Acharya, "Promoting Cross Border Electricity Trade in South Asia", South Asia Department, ADB, June 2023

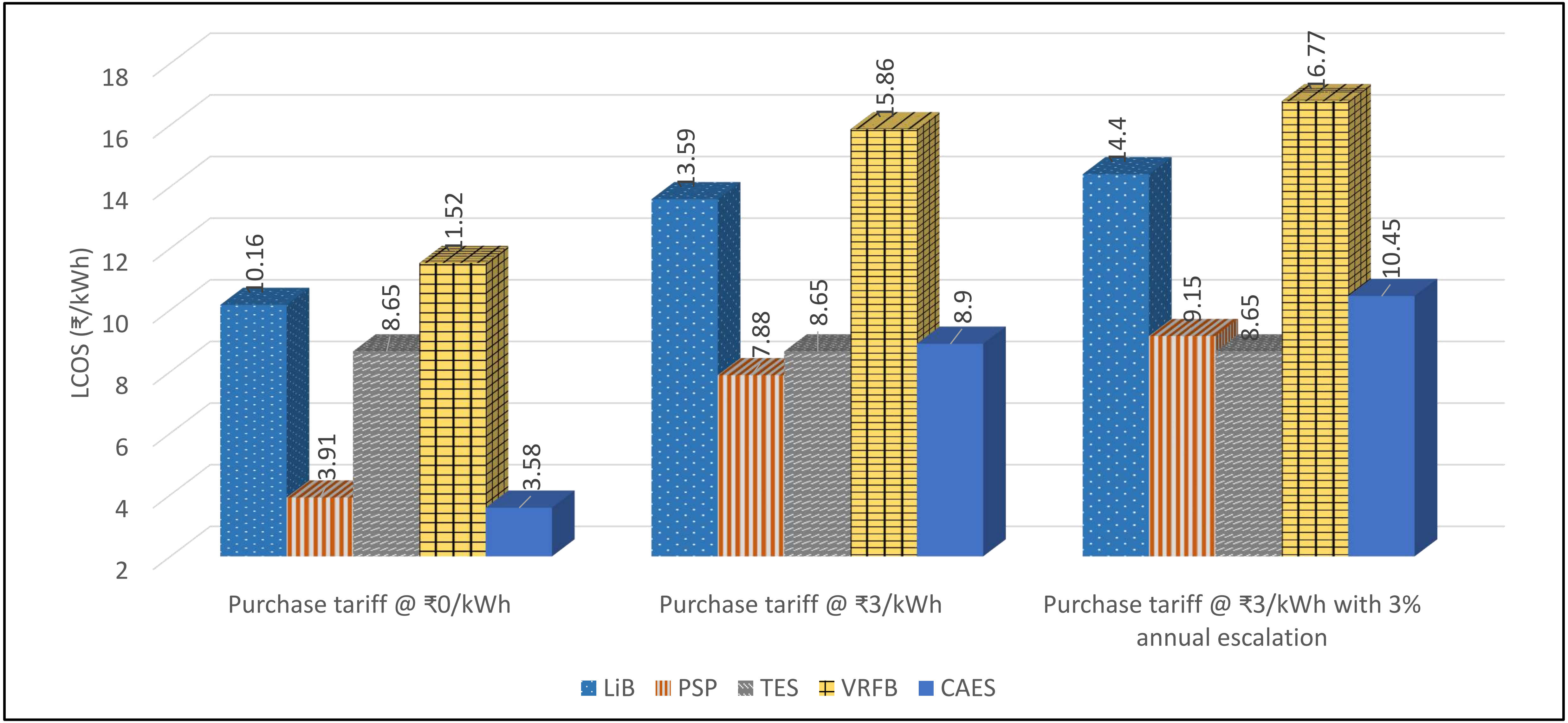
Assumption for Economical Analysis

Storage Technology	Round-trip Efficiency	Lifetime (Years)	CAPEX	Project construction time (years)	LCoS most sensitive parameter
Pumped Hydro Storage	80%	40	₹ 4 Crores/MW	5	Electricity Buy price
Compressed Air ES	60%	40	₹ 4 Crores/MW	5	Electricity Buy price
Lithium-ion Battery	90%	8	₹ 18,450/kWh	1	CAPEX
Molten Salt Storage	80%	25	₹ 24 Crores/MW	3	CAPEX
Vanadium Redox Flow Battery	83%	24	₹ 26,650/kWh	1	CAPEX

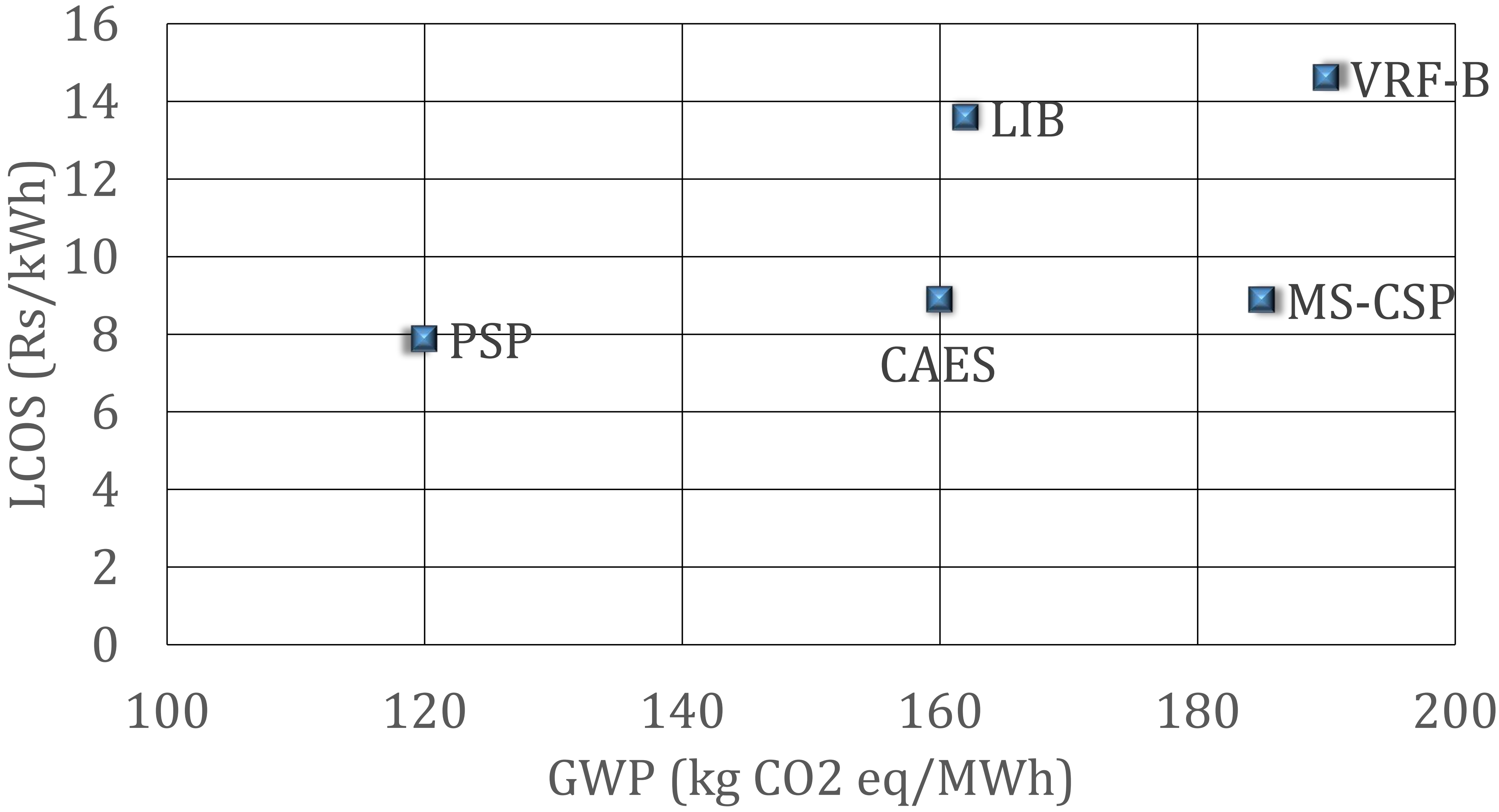
One Charging and discharging cycle per day of 4 hours.
However for PSP and thermal this may go up to 8-10 hours

Equity	30%	Return on Equity	16.5%
Interest on loan	9%	Discount rate	11.75%

Life cycle cost of storage (LCOS)



Levelised Cost of Storage vs Global Warming Potential



INDEPENDENT HYDRAULIC TURBINE R&D LABORATORY

As per IEC-60193, ISO-17025, and NABL accreditation

Turbine Model Testing of New / Refurbished Projects

- Francis Turbine
- Kaplan Turbine
- Pelton Turbine
- Reversible Pump Storage Turbine

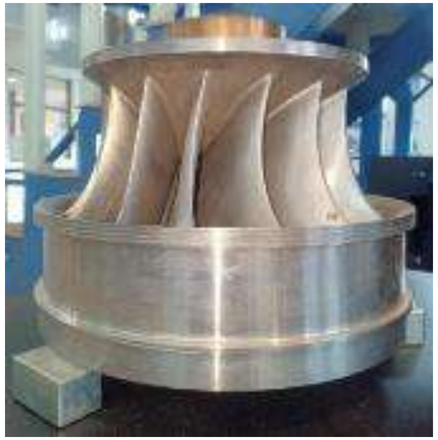
SCADA based Control

Overall uncertainty of ±0.25 % , Repeatability ±0.15 %

Main Hydraulic Performance & Additional Performance Test

Design Validation through CFD Analysis

Third Party Witness Consultancy/Support





Thank You