

# India's Shift to Renewable Energy from Conventional Energy and Focus on Pumped Storage Power Plants to Ensure Net Zero

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**Abstract - India's transition from conventional and fossil fuel to renewable non-conventional energy sources is remarkable, in terms of electricity generation. Fifty percent of the capacity, India's electricity generation depends on non-fossil fuels, ie, almost 250 GW. India has taken the oath to reach zero emission by 2070. To ensure intermittency the country is focusing on solar energy, wind energy, pumped storage projects and battery storage and other much more sustainable and reliable energy sources. The dependency on renewable green energies is gradually increasing. It is expected that India will reach 500 GW electricity production from non-fossil fuel and renewable sources by the end of 2030. The Indian Government has allowed one hundred percent foreign direct investment in these various renewable energy sources. India is also focusing on other pollution free sources and has launched National Green Hydrogen Mission, an initiative to generate, utilize and export pollution free green hydrogen. In generating green electricity, pumped storage hydropower has been named as water battery. In recent years its advantages has attracted important development projects and policy support from Indian government. Currently, India has the total potential of 200 GW from pumped storage power plants. The Central Electricity Authority has approved new development of pumped storage plants with a capacity of 7.5 GW in 2024-2025. In future years India will expand the installed and operational capacity of pumped storage plants. Many new plants are under construction, increasing the overall potential. The Energy and Resources Institute of India has predicted the potential of on-river pumped storage power plants would reach the capacity of 103 GW, it would aid in zero emission and decarbonisation aim of the country.**

**Keywords - Conventional energy, hydroelectric power plant, hydropower, net zero, non-conventional energy, non-renewable energy, pumped storage power plant, renewable energy**

## 1. INTRODUCTION

India, as a developing country has always been keen with the renewable energy sources as well as the conventional sources. With the huge use of water plants utilizing the hydro-energy, Pumped storage plants (PSPs) in India were in development during the 1970s and 1980s. The main reason to bring this

into the energy sector was to address grid balancing and peak demand. Nagarjunasagar hydroelectric power plant, on the Nagarjunasagar dam, built on Krishna River in 1970, is often cited as the first pumped storage plant. Kadamparai PSP, built in 1980s, in the basin of Kadamparai river, was the second one. The industry matured with key projects like Bhira built in 1997 by the Mulshi dam, in the 1997. It was a landmark projecting India internationally with its 150 MW facility and one of Asia's first PSP which was utilized for energy storage and grid stability. In present days India has 4.75 GW of installed capacity. CEA has predicted that India will reach on-river pumped storage hydro potential with major initiatives concentrating on expanding this to 103 GW potential to meet renewable energy storage needs, through various stages of development. The Indian Government has emphasised on the development of pumped storage plants in the country as the major priority amongst the energy storage systems, focusing on renewable energy and Roadmap to India's 2030 Decarbonization targets and net zero attainment [2] [7] [8].

## 2. ENERGY CRISIS IN INDIA AND NEED TO SHIFT TO RENEWABLE ENERGY

The required energy demand of India is growing day by day where the with peak electricity demand is expected to attain 277.2 GW. It is expected in 2026-2027 the energy consumption would be at 1907.8 Billion Units (BU). This demand is rapidly increasing at 6-6.5% annually, as the requirement of electricity is increasing in various sectors such as household or residential, office and commercial sector, healthcare area, industrial and manufacturing area, and area of transportation and industry and agriculture and public utility areas. Communication system, entertainment system and various outdoor areas also require electricity to work properly. Even in late 2025, India depends on conventional sources of electrical energy such as coal, oil, gas and nuclear. India has the world's 5th largest coal reservoir and utilizing that, 44% of the generated electricity comes from coal. Oil

and gas share a 4% of generation of the total generated electricity. Nuclear energy contributes to the generation of 1.7% of the total generated electricity. The electricity generation target for 2023-24 was 1750 Billion Units (BU), with a substantial portion (1324.110 BU) from all the available sources such as thermal, hydro, nuclear and renewables. India is taking a big step to diversify its energy sectors and generate electricity from renewable sources with the capacity of 55% of the generation.

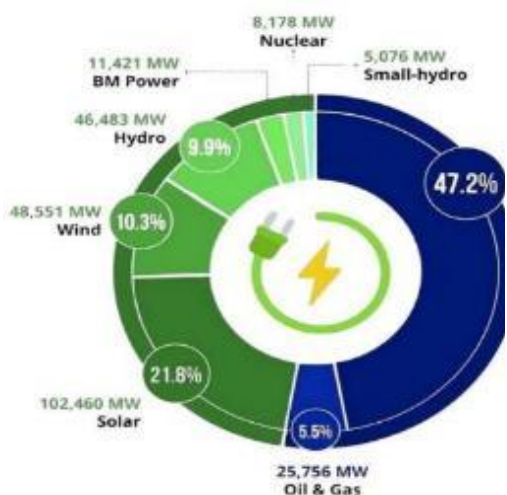


Fig. 1 Energy Production from Various Sources

Even though coal dominates the energy sector, there has been a shortage of coal in the recent years due the huge electricity demand and supply chain bottleneck conditions. In spite of record domestic coal production, almost exceeding 893 MT, the shortage prevails in coal based thermal power plants. The low stock level lasts for 4-9 days causing power cuts and needing urgent government intervention to manage the supply demand and production consumption chain [1].

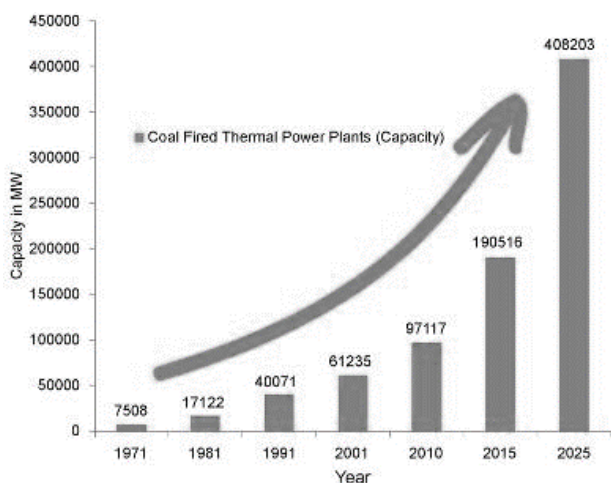


Fig. 2 Growth in Capacity in Coal Fired Thermal Power Plants over the Years

Coal-based thermal power plants are enormous pollution

sources. They contribute roughly 60% of particulate matter, 45% of Sulfur Dioxide 30% of nitrogen oxides and 80% of mercury emissions within the industrial sector. They also emit significant quantities of carbon dioxide, sulfur dioxide and nitrogen oxides. They all leading to substantial pollution of air, water and soil contamination and fly ash accumulation, resulting in rapid degradation in the air quality.

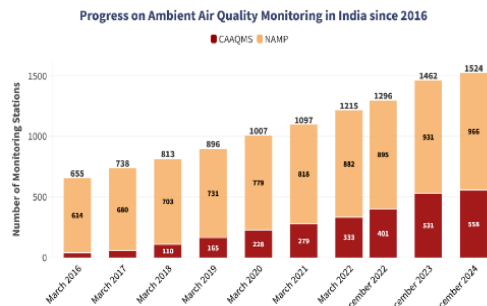


Fig. 3 Progress on Ambient Air Quality Monitoring in India since 2016

All these reasons are sufficient for India to shift to renewable energy sources, a much cleaner and greener option with zero carbon emission.

### 3. WORKING PRINCIPLE OF A PUMPED STORAGE POWER PLANT

Pumped Storage Plant is an arrangement of two water reservoirs present at different height elevations that can produce electrical power as water moves down from one reservoir to the other during the discharge and passing through a water turbine. PSP uses the very basic principle of energy conversion. The stored potential energy in water in the reservoir is converted into mechanical energy and generate electricity.

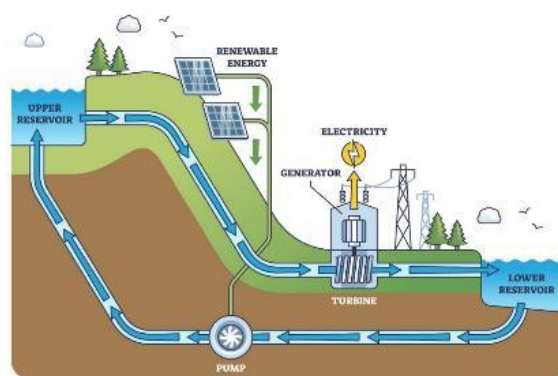


Fig. 4 Working of a Pumped Storage Hydro Electric Power Plant

Pumped storage power plants are often considered as a gigantic green battery which is rechargeable as the source is water, stored in reservoirs in the form of gravitational potential energy. PSP works usually in two different modes.

One is storage phase or pumping mode, the second one is generation phase or turbine mode. Pumping mode occurs when electricity demand is low or there is some additional surplus of renewable energy that may be solar or it may be wind, depending on the location or the setup. The motor-generators of the plant drive the pump-turbines. They push water from the lower reservoir to the upper reservoir via the penstock and store the energy for future practice. The generation phase or the turbine mode occurs when there is peak electricity demand peaks or renewable production from the additional solar or wind source drops. The process of pumping mode is reversed. Water gets released from the upper reservoir which is placed in higher elevation. Under the gravitational pull water from the upper reservoir falls through the penstock and rotates the turbines, which eventually drive the generators to produce electricity for the grid. The water then settles in the lower reservoir after passing through the tailrace [6].

Based on the source of water, PSPs can be of two types, open-loop pumped storage and closed-loop pumped storage. In open-loop pumped storage plants, one water reservoir (either the upper one or the lower one) is unceasingly connected to a naturally flowing water source, like a river. In closed-loop pumped storage, the pumped storage site is considered to be off-river and it produces electricity from water pumped up to an upper reservoir without any substantial natural inflow.

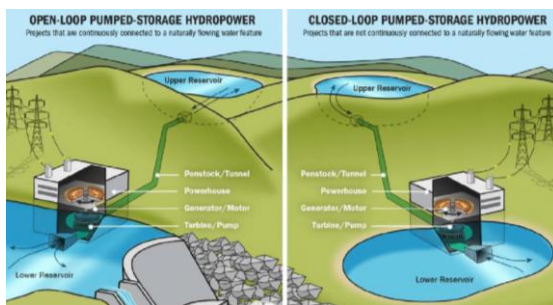


Fig. 5 Open Loop and Closed Loop Pumped Storage Hydropwer

### 3.1 VARIABLE SPEED PUMPED STORAGE PLANT (VSPSP)

Variable Speed Pumped Storage plants are the more economical and advanced from of pumped storage plants. This gigantic water battery provides motor and generator system where the speed can be adjusted. Various power electronics converters are used so that the grid frequency can be managed. This provides optimized overall efficiency as pumping mode and generating mode both can be adjusted depending on the load requirement. Variable speed pumped storage plants have many advantages over the fixed speed pumped storage plants. Since the pump speed can be varied and adjusted, the speed here matches the renewable energy water intake input as it is fluctuating in many times. The

advanced stability system together with much faster response time of variable speed pumped storage plant provides increase in overall efficiency of the plant.

In the pumping phase or the energy storage phase, the pumps use the electricity to run and pump the water up from the lower reservoir to the upper reservoir. When variable power input is available, the variable speed of the system provides peak efficiency for the plant. During the generation phase or energy release phase, water from the upper reservoir reaches the lower reservoir driving the turbines with the kinetic energy of the water in motion. A doubly fed induction motor and power electronic convertors are utilized for maximum efficiency. Due to variable speed, wide range of turbine operations can be made possible. Considering pumped storage hydel plant to be a huge water battery, the pumping phase can be compared to the charging and the generating mode can be compared to the discharging of a battery. Maximum power point tracking algorithms and energy management strategies are typically used in the control system. The very first Variable Speed Pumped Storage Plant of this country is situated and constructed at Tehri, Uttarakhand. It has the potential capacity to operate with a 250 MW unit [2] [3].

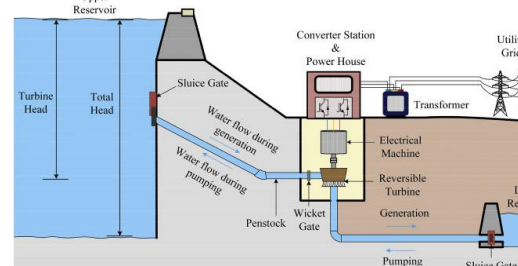


Fig. 6 Working of a Variable Speed Pumped Storage Hydro Power Plant

### 4. ADVANTAGES OF PUMPED STORAGE PLANTS OVER CONVENTIONAL SOURCES

A very reliable and dependable source of renewable energy and 'water battery' pumped storage power plants use stored water in the reservoirs as the driving force for the water turbines. They have the leading advantage of being a cradle of green energy and they are free from pollution. They do not harm the atmosphere compared to conventional fossil fuel sources that are extremely harmful for the nature. It has other various significant advantages as well. Once developed, it can run for 80-100 years with a very minimum of running or maintenance cost. It does not need capital investment for the fuel cost or any expensive raw material. It runs on water cycle, which makes it a renewable source of energy. Pumped storage power plants are much more reliable and sustainable than the conventional hydro power plants, as the lower reservoir of the plant at lower elevation collects a generous amount of water for running an crucial isolated cycle when

necessary. Pumped storage power plants have the ability to utilize subsurface subsoil water. In many cases jilted forsaken mine pits have been used as the lower reservoir. This helps pumped storage power plants to produce and generate electrical energy on a short term demand and address the sudden energy fluctuation in demand supply chain. The large waterbody reservoirs can also be used for the purpose of agriculture, irrigation and aquaculture as well. In case of water shortage or drought, the water from the reservoirs can be used to supply water in required areas. Again, in case of flood, the huge quantity of excess water can be accumulated into the reservoir. This would avert the flood like situation and keep the localities safe [5].



Fig. 7 Advantages of Pumped Storage Power Plant

Pumped storage power plants are regaining popularity due to

**Table 1: Pumped Storage Power Capacity Addition Plan till 2035-36**

S.No.	Name of Project	State	IC (MW)	Developer	Stage
2025-26					
1	Pinnapuram	Andhra Pradesh	1680	Greenko	Under Construction (7 units commissioned total 1440MW)
2	Tehri PSS	Uttarakhand	1000	THDC	Under Construction

its flexibility and reliable nature. The following data from the International Hydropower Association shows the growth and planned projects of PSPs all over the world. 600 GW of production system is currently under process on construction in various stages. The off-river sites possess unparalleled potential in this scenario of being a gigantic battery of green energy.

**Pumped storage hydropower capacity pipeline (MW)**

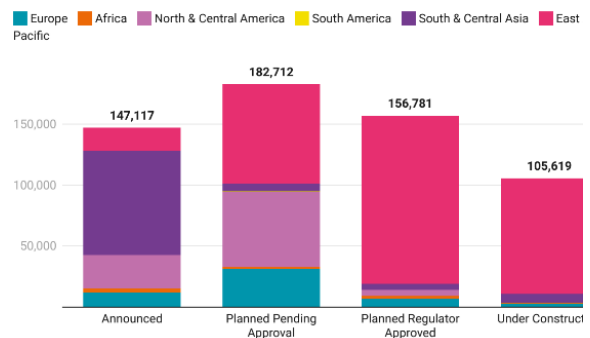


Fig. 8 Pumped Storage Hydropower Capacity Pipeline in MW all over the World

### 5. CAPACITY ADDITION PLAN OF PUMPED STORAGE PLANTS TILL 2031-32

By 2031-32, India will increase the pumped storage projects in a momentous way with the intensification in storage capacity of 175.18 GW, to support the renewable grid [12]. India's leading power sector body, Central Electricity Authority has approved development of future projects of 47.65 GW electricity requirement that would be generated from pumped storage plants only. The Ministry of Power has proposed to provide single window clearance systems to ensure speedy development [13].

					ction (2 Units Commissioned total 500 MW)
	<b>Sub Total</b>	<b>2680</b>			
2026-27					
3	Kundah PSP PhI,II & III	Tamilnadu	500	TANGEDCO	Under Construction
4	MP 30 Gandhi Sagar	Madhya Pradesh	1920	Greenko	Under Construction

5	Chitravathi	Andhra Pradesh	500	Adani Green	Under Construction
	<b>Sub Total</b>	<b>2920</b>			
<b>2027-28</b>					
6	Saundatti	Karnataka	1600	Greenko	Under Construction
	<b>Sub Total</b>	<b>1600</b>			
<b>2028-29</b>					
7	Upper Sileru	Andhra Pradesh	1350	APGENCO	Under Constuction
8	Bhivpuri	Maharashtra	1000	Tata Power	Under Construction
9	Bhavali	Maharashtra	1500	JSW Energy	Under Construction
10	Gandikota	Andhra Pradesh	1000	Adani Green	Under Constuction
11	Tarali	Maharashtra	1500	Adani Green	S&I
	<b>Sub Total</b>	<b>6350</b>			
<b>2029-30</b>					
12	Kandhaura	Uttar Pradesh	1680	JSW Energy	Concurr ed by CEA and yet to be taken up for construction
13	UP01	Uttar Pradesh	3660	Greenko	S&I
14	Chichlik	Uttar Pradesh	1560	Avaada	S&I
15	Sirohi	Rajasthan	1200	JSW Energy	S&I
16	Narihall	Karnataka	300	JSW	S&I

	a	ka		Energy	
17	Nayagon	Maharashtra	2000	Greenko	S&I
18	Panaura	Uttar Pradesh	1500	Adani Green	S&I
19	Ukai	Gujarat	1600	Greenko	S&I
	<b>Sub Total</b>	<b>13500</b>			
<b>2030-31</b>					
20	Shahpur	Rajasthan	1800	Greenko	S&I
21	Bilaspur	Chhattisgarh	1000	Jindal Renewables	S&I
22	Pane	Maharashtra	1500	JSW Energy	Concurr ed by CEA and yet to be taken up for construction
23	Malshej ghat Bhorendre	Maharashtra	1500	Adani Green	S&I
24	Warasgaon Warangi	Maharashtra	1500	Adani Green	S&I
25	Raiwada	Andhra Pradesh	900	Adani Green	S&I
26	Kamalapadu	Andhra Pradesh	950	APGENCO	S&I
27	Shirawta	Maharashtra	1800	Tata Power	Concurr ed by CEA and yet to be taken up for construction
28	Saidongar 1 -	Maharashtra	3000	Torrent PSH 4	S&I

	Karjat			Pvt. Ltd.	
29	Indira Sagar	Madhya Pradesh	640	NHDC	DPR submitted & under examination
30	Vempalli	Andhra Pradesh	1500	JSW energy	S&I
31	Shoma	Uttar Pradesh	2400	Torrent PSH 1 Pvt. Ltd.	S&I
32	Koyna Nivakane	Maharashtra	2700	Adani Green	S&I
	<b>Sub Total</b>	21190			
<b>2031-32</b>					
33	Kamod	Maharashtra	2000	Megha Engineering	S&I
34	Ghosla	Maharashtra	2000	Megha Engineering	S&I
35	Pedakota	Andhra Pradesh	1800	Adani Green	S&I
36	Upper Bhavani	Tamilnadu	1000	NTECL	S&I
37	Masinta	Odisha	1000	NHPC	S&I
38	Turga	West Bengal	1000	WBSE DCL	Concurrent by CEA and yet to be taken up for construction
	Sub Total	8800			
<b>2032-33</b>					
39	Upper Indravat	Odisha	500	OHPC	Concurrent by

	i				CEA and yet to be taken up for construction
40	Sharavathy	Karnataka	2000	KPCL	Under Construction
41	Musakhand	Uttar Pradesh	600	ACME	S&I
42	Sukhpura	Rajasthan	2560	Greenko	S&I
43	Serula	Gujarat	960	GSECL	S&I
44	Dharoi	Gujarat	500	GSECL	S&I
45	Saidongar 2 - Maval	Maharashtra	1200	Torrent PSH 4 Pvt. Ltd.	S&I
46	Jhariya	Uttar Pradesh	1620	Jhariya Ananturja	S&I
47	Rayavaram	Andhra Pradesh	1500	APGENCO & ONGC	S&I
48	Brahmani	Rajasthan	600	ACME Urja Two Private Limited	S&I
49	Balimela	Odisha	500	OHPC	S&I
50	Gadikota	Andhra Pradesh	1200	APGENCO & NHPC	S&I
	<b>Sub Total</b>	<b>13740</b>			
<b>2033-34</b>					
51	Juni Kayaliwel	Gujarat	300	GSECL	S&I
52	Amalpada	Gujarat	300	GSECL	S&I
53	Juni	Gujarat	450	GSECL	S&I

	Bavli				
54	Satkashi	Gujarat	330	GSECL	S&I
55	Upper Kolab	Odisha	600	OHPC	S&I
56	Savitri	Maharashtra	2400	NHPC	S&I
57	Hasdeo Bango	Chhattisgarh	800	CSPGCL	S&I
58	Sikaser	Chhattisgarh	1200	CSPGCL	S&I

59	Rouni	Chhattisgarh	2100	CSPGCL	S&I
60	Kalu Patti	Uttar Pradesh	1000	Renew Hydro	S&I
61	Pawana Falyan	Maharashtra	2400	Avaada	S&I
	<b>Sub Total</b>	<b>11880</b>			
	<b>Total</b>	<b>82660</b>			

**Table 2: The consolidated data of Table 1**

SL. NO	YEAR	IC (MW)
1.	2025-2026	2680
2.	2026-2027	2920
3.	2027-2028	1600

4.	2028-2029	6350
5.	2029-2030	13500
6.	2030-2031	21190
7.	2031-2032	8800
	<b>TOTAL</b>	<b>82660</b>

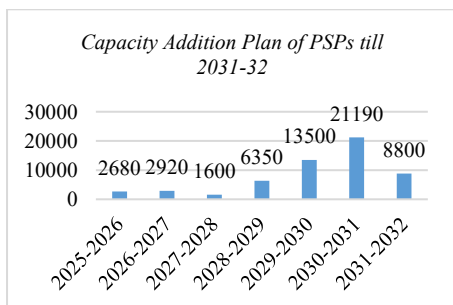


Fig. 9 Capacity Addition Plan of PSPs till 2031-32

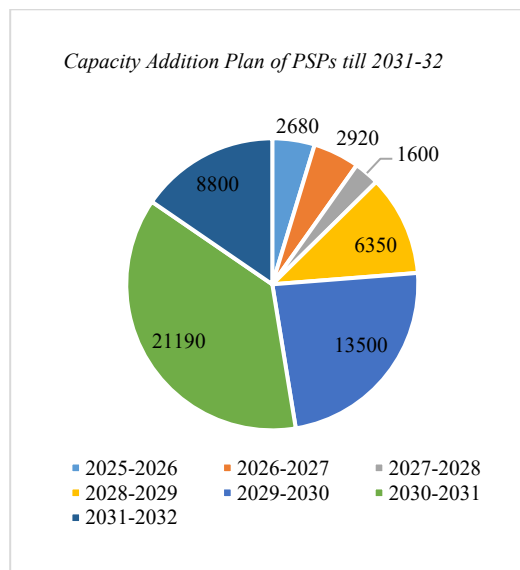


Fig. 10 Total Capacity Addition plan of PSPs till 2031-32

## 6. DISADVANTAGES OF PUMPED STORAGE POWER PLANT



Fig. 11 Disadvantages of Pumped Storage Hydro Power Plants

Pumped storage power plants have some minor disadvantages in case of large scale analysis in various areas. Initial capital cost of PSP is extremely high. This expensive nature makes the cost per MW generates electricity to be very high. In the process of pumping back water from the lower reservoir to the upper reservoir, the pumps need to consume electricity to run. This reduces the overall efficiency of the pumped storage power plant. The water when stored in upper and lower reservoirs, go through various significant losses such as evaporation, leakage and water theft. This reduction in mass eventually reduces the overall potential of the water. It causes severe threat to aquatic life, causing damage in the migration pattern of the fishes. This aquatic habitat can cause a sudden drop in the oxygen level of the stored water in reservoirs. This phenomenon of eutrophication impacts the water quality. Due to deoxygenation in water bodies, the riparian areas get negatively affected too. After all these, it has to be kept in mind, pumped storage hydel power plants are completely climate dependant. Natural calamities such as flood or drought or earthquake will affect the production of electricity [4].

## 7. CONCLUSION

Pumped storage plants, also known as the water batteries are undeniably important when talking about energy crisis or pollution management from conventional fossil fuels. The do not any fossil fuel that can produce harmful oxides when burned or when combustion occurs. The carbon footprint can be managed and net zero would be achievable if pumped storage power plants are widely used. They work effectively

in both off-peak loads and peak loads, balancing grid stability and managing change in load demand. The electricity generated from pumped storage power plants can be cost effective. The plant is reliable and long lasting. During electricity shortage they can be used to provide the much needed back-up. They can also provide the very crucial black start for the grid. Other than environmental benefits, they can be beneficial to the local people living near the plant area. The central government is now focusing to promote pumped storage power plants, they have made developments and the same thing is accepted globally as well.

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